FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)
U.S. DEPARTMENT OF ENERGY

EXPLORATORY TOPICS SBIR/STTR

Announcement Type: Modification ~~08~~ 09
Funding Opportunity No. DE-FOA-0002785
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	September 13, 2022
FOA Close Date:	Open continuously until otherwise amended.
Application Due Date:	See Exploratory Topics Table for topic-specific application due dates.
Total Amount to Be Awarded	Approximately $95 million, subject to the availability of appropriated funds to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785. See Exploratory Topics Table for topic-specific information.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $100,000 and $4,398,504. See Exploratory Topics Table for topic-specific award amount requirements.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.E of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.G.1 of the FOA.
- Applicants are responsible for meeting each submission deadline associated with each Exploratory Topic. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the Exploratory Topic submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.F.1 through III.F.3 of the FOA.

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

MODIFICATIONS

All modifications to the Funding Opportunity Announcement (FOA) are highlighted in yellow in the body of the FOA.

MOD NO.	DATE	DESCRIPTION OF MODIFICATION
1	2/17/2023	• Reserved Appendix B. See Table 1. Exploratory Topics, Appendix B. • Inserted new Exploratory Topic, Topic C: Creating Revolutionary Energy And Technology Endeavors (CREATE). See Table 1. Exploratory Topics, Appendix C and Total Amounts to be awarded on Cover Page. • Updated Total Amounts to be awarded on Cover Page. • Updated Maximum Funding Amounts on the Cover Page and in Section II.A Award Overview. • Updated Responsive Criteria in Section III.F.2 Responsiveness Criteria. • Updated language in Section IV.C. Content and Form of Full Applications. • Updated language in Section IV.C.1 First Component: Technical Volume. • Updated language in Section V.C Anticipated Announcement and Award Dates. • Updated language in Section VI.B.1 Unique Entity Identifier and SAM, FSRS, and FEDCONNECT Registrations.
2	2/23/2023	• Inserted new Exploratory Topic, Topic D: Predictive Real-time Emissions Technologies Reducing Aircraft Induced Lines in the Sky (PRE-TRAILS). See Table 1. Exploratory Topics, Appendix C, and Total Amounts to be awarded on Cover Page.
3	3/31/2023	• Updated Topic D: Predictive Real-time Emissions Technologies Reducing Aircraft Induced Lines in the Sky (PRE-TRAILS) Submission Deadline for Replies to Reviewer Comments to June 1, 2023. See Table 1. Exploratory Topics and Appendix D.
4	5/30/2023	• Inserted new Exploratory Topic, Topic F: Novel Superconducting Technologies for Conductors. See Table 1. Exploratory Topics, Appendix F, and Total Amounts to be awarded on Cover Page. • Updated language in Section IV.C.3 Third Component: Budget Justification Workbook. • Updated language in Section IV.C.8 Eighth Component Budget Assurances and Disclosure Form. • Updated language in Section IV.F.7 Purchase of New Equipment. • Updated language in Section IV.F.8 Technology Transfer and Outreach. • Inserted Section IV.F.13 Buy America Requirement for Public Infrastructure Projects. • Inserted Section IV.F.14 Requirement for Financial Personnel. • Inserted Section VI.B.12 Commercialization Plan and Software Reporting.

5	9/7/2023	• Inserted new Exploratory Topic, Topic G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes. See Table 1. Exploratory Topics, Appendix G, and Total Amounts to be awarded on Cover Page. • Inserted new Exploratory Topic, Topic H: Subsurface Engineering for Hydrogen Reservoir Management. See Table 1. Exploratory Topics, Appendix H, and Total Amounts to be awarded on Cover Page. • Updated language in Section VI.B.10 Applicant Risk Analysis. • Updated language in Section VIII.K Export Control Information. • Updated language in Section IX Glossary.
6	9/26/2023	• Updated language and citations in Appendix G Section 3.A and Appendix G Section 4. • Updated language in Appendix H Section 4.
7	3/21/2024	• Inserted new Exploratory Topic, Topic L: Plant HYperaccumulators TO MIne Nickel-Enriched Soils (PHYTOMINES). See Table 1. Exploratory Topics, Appendix L, and Total Amounts to be awarded on Cover Page.
8	4/25/2024	• Updated SBIR/STTR funding limits on cover page and in Section II.A. • Inserted new Exploratory Topic, Topic M: H2SENSE. See Table 1. Exploratory Topics, Appendix M, and Total Amounts to be awarded on Cover Page.
9	4/30/2024	• Updated language and metrics in Topic L: Plant HYperaccumulators TO MIne Nickel-Enriched Soils (PHYTOMINES) Section 4 and Section 5.

TABLE 1. EXPLORATORY TOPICS

Appendix	Exploratory Topic Title	Issue Date	Deadline for Questions to ARPA-E CO	Full Application Submission Deadline	Submission Deadline for Replies to Reviewer Comments	Total Federal Funds to be Awarded (subject to availability)	Anticipated Awards	Max Period of Performance	Expected Date for Notifications
A	LOW-ENERGY NUCLEAR REACTIONS	9/13/2022	5 PM ET, 11/4/2022	9:30 AM ET, 11/15/2022	5:00 PM ET, 12/20/2022	Approximately $10M total	5-8 awards	30 months	February 2023
B	<Reserved>								
C	CREATING REVOLUTIONARY ENERGY AND TECHNOLOGY ENDEAVORS.	2/17/2023	5 PM ET, 3/10/2023	9:30 AM ET, 3/21/2023	N/A	Approximately $10M total	20-30 awards	24 months	June 2023
D	PREDICTIVE REAL-TIME EMISSIONS TECHNOLOGIES REDUCING AIRCRAFT INDUCED LINES IN THE SKY	2/23/2023	5 PM ET, 4/14/2023	9:30 AM ET, 4/25/2023	5:00 PM ET, 6/6/2023	Approximately $10M total	4-6 awards	18 months	July 2023
E	<Reserved>								
F	NOVEL SUPERCONDUCTING TECHNOLOGIES FOR CONDUCTORS	5/25/2023	5:00 PM ET, 6/30/2023	9:30 AM ET, 7/11/2023	5:00 PM ET 8/11/2023	Approximately $10M total	2-4 awards	36 months	September 2023
G	PRODUCTION OF GEOLOGIC HYDROGEN THROUGH STIMULATED MINERALOGICAL PROCESSES	9/7/2023	5:00 PM ET, 10/13/2023	9:30 AM ET, 10/24/2023	5:00 PM ET 11/27/2023	Approximately $10M total	4-6 awards	24 months	January 2024
H	SUBSURFACE ENGINEERING FOR HYDROGEN RESERVOIR MANAGEMENT	9/7/2023	5:00 PM ET, 10/13/2023	9:30 AM ET, 10/24/2023	5:00 PM ET 11/27/2023	Approximately $10M total	4-6 awards	24 months	January 2024
I	<Reserved>								
J	<Reserved>								
K	<Reserved>								
L	PLANT HYPERACCUMULATORS TO MINE NICKEL-ENRICHED SOILS	3/21/2024	5:00 PM ET, 4/26/2024	9:30 AM ET, 5/7/2024	5:00 PM ET, 6/12/2024	Approximately $10M total	4-6 awards	36 months	October 2024
M	H2SENSE	4/25/2024	5:00 PM ET, 5/28/2024	9:30 AM ET, 6/7/2024	5:00 PM ET, 7/12/2024	Approximately $20M total	4-6 awards	36 months	August 2024

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

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REQUIRED DOCUMENTS CHECKLIST

Unless an exception or exceptions are described under a particular Exploratory Topic, the following are applicable to all Exploratory Topics published under this FOA.

- For an overview of the application process, see Section IV.A of the FOA.
- For guidance regarding requisite application forms, see Section IV.B of the FOA.
- For guidance regarding the content and form of Full Applications see Sections IV.C of the FOA.

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION

Full Application	• Each Applicant must submit a Technical Volume in Adobe PDF format by the stated deadline. The Technical Volume must include the following:
	  ○ Executive Summary (1 page max.)
	  ○ Sections 1-5 (14 pages max.)
	  • 1. Innovation and Impact
	  • 2. Proposed Work
	  • 3. Team Organization and Capabilities
	  • 4. Technology to Market
	  • 5. Budget
	  ○ Bibliographic References (no page limit)
	  ○ Personal Qualification Summaries (each Personal Qualification Summary limited to 3 pages in length, no cumulative page limit)
	• The Technical Volume must be accompanied by:
	  ○ SF-424 (no page limit, Adobe PDF format);
	  ○ Budget Justification Workbook/SF424A (no page limit, Microsoft Excel format);
	  ○ Summary for Public Release (250 words max., Adobe PDF format);
	  ○ Summary Slide (1 page limit, Microsoft PowerPoint format);
	  ○ SBA Company Registration Certificate generated in the SBA Company Registry (http://sbir.gov/registration) (Adobe PDF format);
	  ○ If applicable, Certification for Applicants that are (a) Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, or Private Equity Firms; and/or (b) joint ventures minority-owned by a foreign entity (Adobe PDF format);
	  ○ Completed and signed Business Assurances & Disclosures Form (no page limit, Adobe PDF format)
		Mandatory	IV.C

Reply to Reviewer Comments	• As set forth in Table 1, each Applicant may submit a Reply to Reviewer Comments in Adobe PDF format. This submission is optional. The Reply may include:
	  ○ Up to 2 pages of text; and
	  ○ Up to 1 page of images.
		Optional	IV.D

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

The Advanced Research Projects Agency – Energy (ARPA-E), an organization within the Department of Energy (DOE), is chartered by Congress in the America COMPETES Act of 2007 (P.L. 110-69), as amended by the America COMPETES Reauthorization Act of 2010 (P.L. 111-358) as further amended by the Energy Act of 2020 (P.L. 116-260) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that
(i) reduce imports of energy from foreign sources;
(ii) reduce energy-related emissions, including GHGs;
(iii) improve the energy efficiency of all economic sectors;
(iv) provide transformative solutions to improve the management, clean-up, and disposal of radioactive waste and spent nuclear fuel; and
(v) improve the resilience, reliability, and security of infrastructure to produce, deliver, and store energy; and

(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

ARPA-E issues this Funding Opportunity Announcement (FOA) under its authorizing statute codified at 42 U.S.C. § 16538. The FOA and any Grants or Cooperative Agreements made under this FOA are subject to 2 C.F.R. Part 200 as supplemented by 2 C.F.R. Part 910.

ARPA-E funds research on and the development of transformative science and technology solutions to address the energy and environmental missions of the Department. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive improvements to the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector or the applied technology offices within DOE. In contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly better than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as an "original investigation undertaken in order to acquire new knowledge…directed primarily towards a specific practical aim or objective" and defines "experimental development" as "creative and systematic work, drawing on knowledge gained from research and practical experience, which is directed at producing new products or processes or improving existing products or processes."[1] Applicants interested in receiving financial assistance for basic research (defined by the Office of Management and Budget as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts")[2] should contact the DOE's Office of Science (http://science.energy.gov/). Office of Science national scientific user facilities (http://science.energy.gov/user-facilities/) are open to all researchers, including ARPA-E Applicants and awardees. These facilities provide advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere. Projects focused on early-stage R&D for the improvement of technology along defined roadmaps may be more appropriate for support through the DOE applied energy offices including: the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy and Carbon Management (https://www.energy.gov/fecm/office-fossil-energy-and-carbon-management), the Office of Nuclear Energy (http://www.energy.gov/ne/office-nuclear-energy), and the Office of Electricity (https://www.energy.gov/oe/office-electricity).

B. SBIR/STTR PROGRAM OVERVIEW

The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are Government-wide programs authorized under Section 9 of the Small Business Act (15 U.S.C. § 638). The objectives of the SBIR program are to (1) stimulate technological innovation in the private sector, (2) strengthen the role of Small Business Concerns in meeting Federal R&D needs, (3) increase private sector commercialization of innovations derived from Federal R&D activities, (4) foster and encourage participation by socially and economically disadvantaged and women-owned Small Business Concerns, and (5) improve the return on

[1] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.
[2] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.

investment from Federally funded research and economic benefits to the Nation. The objective of the STTR program is to stimulate cooperative partnerships of ideas and technologies between Small Business Concerns and partnering Research Institutions through Federally funded R&D activities.[3]

ARPA-E administers a joint SBIR/STTR program in accordance with the Small Business Act and the SBIR and STTR Policy Directive issued by the U.S. Small Business Administration (SBA).[4] ARPA-E provides SBIR/STTR funding in three phases (Phase I, Phase II, and Phase IIS).

C. PROGRAM OVERVIEW AND OBJECTIVES

This announcement is purposely broad in scope, and will cover a wide range of topics to encourage the submission of the most innovative and unconventional ideas in energy technology. The objective of this solicitation is to support high-risk R&D leading to the development of potentially disruptive new technologies across the full spectrum of energy applications. Topics under this FOA will explore new areas of technology development that, if successful, could establish new program areas for ARPA-E, or complement the current portfolio of ARPA-E programs.

Applications to this solicitation must have the potential for high impact — if successful, it could create a new class or new trajectory for an energy technology, with the potential to make a significant impact on ARPA-E's Mission Areas (see Section I.A).

Awards under this program may take the form of analyses or exploratory research that provides the agency with information useful for the subsequent development of focused technology programs. Alternatively, awards may support proof-of-concept research for a particular new technology, either in an area not currently supported by the agency or as a potential enhancement to an ongoing focused technology program.

D. EXPLORATORY TOPICS OVERVIEW

This FOA will only accept applications in prespecified Exploratory Topics. Specific areas of interest and relevant deadlines will be posted on the ARPA-E eXCHANGE website (https://arpa-e-foa.energy.gov). For your convenience you can subscribe to the ARPA-E mailing list to receive ARPA-E newsletters and news alerts, as well as updates on when new Exploratory Topics are posted.

[3] Research Institutions include FFRDCs, nonprofit educational institutions, and other nonprofit research organizations owned and operated exclusively for scientific purposes. Eligible Research Institutions must maintain a place of business in the United States, operate primarily in the United States, or make a significant contribution to the U.S. economy through the payment of taxes or use of American products, materials, or labor.

[4] *See* 85 Fed. Reg. 50062 (Aug. 17, 2020).

Each Exploratory Topic announcement will be visible on ARPA-E eXCHANGE as a supporting FOA document. Exploratory Topic details will only be visible in eXCHANGE while the notice is accepting applications. Once the topic deadline has passed the notice will be taken down and ARPA-E will no longer be accepting applications in that area. ARPA-E will only review applications that are responsive to the Exploratory Topic(s) open at the time the application is submitted.

II. AWARD INFORMATION

A. AWARD OVERVIEW

See Exploratory Topic Table and Topic Appendices for total amounts and anticipated number of awards for each Topic.

See Exploratory Topic Table and Topic Appendices for the total period of performance for a Combined Phase I/II Award or Combined Phase I/II/IIS Award.

ARPA-E will accept only new submissions under this FOA. Applicants may not seek renewal or supplementation of their existing awards through this FOA.

Unless otherwise stated in the Exploratory Topic, ARPA-E plans to fully fund negotiated budgets at the time of award.

Applicants must apply for a Combined Phase I/II/IIS Award (unless the applicable Topic Appendix states otherwise). Combined Phase I/II/IIS Awards are intended to develop transformational technologies with disruptive commercial potential. Such commercial potential may be evidenced by (1) the likelihood of follow-on funding by private or non-SBIR/STTR sources if the project is successful, or (2) the Small Business Concern's record of successfully commercializing technologies developed under prior SBIR/STTR awards. Phase IIS awards are a "sequential" (i.e., additional) Phase II award, intended to allow the continued development of promising energy technologies. Combined Phase I/II/IIS awards may be funded up to $4,398,504. Funding amounts will be consistent with the Phase I and Phase II limits posted on the SBA's website.[5]

ARPA-E reserves the right to select all or part of a proposed project (i.e. only Phase I, or only Phase I and Phase II). In the event that ARPA-E selects Phase I only or Phase I/II only, then the maximum award amount for a Phase I award is $306,872 and the maximum amount for a Phase I/II award is $2,352,688.

B. RENEWAL AWARDS

At ARPA-E's sole discretion, awards resulting from this FOA may be renewed by adding one or more budget periods extending the period of performance of the initial award, or a new award. Renewal funding is contingent on: (1) availability of funds appropriated by Congress for the purpose of this program; (2) substantial progress towards meeting the objectives of the approved application; (3) submittal of required reports; (4) compliance with the terms and

[5] For current SBIR Phase I and Phase II funding amounts, see https://www.sbir.gov/about/about-sbir. For current STTR Phase I and Phase II funding amounts, see https://www.sbir.gov/about/about-sttr. Phase IIS funding amounts are equal to Phase II funding amounts for both SBIR and STTR awards.

conditions of the award; (5) ARPA-E approval of a renewal application; and (6) other factors identified by the Agency at the time it solicits a renewal application.

C. ARPA-E FUNDING AGREEMENTS

Through Grants, Cooperative Agreements, other transactions, and similar agreements, ARPA-E provides financial and other support to projects that have the potential to realize ARPA-E's statutory mission. ARPA-E does not use such agreements to acquire property or services for the direct benefit or use of the U.S. Government.

1. GRANTS

A Grant is a legal instrument that is used to provide Federal financial assistance or other things of value to carry out a public purpose of support or stimulation authorized by Federal statute. Grants are distinguished from Cooperative Agreements in that they do not provide for substantial involvement between the Federal awarding agency (in this case ARPA-E) and the Recipient.

2. COOPERATIVE AGREEMENTS

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[6] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.D below.

Phase I will be made as a fixed-amount award. Phase II and Phase IIS of Combined Phase I/II/IIS awards will be made on a cost-reimbursement basis.

Any Federally Funded Research and Development Centers (FFRDC) involved as a member of a Project Team must provide the information requested in the "FFRDC Lab Authorization" and "Field Work Proposal" section of the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

When a FFRDC/DOE Lab is a subrecipient, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with the Prime Recipient, the lead entity for the rest of the Project Team. Notwithstanding the use of multiple agreements, the Prime Recipient under the Cooperative Agreement is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

[6] U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs (including NETL), and Federal instrumentalities (e.g., Tennessee Valley Authority) will be consistent with the sponsoring agreement between the U.S. Government and the Laboratory. Any funding agreement with an FFRDC or GOGO will have similar terms and conditions as ARPA-E's Model Cooperative Agreement (https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/funding-agreements).

Non-DOE GOGOs and Federal agencies may be proposed to provide support to the Project Team members on an applicant's project, through a Cooperative Research and Development Agreement (CRADA) or similar agreement.

ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement, which is available at https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/funding-agreements

D. FEDERAL STEWARDSHIP

ARPA-E will exercise Federal stewardship in overseeing the project activities performed under a grant. Stewardship activities include, but are not limited to, conducting site visits; reviewing performance and financial reports; providing technical assistance and/or temporary intervention in unusual circumstances to correct deficiencies which develop during the project; assuring compliance with terms and conditions of the Award; and reviewing technical performance during and after project completion to ensure that the Award objectives are being/have been accomplished.

E. STATEMENT OF SUBSTANTIAL INVOLVEMENT

ARPA-E is substantially involved in the direction of Cooperative Agreements from inception to completion. For the purposes of an ARPA-E project, substantial involvement means:

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- ARPA-E may, at its sole discretion, modify or terminate projects that fail to achieve predetermined Go/No Go decision points or technical milestones and deliverables.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must

be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.339 – 200.343.

- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits[7] to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

[7] The term "nonprofit organization" or "nonprofit" is defined in Section IX.

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

1. SBIR ELIGIBILITY

SBA rules and guidelines govern eligibility to apply to this FOA. For information on program eligibility, please refer to the SBIR/STTR website, available at https://www.sbir.gov, and to the "Eligibility" section for SBIR/STTR programs at https://www.sbir.gov/about.

A Small Business Concern[8] may apply as a Standalone Applicant[9] or as the lead organization for a Project Team.[10] If applying as the lead organization, the Small Business Concern must perform at least 66.7% of the work in Phase I and at least 50% of the work in Phase II and Phase IIS, as measured by the Total Project Cost.[11]

For information on eligibility as a Small Business Concern, please refer to SBA's website (https://www.sba.gov/content/am-i-small-business-concern).

2. STTR ELIGIBILITY

SBA rules and guidelines govern eligibility to apply to this FOA. For information on program eligibility, please refer the SBIR/STTR website, available at https://www.sbir.gov, and to the "Eligibility" section for SBIR/STTR programs at https://www.sbir.gov/about.

Only a Small Business Concern may apply as the lead organization for a Project Team. The Small Business Concern must perform at least 40% of the work in Phase I, Phase II, and/or Phase IIS, as measured by the Total Project Cost. A single Research Institution must perform at least 30% of the work in Phase I, Phase II, and/or Phase IIS, as measured by the Total Project Cost. Please refer to Section III.B.1 of the FOA for guidance on Research Institutions' participation in STTR projects. For information on eligibility as a Small Business Concern, please refer to SBA's website (https://www.sba.gov/content/am-i-small-business-concern).

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[8] A Small Business Concern is a for-profit entity that: (1) maintains a place of business located in the United States; (2) operates primarily within the United States or makes a significant contribution to the United States economy through payment of taxes or use of American products, materials or labor; (3) is an individual proprietorship, partnership, corporation, limited liability company, joint venture, association, trust, or cooperative; and (4) meets the size eligibility requirements set forth in 13 C.F.R. § 121.702. Where the entity is formed as a joint venture, there can be no more than 49% participation by foreign business entities in the joint venture. Small Business Concerns that are majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms are eligible to apply to this FOA.

[9] A "Standalone Applicant" is an Applicant that applies for funding on its own, not as part of a Project Team.

[10] A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.

[11] The Total Project Cost is the sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs, FFRDCs, and GOCOs.

3. JOINT SBIR AND STTR ELIGIBILITY

An Applicant that meets both the SBIR and STTR eligibility criteria above may request both SBIR and STTR funding if:

- The Small Business Concern is partnered with a Research Institution;
- The Small Business Concern performs at least 66.7% of the work in Phase I and at least 50% of the work in Phase II and/or Phase IIS (as applicable), as measured by the Total Project Cost;
- The partnering Research Institution performs 30-33.3% of the work in Phase I and 30-50% of the work in Phase II and/or Phase IIS (as applicable), as measured by the Total Project Cost; and
- The Principal Investigator (PI) is employed by the Small Business Concern. If the PI is employed by the Research Institution, submissions will be considered only under the STTR program.

B. ELIGIBLE SUBRECIPIENTS

1. RESEARCH INSTITUTIONS

A Research Institution[12] may apply only as a member of a Project Team (i.e., as a Subrecipient to a Small Business Concern). In STTR projects, a single Research Institution must perform at least 30%, but no more than 60%, of the work under the award in Phase I, Phase II, and/or Phase IIS (as applicable), as measured by the Total Project Cost.

2. OTHER PROJECT TEAM MEMBERS

The following entities are eligible to apply for SBIR/STTR funding as a member of a Project Team (i.e., as a Subrecipient to a Small Business Concern):

- For-profit entities, including Small Business Concerns
- Nonprofits other than Research Institutions[13]
- Government-Owned, Government Operated laboratories (GOGOs)
- State, local, and tribal government entities
- Foreign entities[14]

[12] Research Institutions include FFRDCs, nonprofit educational institutions, and other nonprofit research organizations owned and operated exclusively for scientific purposes. Eligible Research Institutions must maintain a place of business in the United States, operate primarily in the United States, or make a significant contribution to the U.S. economy through the payment of taxes or use of American products, materials, or labor.

[13] Nonprofit organizations described in section 501(c)(4) of the Internal Revenue Code of 1986 that engaged in lobbying activities after December 31, 1995 are not eligible to apply for funding as a Subrecipient.

[14] All work by foreign entities must be performed by subsidiaries or affiliates incorporated in the United States (see Section IV.F.6 of the FOA). However, the Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form submitted with the Full Application.

In SBIR projects, Project Team members other than the lead organization, including but not limited to Research Institutions, may collectively perform no more than 33.3% of the work under the award in Phase I and no more than 50% of the work under the award in Phase II and/or Phase IIS. This includes efforts performed by Research Institutions.

In STTR projects, Project Team members (other than the lead organization and the partnering Research Institution) may collectively perform no more than 30% of work under the award in Phase I, Phase II, and/or Phase IIS.

C. ELIGIBLE PRINCIPAL INVESTIGATORS

1. SBIR

For the duration of the award, the PI for the proposed project (or, if multiple PIs, at least one PI) must be employed by, and perform more than 50% of his or her work for, the Prime Recipient. The Contracting Officer may waive this requirement or approve the substitution of the PI after consultation with the ARPA-E SBIR/STTR Program Director.

For projects with multiple PIs, at least one PI must meet the primary employment requirement. That PI will serve as the contact PI for the Project Team.

2. STTR

For the duration of the award, the PI for the proposed project (or, if multiple PIs, at least one PI) must be employed by, and perform more than 50% his or her work for, the Prime Recipient or the partnering Research Institution. The Contracting Officer may waive this requirement or approve the substitution of the PI after consultation with the ARPA-E SBIR/STTR Program Director.

For projects with multiple PIs, at least one PI must meet the primary employment requirement. That PI will serve as the contact PI for the Project Team.

D. ELIGIBILITY OF PRIOR SBIR AND STTR AWARDEES: SBA BENCHMARKS ON PROGRESS TOWARDS COMMERCIALIZATION

Applicants awarded multiple prior SBIR or STTR awards must meet DOE's benchmark requirements for progress towards commercialization before ARPA-E may issue a new Phase I award. For purposes of this requirement, Applicants are assessed using their prior Phase I and Phase II SBIR and STTR awards across all SBIR agencies. If an awardee fails to meet either of the benchmarks, that awardee is not eligible for an SBIR or STTR Phase I award and any Phase II award for a period of one year from the time of the determination.

ARPA-E applies two benchmark rates addressing an Applicant's progress towards commercialization: (1) the DOE Phase II Transition Rate Benchmark and (2) the SBA Commercialization Rate Benchmark:

- The DOE Phase II Transition Rate Benchmark sets the minimum required number of Phase II awards the Applicant must have received for a given number of Phase I awards received during the specified period. **This Transition Rate Benchmark applies only to Phase I Applicants that have received more than 20 Phase I awards during the last five (5) year period, excluding the most recently completed fiscal year**. DOE's Phase II Transition Rate Benchmark requires that 25% of all Phase I awards received over the past five years transition to Phase II awards.

  The SBIR/STTR Phase II transition rates and commercialization rates are calculated using the data in the SBA's TechNet database. For the purpose of these benchmark requirements, awardee firms are assessed once a year, on June 1st, using their prior SBIR and STTR awards across all agencies. SBA makes this tabulation of awardee transition rates and commercialization rates available to all federal agencies. ARPA-E uses this tabulation to determine which companies do not meet the DOE benchmark rates and are, therefore, ineligible to receive new Phase I awards.

- The Commercialization Rate Benchmark sets the minimum Phase III[15] commercialization results that an Applicant must have achieved from work it performed under prior Phase II awards (i.e. this measures an Applicant's progress from Phase II or Phase IIS to Phase III awards). **This benchmark requirement applies only to Applicants that have received more than 15 Phase II awards during the last 10 fiscal years, excluding the two most recently completed fiscal years.**

  The current Commercialization Benchmark requirement, agreed upon and established by all 11 SBIR agencies, is that the Applicants must have received, to date, an average of at least $100,000 of sales and/or investments per Phase II award received, or have received a number of patents resulting from the relevant SBIR/STTR work equal to or greater than 15% of the number of Phase II awards received during the period.

- On June 1 of each year, SBIR/STTR awardees registered on SBIR.gov are assessed to determine if they meet the Phase II Transition Rate Benchmark requirement. (At this time, SBA is not identifying companies that fail to meet the Commercialization Rate

[15] Phase III refers to work that derives from, extends or completes an effort made under prior SBIR/STTR funding agreements, but is funded by sources other than the SBIR/STTR Program. Phase III work is typically oriented towards commercialization of SBIR/STTR research or technology. For more information please refer to the Small Business Administration's "Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program Program Policy Directive" at https://www.sbir.gov/sites/default/files/SBIR-STTR_Policy_Directive_2019.pdf.

Benchmark requirement). Companies that fail to meet the Phase II Transition Rate Benchmark as of June 1 of a given year will not be eligible to apply to an SBIR/STTR FOA for the following year. For example, if SBA determined on June 1, 2017 that a small business failed to meet the Phase II Transition Rate Benchmark requirement, that small business would not be eligible to apply to an ARPA-E SBIR/STTR FOA from June 1, 2017 to May 31, 2018.

E. COST SHARING[16]

Cost share is not required for this FOA.

F. OTHER

1. COMPLIANT CRITERIA

Full Applications are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Full Application complies with the content and form requirements in Section IV.C of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the Exploratory Topic submission deadline stated in Table 1 of this FOA.

Full Applications found to be noncompliant may not be merit reviewed or considered for award. ARPA-E may not review or consider noncompliant Full Applications, including Full Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

If applicable to the Exploratory Topic (refer to Table 1), Replies to Reviewer Comments are deemed compliant if:

- The Applicant successfully uploads its response to ARPA-E eXCHANGE by the deadline stated in the FOA; and
- The Replies to Reviewer Comments comply with the content and form requirements of Section IV.D of the FOA.

[16] Please refer to Section VI.B.3-4 of the FOA for guidance on cost share payments and reporting.

ARPA-E will not review or consider noncompliant Replies to Reviewer Comments, including Replies submitted through other means and Replies submitted after the applicable deadline. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information due to server/connection congestion. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be noncompliant.

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Full Applications. The following types of submissions may be deemed nonresponsive and may not be reviewed or considered:

- Submissions that fall outside the technical parameters specified in the Exploratory Topic Appendix
- Submissions that have been submitted in response to currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.
- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA. Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by any other office within Department of Energy.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by other government agencies or the private sector.
- Submissions that do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.
- Submissions that do not propose a Combined Phase I/II/IIS Award, as described in Section II.A of the FOA (unless the applicable Topic Appendix states otherwise).

Each Exploratory Topic may also include a section entitled "Submissions Specifically not of Interest." Submissions that propose items contained within this section in each Exploratory Topic may be deemed nonresponsive and may not be reviewed or considered.

3. LIMITATION ON NUMBER OF SUBMISSIONS

ARPA-E is not limiting the number of submissions from Applicants. Applicants may submit more than one application to each Exploratory Topic attached to this FOA, provided that each application is scientifically distinct.

Small business Applicants that qualify as a "Small Business Concern"[17] may apply to only one of the two ARPA-E, Exploratory Topics FOAs for each Exploratory Topics: DE-FOA-0002785 (Exploratory Topics SBIR/STTR), or DE-FOA-0002784 (Exploratory Topics). Small businesses that qualify as "Small Business Concerns" are strongly encouraged to apply under the former (SBIR/STTR FOA). To determine eligibility as a "Small Business Concern" under DE-FOA-0002785 (SBIR/STTR), please review the eligibility requirements in Sections III.A – III.D of that FOA.

[17] Please refer to the U.S. Small Business Administration (SBA) website. A Small Business Concern is a for-profit entity that: (1) maintains a place of business located in the United States; (2) operates primarily within the United States or makes a significant contribution to the United States economy through payment of taxes or use of American products, materials or labor; (3) is an individual proprietorship, partnership, corporation, limited liability company, joint venture, association, trust, or cooperative; and (4) meets the size eligibility requirements set forth in 13 C.F.R. § 121.702. Where the entity is formed as a joint venture, there can be no more than 49% participation by foreign business entities in the joint venture.

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN SBA COMPANY REGISTRY

The first step in applying to this FOA is registering in the U.S. Small Business Administration (SBA) Company Registry (http://sbir.gov/registration). Upon completing registration, Applicants will receive a unique small business Control ID and Registration Certificate in Adobe PDF format, which may be used at any participating SBIR and STTR agencies. Applicants that have previously registered in the SBA Company Registry need not register again.

Applicants must submit their Registration Certificate in ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov) as part of their Full Application (see Section IV.C.6 of the FOA).

2. REGISTRATION IN ARPA-E eXCHANGE

The second step in applying to this FOA is registration in ARPA-E eXCHANGE, ARPA-E's online application portal. For detailed guidance on using ARPA-E eXCHANGE, please refer to Section IV.G.1 of the FOA and the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

3. FULL APPLICATIONS

Applicants must submit a Full Application by the Exploratory Topic Full Application Submission Deadline stated in Table 1 of this FOA. Section IV.C of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.F of the FOA. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.1 and V.B.1 of the FOA.

4. REPLY TO REVIEWER COMMENTS

If applicable to the Exploratory Topic (refer to Table 1), once ARPA-E has completed its review of Full Applications, reviewer comments on compliant and responsive Full Applications are made available to Applicants via ARPA-E eXCHANGE. Applicants may submit an optional Reply to Reviewer Comments, which must be submitted by the deadline stated in the FOA. Section IV.D of the FOA provides instructions on submitting a Reply to Reviewer Comments.

ARPA-E performs a preliminary review of Replies to determine whether they are compliant, as described in Section III.D of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

5. PRE-SELECTION CLARIFICATIONS AND "DOWN-SELECT" PROCESS

Once ARPA-E completes its review of Full Applications, (and Replies to Reviewer Comments, if applicable), it may, at the Contracting Officer's discretion, conduct a pre-selection clarification process and/or perform a "down-select" of Full Applications. Through the pre-selection clarification process or down-select process, ARPA-E may obtain additional information from select Applicants through pre-selection meetings, webinars, videoconferences, conference calls, written correspondence, or site visits that can be used to make a final selection determination. ARPA-E will not reimburse Applicants for travel and other expenses relating to pre-selection meetings or site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for award negotiations and make awards without pre-selection meetings and site visits. Participation in a pre-selection meeting or site visit with ARPA-E does not signify that Applicants have been selected for award negotiations.

6. SELECTION FOR AWARD NEGOTIATIONS

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria, risk reviews, and program policy factors in Sections V.A.1, V.B.1 and VI.B.10 of the FOA. The Selection Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

Applicants are promptly notified of ARPA-E's selection determination. ARPA-E may stagger its selection determinations. As a result, some Applicants may receive their notification letter in advance of other Applicants. Please refer to Section VI.A of the FOA for guidance on award notifications.

B. APPLICATION FORMS

Required forms for Full Applications are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov), including the SF-424 and Budget Justification Workbook/SF-424A. A sample Summary Slide is available on ARPA-E eXCHANGE. Applicants may use the templates available on ARPA-E eXCHANGE, including the template for the Technical Volume of the Full Application, the template for the Summary Slide, the template for the Summary for Public Release, the template for the Reply to

Reviewer Comments and the template for the Business Assurances & Disclosures Form. A sample response to the Business Assurances & Disclosures Form is available on ARPA-E eXCHANGE.

C. CONTENT AND FORM OF FULL APPLICATIONS

Full Applications must conform to the following formatting requirements:

- Each document must be submitted in the file format prescribed below.
- The Full Application must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.

Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award (see Section III.F of the FOA).

Each Full Application should be limited to a single concept or technology. Unrelated concepts and technologies should not be consolidated in a single Full Application.

Fillable Full Application template documents are available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

ARPA-E provides detailed guidance on the content and form of each component below.

Full Applications must conform to the content requirements described below.

Component	Required Format	Description and Information
Technical Volume	PDF	The centerpiece of the Full Application. Provides a detailed description of the proposed R&D project and Project Team.
SF-424	PDF	Application for Federal Assistance. Applicants are responsible for ensuring that the proposed costs listed in eXCHANGE match those listed on forms SF-424 and SF-424A. Inconsistent submissions may impact ARPA-E's final award determination.
Budget Justification Workbook/SF-424A	XLS	Budget Information – Non-Construction Programs (https://arpa-e-foa.energy.gov)

Summary for Public Release	PDF	Short summary of the proposed R&D project. Intended for public release.
SBA Company Registration Certificate	PDF	Registration Certificate generated upon completion of registration in the SBA Company Registry (http://sbir.gov/registration).
Certification for Applicants Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, or Private Equity Firms (if applicable)	PDF	Requires SBIR Applicants that are majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms or that are joint ventures minority-owned by a foreign entity to self-identify, provide certain information, and verify registration as such in the SBA Company Registry (http://sbir.gov/registration).
Summary Slide	PPT	A four-panel project slide summarizing different aspects of the proposed R&D project.
Business Assurances & Disclosures Form	PDF	Applicants should provide comprehensive responses to the questions on this form. Requires the Applicant to acknowledge eligibility with SBIR/STTR program requirements, make responsibility disclosures, and disclose conflicts of interest within the Project Team. Requires the Applicant to describe the additionality and risks associated with the proposed project, disclose applications for funding currently pending with Federal and non-Federal entities, and disclose funding from Federal and non-Federal entities for work in the same technology area as the proposed R&D project. If an Applicant Team Member is a FFRDC/DOE Lab, the lab is required to provide written authorization from the cognizant Federal agency and, if a DOE/NNSA FFRDC/DOE Lab, a Field Work Proposal. This form allows the Applicant to request a waiver or modification of the Performance of Work in the United States requirement. A sample response to the Business Assurances & Disclosures Form is also available on ARPA-E eXCHANGE.

1. FIRST COMPONENT: TECHNICAL VOLUME

The Technical Volume must be submitted in Adobe PDF format. A Technical Volume template is available at https://arpa-e-foa.energy.gov. Exploratory Topics may have topic specific Technical Volumes. The Technical Volume must conform to the content and form requirements included within the template, including maximum page lengths. If Applicants exceed the maximum page lengths specified for each section, ARPA-E may review only the authorized number of pages and disregard any additional pages, or ARPA-E may determine that the submission as a whole is noncompliant.

Applicants must provide sufficient citations and references to the primary research literature to justify the claims and approaches made in the Technical Volume. ARPA-E and reviewers may review primary research literature in order to evaluate applications. However, all relevant technical information should be included in the body of the Technical Volume.

2. SECOND COMPONENT: SF-424

The SF-424 must be submitted in Adobe PDF format. This form is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

The SF-424 includes instructions for completing the form. Applicants must complete all required fields in accordance with the instructions. Applicants may identify and include in Block 14 the entities, their addresses, and corresponding census tract numbers for any project activities that will occur within any designated Qualified Opportunity Zone (QOZ). To locate Qualified Opportunity Zones go to: https://www.cdfifund.gov/opportunity-zones.

Prime Recipients and Subrecipients are required to complete SF-LLL (Disclosure of Lobbying Activities), available at https://www.grants.gov/forms/post-award-reporting-forms.html, if any non-Federal funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any Federal agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with your application or funding agreement. The completed SF-LLL must be appended to the SF-424.

ARPA-E provides the following supplemental guidance on completing the SF-424:

- Each Project Team should submit only one SF-424 (i.e., a Subrecipient should not submit a separate SF-424).
- The list of certifications and assurances in Block 21 can be found at http://energy.gov/management/downloads/certifications-and-assurances-use-sf-424.
- The dates and dollar amounts on the SF-424 are for the entire period of performance (from the project start date to the project end date), not a portion thereof.
- Applicants are responsible for ensuring that the proposed costs listed in eXCHANGE match those listed on forms SF-424 and SF-424A. Inconsistent submissions may impact ARPA-E's final award determination.

3. THIRD COMPONENT: BUDGET JUSTIFICATION WORKBOOK/SF-424A

Applicants are required to complete the Budget Justification Workbook/SF-424A Excel spreadsheet. This form is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov. Prime Recipients must complete each tab of the Budget Justification Workbook for the project as a whole, including all work to be performed by the Prime Recipient and its Subrecipients and

Contractors. The SF-424A form included with the Budget Justification Workbook will "auto-populate" as the Applicant enters information into the Workbook. Applicants should carefully read the "Instructions and Summary" tab provided within the Budget Justification Workbook.

Subrecipient information must be submitted as follows:

- Each Subrecipient incurring greater than or equal to 10% of the Total Project Cost must complete a separate Budget Justification workbook to justify its proposed budget. These worksheets must be inserted as additional sheets within in the Prime Recipient's Budget Justification.
- Subrecipients incurring less than 10% of the Total Project Cost are not required to complete a separate Budget Justification workbook. However, such Subrecipients are required to provide supporting documentation to justify their proposed budgets. At a minimum, the supporting documentation must show which tasks/subtasks are being performed, the purpose/need for the effort, and a sufficient basis for the estimated costs.

ARPA-E provides the following supplemental guidance on completing the Budget Justification Workbook/SF-424A:

- Applicants may request funds under the appropriate object class category tabs as long as the item and amount requested are necessary to perform the proposed work, meet all the criteria for allowability under the applicable Federal cost principles, and are not prohibited by the funding restrictions described herein.
- If Patent costs are requested, they must be included in the Applicant's proposed budget (see Section IV.E.3 of the FOA for more information on Patent Costs).
- Unless a waiver is granted by ARPA-E, each Project Team must spend at least 5% of the Federal funding (i.e., the portion of the award that does not include the recipient's cost share) on Technology Transfer & Outreach (TT&O) activities to promote and further the development and eventual deployment of ARPA-E-funded technologies.
- All TT&O costs requested must be included in the Applicant's proposed budget and identified as TT&O costs in the Budget Justification Workbook/SF-424A with the costs being requested under the "Other" budget category. All budgeted activities must relate to achieving specific objectives, technical milestones and deliverables outlined in Section 2.4 Task Descriptions of the Technical Volume.
- For more information, please refer to the ARPA-E Budget Justification Guidance document at https://arpa-e-foa.energy.gov.

4. FOURTH COMPONENT: SUMMARY FOR PUBLIC RELEASE

Applicants are required to provide a 250 word maximum Summary for Public Release. A Summary for Public Release template is available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov). The Summary for Public Release must be submitted in Adobe PDF format. This

summary should not include any confidential, proprietary, or privileged information. The summary should be written for a lay audience (e.g., general public, media, Congress) using plain English.

250 Words	**SUMMARY FOR PUBLIC RELEASE**	Briefly describe the proposed effort, summarize its objective(s) and technical approach, describe its ability to achieve the "Program Objectives" (see Section I.C of the FOA), and indicate its potential impact on "ARPA-E Mission Areas" (see Section I.A of the FOA). The summary should be written at technical level suitable for a high-school science student and is designed for public release. **INSTRUCTIONS:** (1) The Summary for Public Release shall not exceed 250 words and one paragraph. (2) The Summary for Public Release shall consist only of text—no graphics, figures, or tables. (3) For applications selected for award negotiations, the Summary may be used as the basis for a public announcement by ARPA-E; therefore, **this Cover Page and Summary should not contain confidential or proprietary information**. See Section VIII.I of the FOA for additional information on marking confidential information.

5. FIFTH COMPONENT: SUMMARY SLIDE

Applicants are required to provide a single PowerPoint slide summarizing the proposed project. The slide must be submitted in Microsoft PowerPoint format. This slide will be used during ARPA-E's evaluation of Full Applications. A summary slide template and a sample summary slide are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov).

Summary Slides must conform to the content requirements described below:

- Exploratory Topic Name
- A Technology Summary;
  - Bullet points that describe novel aspects of the proposed technology and technology approach;
- A description of the technology's impact;
  - Quantitative description (through text or graphic) of the impact the proposed project will provide to the market and ARPA-E mission areas;
- Proposed Targets;
  - Including any important technical performance metrics and/or impact categories;
  - Including quantitative description of the state of the art;
  - Including quantitative descriptions of the proposed targets;
- Any key graphics (illustrations, charts and/or tables) summarizing technology development and/or impact;
- The project's key idea/takeaway;

- Project title and Principal Investigator information; and
- Requested ARPA-E funds and proposed Applicant cost share.

6. SIXTH COMPONENT: SBA REGISTRATION CERTIFICATE

Applicants are required to provide a copy of the SBA Registration Certificate generated in the SBA Company Registry (http://sbir.gov/registration) in Adobe PDF format (see Section IV.A.1 of the FOA). Applicants that have previously registered in the SBA Company Registry may submit a copy their existing Registration Certificate.

7. SEVENTH COMPONENT: CERTIFICATION FOR APPLICANTS MAJORITY-OWNED BY MULTIPLE VENTURE CAPITAL OPERATING COMPANIES, HEDGE FUNDS, AND PRIVATE EQUITY FIRMS AND/OR (B) JOINT VENTURES MINORITY-OWNED BY A FOREIGN ENTITY

Only those Applicants that are (a) majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms and/or (b) joint ventures minority-owned by a foreign entity are required to complete the Certification for Applicants Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, and Private Equity Funds and Joint Venture Applicants Minority-Owned by Foreign Business Entities (VCOC/FJV Certification). The certification must be submitted in Adobe PDF format. This form is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

In the VCOC/FJV Certification, the Applicant is required to self-identify as an entity that falls into one of those categories, provide certain information, verify its ownership status, and verify that it has registered in the SBA Company Registry (http://sbir.gov/registration) as such an entity.

Applicants that are neither (a) majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms nor (b) joint ventures minority-owned by a foreign entity are not required to complete the VCOC/FJV Certification.

8. EIGHTH COMPONENT: BUSINESS ASSURANCES & DISCLOSURES FORM

Applicants are required to provide the information requested in the Business Assurances & Disclosures Form. The information must be submitted in Adobe PDF format. A fillable Business Assurances & Disclosures Form template is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov. A sample response to the Business Assurances & Disclosures Form is also available on ARPA-E eXCHANGE.

As described in the Business Assurances & Disclosures Form, the Applicant is required to:

- Acknowledge that it has reviewed SBA's eligibility requirements for the SBIR and STTR programs and that it anticipates that it will be able to certify eligibility to participate in ARPA-E's SBIR/STTR program at the time of award
- Disclose conditions bearing on responsibility, such as criminal convictions and Federal tax liability
- Disclose conflicts of interest within the Project Team and provide the Applicant's up-to-date, written, and enforced conflict of interest policy in accordance with DOE Interim COI Policy guidance at https://www.energy.gov/management/financial-assistance-letter-no-fal-2022-02
- If a FFRDC/DOE Lab is a member of the Project Team, submit written authorization from the cognizant Federal agency
- If a DOE/NNSA FFRDC/DOE Lab is a subrecipient, submit a Field Work Proposal.

In addition, ARPA-E is required by statute to "accelerat[e] transformational technological advances in areas that industry is by itself not likely to undertake because of technical and financial uncertainty."[18] In accordance with ARPA-E's statutory mandate, the Applicant is required to:

- Describe the additionality and risks associated with the proposed R&D project
- Disclose any applications for the same project or related work currently pending with any Federal or non-Federal entities
- Disclose all funding for work in the same technology area as the proposed project received from any Federal or non-Federal entity within the last 5 years

The Applicant may use the Business Assurances & Disclosures Form to:

- Request authorization to perform some work ~~overseas~~ outside of the United States; and
- Request a waiver of the TT&O spending requirement (applies for Topics dated April 18, 2023 and later).

D. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

If Applicable to the Exploratory Topic (refer to Table 1), written feedback on Full Applications is made available to Applicants before the submission deadline for Replies to Reviewer Comments. Applicants have a brief opportunity to prepare a short Reply to Reviewer Comments responding to one or more comments or supplementing their Full Application. A fillable Reply to Reviewer Comments template is available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov).

[18] America COMPETES Act, Pub. L. No. 110-69, § 5012 (2007), as amended (codified at 42 U.S.C. § 16538).

Replies to Reviewer Comments must conform to the following requirements:

- The Reply to Reviewer Comments must be submitted in Adobe PDF format.
- The Reply to Reviewer Comments must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Use Times New Roman typeface, a black font color, and a font size of 12 points or larger (except in figures and tables).
- The Control Number must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.

ARPA-E may not review or consider noncompliant Replies to Reviewer Comments (see Section III.D of the FOA). ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be noncompliant.

Replies to Reviewer Comments must conform to the following content and form requirements, including maximum page lengths, described below. If a Reply to Reviewer Comments is more than three pages in length ARPA-E may review only the first three pages and disregard any additional pages, or ARPA-E may determine that the submission as a whole is noncompliant.

SECTION	PAGE LIMIT	DESCRIPTION
Text	2 pages maximum	• Applicants may respond to one or more reviewer comments or supplement their Full Application.
Images	1 page maximum	• Applicants may provide graphs, charts, or other data to respond to reviewer comments or supplement their Full Application.

E. INTERGOVERNMENTAL REVIEW

This program is not subject to Executive Order 12372 (Intergovernmental Review of Federal Programs).

F. FUNDING RESTRICTIONS

1. ALLOWABLE COSTS

All expenditures must be allowable, allocable, and reasonable in accordance with the applicable Federal cost principles. ARPA-E has listed the Federal cost principles for different categories of Applicants at https://arpa-e.energy.gov/technologies/project-guidance/post-award-guidance.

2. PRE-AWARD COSTS

ARPA-E will not reimburse any pre-award costs incurred by Applicants before they are selected for award negotiations. Please refer to Section VI.A of the FOA for guidance on award notices.

Upon selection for award negotiations, Applicants may incur pre-award costs at their own risk, consistent with the requirements in 2 C.F.R. Part 200, as modified by 2 C.F.R. Part 910, and other Federal laws and regulations. All submitted budgets are subject to change and are typically reworked during award negotiations. ARPA-E is under no obligation to reimburse pre-award costs if, for any reason, the Applicant does not receive an award or the award is made for a lesser amount than the Applicant expected, or if the costs incurred are not allowable, allocable, or reasonable.

3. PATENT COSTS

For Subject Inventions disclosed to DOE under an award, ARPA-E will reimburse the Prime Recipient – in addition to allowable costs associated with Subject Invention disclosures - up to $30,000 of expenditures for filing and prosecution of United States patent applications, including international applications (PCT application) submitted to the United States Patent and Trademark Office (USPTO).

The Prime Recipient may request a waiver of the $30,000 cap. Note that, patent costs are considered to be Technology Transfer & Outreach (TT&O) costs (see Section IV.F.8 of the FOA below), and should be requested as such.

4. CONSTRUCTION

ARPA-E generally does not fund projects that involve major construction. Recipients are required to obtain written authorization from the Contracting Officer before incurring any major construction costs.

5. FOREIGN TRAVEL

ARPA-E generally does not fund projects that involve foreign travel. Recipients are required to obtain written authorization from the ARPA-E Program Director before incurring any foreign travel costs and provide trip reports with their reimbursement requests.

6. PERFORMANCE OF WORK IN THE UNITED STATES

ARPA-E strongly encourages interdisciplinary and cross-sectoral collaboration spanning organizational boundaries. Such collaboration enables the achievement of scientific and technological outcomes that were previously viewed as extremely difficult, if not impossible.

ARPA-E requires all work under ARPA-E funding agreements to be performed in the United States. However, Applicants may request a waiver of this requirement where their project would materially benefit from, or otherwise requires, certain work to be performed overseas.

Applicants seeking a waiver of this requirement are required to include an explicit request in the Business Assurances & Disclosures Form, which is part of the Full Application submitted to ARPA-E. Such waivers are granted where there is a demonstrated need, as determined by ARPA-E.

7. PURCHASE OF NEW EQUIPMENT

All equipment purchased under ARPA-E funding agreements must be made or manufactured in the United States, to the maximum extent practicable. This requirement does not apply to used or leased equipment. The Prime Recipients are required to notify the ARPA-E Contracting Officer reasonably in advance of purchasing any equipment that is not made or manufactured in the United States with a total acquisition cost of $250,000 or more. Purchases of foreign equipment with a total acquisition cost of $1,000,000 or more require the approval of the Head of Contracting Activity (HCA). The ARPA-E Contracting Officer will provide consent to purchase or reject within 30 calendar days of receipt of the Recipient's notification.

8. TECHNOLOGY TRANSFER AND OUTREACH

ARPA-E is required to contribute a percentage of appropriated funds to Technology Transfer and Outreach (TT&O) activities. In order to meet this mandate, every Project Team must spend at least 5% of the Federal funding (i.e., the portion of the award that does not include the recipient's cost share) provided by ARPA-E on TT&O activities to promote and further the development and deployment of ARPA-E-funded technologies. Project Teams must also seek a waiver from ARPA-E to spend less than the minimum 5% TT&O expenditure requirement.

All TT&O expenditures are subject to the applicable Federal cost principles (i.e., 2 C.F.R. 200 Subpart E and 48 C.F.R. Subpart 31). Examples of TT&O expenditures are as follows:

- Documented travel and registration for the ARPA-E Energy Innovation Summit and other energy-related conferences and events;
- Documented travel to meet with potential suppliers, partners, or customers;
- Documented work by salaried or contract personnel to develop technology-to-market models or plans;
- Documented costs of acquiring industry-accepted market research reports; and
- Approved patent costs.

ARPA-E will not reimburse recipients for TT&O costs considered to be unallowable in accordance with the applicable cost principles. Examples of unallowable TT&O expenditures include:

- Meals or entertainment;
- Gifts to potential suppliers, partners, or customers;
- TT&O activities that do not relate to the ARPA-E-funded technologies;

- Undocumented TT&O activities; and
- TT&O activities unrelated and/or unallocable to the subject award.

Applicants may seek a waiver of the TT&O requirement by including an explicit request in the Business Assurances & Disclosures Form. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the waiver request. ARPA-E may waive or modify the TT&O requirement, as appropriate.

For information regarding incorporation of TT&O costs into budget documentation, see Section IV.C.3 of the FOA.

9. LOBBYING

Prime Recipients and Subrecipients may not use any Federal funds, directly or indirectly, to influence or attempt to influence, directly or indirectly, congressional action on any legislative or appropriation matters pending before Congress, other than to communicate to Members of Congress as described in 18 U.S.C. § 1913. This restriction is in addition to those prescribed elsewhere in statute and regulation.

Prime Recipients and Subrecipients are required to complete and submit SF-LLL, "Disclosure of Lobbying Activities" (https://www.gsa.gov/forms-library/disclosure-lobbying-activities) if any non-Federal funds have been paid or will be paid to any person for influencing or attempting to influence any of the following in connection with your application:

- An officer or employee of any Federal agency,
- A Member of Congress,
- An officer or employee of Congress, or
- An employee of a Member of Congress.

10. CONFERENCE SPENDING

Prime Recipients and Subrecipients may not use any Federal funds to:

- Defray the cost to the United States Government of a conference held by any Executive branch department, agency, board, commission, or office which is not directly and programmatically related to the purpose for which their ARPA-E award is made and for which the cost to the United States Government is more than $20,000; or
- To circumvent the required notification by the head of any such Executive Branch department, agency, board, commission, or office to the Inspector General (or senior ethics official for any entity without an Inspector General), of the date, location, and number of employees attending such a conference.

11. INDEPENDENT RESEARCH AND DEVELOPMENT COSTS

ARPA-E does not fund Independent Research and Development (IR&D) as part of an indirect cost rate under its financial assistance awards. IR&D, as defined at FAR 31.205-18(a), includes cost of effort that is not sponsored by an assistance agreement or required in performance of a contract, and that consists of projects falling within the four following areas: (i) basic research, (ii) applied research, (iii) development, and (iv) systems and other concept formulation studies.

ARPA-E's goals are to enhance the economic and energy security of the United States through the development of energy technologies and ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies. ARPA-E accomplishes these goals by providing financial assistance for energy technology projects, and has well recognized and established procedures for supporting research through competitive financial assistance awards based on merit review of proposed projects. Reimbursement for independent research and development costs through the indirect cost mechanism could circumvent this competitive process.

To ensure that all projects receive similar and equal consideration, eligible organizations may compete for direct funding of independent research projects they consider worthy of support by submitting proposals for those projects to ARPA-E. Since proposals for these projects may be submitted for direct funding, costs for independent research and development projects are not allowable as indirect costs under ARPA-E awards. IR&D costs, however, would still be included in the direct cost base that is used to calculate the indirect rate so as to ensure an appropriate allocation of indirect costs to the organization's direct cost centers.

12. PROHIBITION ON CERTAIN TELECOMMUNICATIONS AND VIDEO SURVEILLANCE SERVICES OR EQUIPMENT

Per 2 C.F.R. § 200.216, recipients and subrecipients are prohibited from obligating or expending project funds to: (1) procure or obtain; (2) extend or renew a contract to procure or obtain; or (3) enter into a contract (or extend or renew a contract) to procure or obtain equipment, services, or systems that uses covered telecommunications equipment or services as a substantial or essential component of any system, or as critical technology as part of any system. As described in Public Law 115–232, section 889, covered telecommunications equipment is telecommunications equipment produced by Huawei Technologies Company or ZTE Corporation (or any subsidiary or affiliate of such entities). Refer to 2 C.F.R. § 200.216 for possible additional prohibitions and limitations.

13. BUY AMERICA REQUIREMENT FOR PUBLIC INFRASTRUCTURE PROJECTS

Projects funded through this FOA that are for, or contain, construction, alteration, maintenance, or repair of public infrastructure in the United States undertaken by applicable recipient types, require that:

- All iron, steel, and manufactured products used in the infrastructure project are produced in the United States; and
- All construction materials used in the infrastructure project are manufactured in the United States.

However, ARPA-E does not anticipate soliciting for or selecting projects that propose project tasks that are for, or contain, construction, alteration, maintenance, or repair of public infrastructure. If a project selected for award negotiations includes project tasks that may be subject to the Buy America Requirement, those project tasks will be removed from the project before any award is issued – i.e., no federal funding or Recipient cost share will be available for covered project tasks.

This "Buy America" requirement does not apply to an award where the Prime Recipient is a for-profit entity.

14. REQUIREMENT FOR FINANCIAL PERSONNEL

ARPA-E requires Small Business or Nonprofit applicants to identify a finance/budget professional (employee or contracted support) with an understanding of Federal contracting and/or financial assistance and cost accounting (including indirect costs, invoicing, and financial management systems) that will support the team in complying with all applicable requirements.

G. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

To apply to this FOA, Applicants must register with ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). Full Applications and Replies to Reviewer Comments must be submitted through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx). ARPA-E will not review or consider applications submitted through other means (e.g., fax, hand delivery, email, postal mail). For detailed guidance on using ARPA-E eXCHANGE, please refer to the "ARPA-E eXCHANGE Applicant Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

Upon creating an application submission in ARPA-E eXCHANGE, Applicants will be assigned a Control Number. If the Applicant creates more than one application submission, a different Control Number will be assigned for each application.

Once logged in to ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx), Applicants may access their submissions by clicking the "My Submissions" link in the navigation on the left side of the page. Every application that the Applicant has submitted to ARPA-E and the corresponding Control Number is displayed on that page. If the Applicant submits more than one application to a particular FOA, a different Control Number is shown for each application.

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the Exploratory Topic Submission Deadline.** Under normal conditions (i.e., at least 48 hours in advance of the Close Date), Applicants should allow at least 1 hour to submit a Full Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

Applicants should not wait until the last minute to begin the submission process. During the final hours before the submission deadline, Applicants may experience server/connection congestion that prevents them from completing the necessary steps in ARPA-E eXCHANGE to submit their applications. **ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.**

ARPA-E may not review or consider incomplete applications and applications received after the Exploratory Topic submission deadline stated in the FOA. Such applications may be deemed noncompliant (see Section III.F.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

- Failing to comply with the form and content requirements in Section IV of the FOA;
- Failing to enter required information in ARPA-E eXCHANGE;
- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Failing to click the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

ARPA-E urges Applicants to carefully review their applications and to allow sufficient time for the submission of required information and documents.

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive (see Section III.F of the FOA). If applicable, ARPA-E also performs a preliminary review of Replies to Reviewer Comments to determine whether they are compliant.

ARPA-E considers a mix of quantitative and qualitative criteria in determining whether to select a Full Application for award negotiations.

1. CRITERIA FOR FULL APPLICATIONS

Full Applications are evaluated based on the following criteria:

(1) *Impact of the Proposed Technology* (30%) - This criterion involves consideration of the following:

- The potential for a transformational and disruptive (not incremental) advancement in one or more energy-related fields;
- Thorough understanding of the current state-of-the-art and presentation of an innovative technical approach to significantly improve performance over the current state-of-the-art;
- Awareness of competing commercial and emerging technologies and identification of how the proposed concept/technology provides significant improvement over these other solutions; and
- A reasonable and effective strategy for transitioning the proposed technology from the laboratory to commercial deployment.

(2) *Overall Scientific and Technical Merit* (30%) - This criterion involves consideration of the following:

- Whether the proposed work is unique and innovative;
- Clearly defined project outcomes and final deliverables;
- Substantiation that the proposed project is likely to meet or exceed the technical performance targets identified in this FOA;
- Feasibility of the proposed work based upon preliminary data or other background information and sound scientific and engineering practices and principles;
- A sound technical approach, including appropriately defined technical tasks, to accomplish the proposed R&D objectives; and
- Management of risk, to include identifying major technical R&D risks and feasible, effective mitigation strategies.

(3) *Qualifications, Experience, and Capabilities of the Proposed Project Team* (30%) - This criterion involves consideration of the following**:**

- The PI and Project Team have the skill and expertise needed to successfully execute the project plan, evidenced by prior experience that demonstrates an ability to perform R&D of similar risk and complexity; and
- Access to the equipment and facilities necessary to accomplish the proposed R&D effort and/or a clear plan to obtain access to necessary equipment and facilities.

(4) *Soundness of Management Plan* (10%) - This criterion involves consideration of the following:

- Plausibility of plan to manage people and resources;
- Allocation of appropriate levels of effort and resources to proposed tasks;
- Reasonableness of the proposed project schedule, including major milestones; and
- Reasonableness of the proposed budget to accomplish the proposed project.

Submissions will not be evaluated against each other since they are not submitted in accordance with a common work statement.

The above criteria will be weighted as follows:

Impact of the Proposed Technology	30%
Overall Scientific and Technical Merit	30%
Qualifications, Experience, and Capabilities of the Proposed Project Team	30%
Soundness of Management Plan	10%

2. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

ARPA-E has not established separate criteria to evaluate Replies to Reviewer Comments. Instead, Replies to Reviewer Comments are evaluated as an extension of the Full Application.

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

In addition to the above criteria, ARPA-E may consider the following program policy factors in determining which Full Applications to select for award negotiations:

I. **ARPA-E Portfolio Balance**. Project balances ARPA-E portfolio in one or more of the following areas:
   a. Diversity of technical personnel in the proposed Project Team;

b. Technological diversity;
c. Organizational diversity;
d. Geographic diversity;
e. Technical or commercialization risk; or
f. Stage of technology development.

II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
a. Reduction of U.S. dependence on foreign energy sources;
b. Stimulation of U.S. manufacturing; and/or software development;
c. Reduction of energy-related emissions;
d. Increase in U.S. energy efficiency;
e. Enhancement of U.S. economic and energy security; or
f. Promotion of U.S. advanced energy technologies competitiveness.

III. **Synergy of Public and Private Efforts**.
a. Avoids duplication and overlap with other publicly or privately funded projects;
b. Promotes increased coordination with nongovernmental entities for demonstration of technologies and research applications to facilitate technology transfer; or
c. Increases unique research collaborations.

IV. **Low likelihood of other sources of funding.** High technical and/or financial uncertainty that results in the non-availability of other public, private or internal funding or resources to support the project.

V. **High Project Impact Relative to Project Cost.**

VI. **Qualified Opportunity Zone (QOZ).** Whether the entity is located in an urban and economically distressed area including a Qualified Opportunity Zone (QOZ) or the proposed project will occur in a QOZ or otherwise advance the goals of QOZ. The goals include spurring economic development and job creation in distressed communities throughout the United States. For a list or map of QOZs go to: https://www.cdfifund.gov/opportunity-zones.

2. ARPA-E REVIEWERS

By submitting an application to ARPA-E, Applicants consent to ARPA-E's use of Federal employees, contractors, and experts from educational institutions, nonprofits, industry, and governmental and intergovernmental entities as reviewers. ARPA-E selects reviewers based on their knowledge and understanding of the relevant field and application, their experience and skills, and their ability to provide constructive feedback on applications.

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in Full Applications, and Replies to Reviewer Comments. In addition, ARPA-E trains its reviewers in proper evaluation techniques and procedures.

Applicants are not permitted to nominate reviewers for their applications. Applicants may contact the Contracting Officer by email (ARPA-E-CO@hq.doe.gov) if they have knowledge of a potential conflict of interest or a reasonable belief that a potential conflict exists.

3. ARPA-E SUPPORT CONTRACTOR

ARPA-E utilizes contractors to assist with the evaluation of applications and project management. To avoid actual and apparent conflicts of interest, ARPA-E prohibits its support contractors from submitting or participating in the preparation of applications to ARPA-E.

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. ANTICIPATED ANNOUNCEMENT AND AWARD DATES

ARPA-E expects to announce selections for negotiations for each Exploratory Topic in the month indicated in Table 1. ARPA-E anticipates that it will execute a funding agreement no more than 180 calendar days after the Full Application submission deadline of the applicable Exploratory Topic.

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

Noncompliant and nonresponsive Full Applications are rejected by the Contracting Officer and are not merit reviewed or considered for award. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Full Application was rejected.

2. FULL APPLICATION NOTIFICATIONS

ARPA-E promptly notifies Applicants of its determination. ARPA-E sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter may inform the Applicant that its Full Application was selected for award negotiations, or not selected. Alternatively, ARPA-E may notify one or more Applicants that a final selection determination on particular Full Applications will be made at a later date, subject to the availability of funds and other factors.

If authorized per Table 1, written feedback on Full Applications is made available to Applicants before the submission deadline for Replies to Reviewer Comments. By providing feedback, ARPA-E intends to guide the further development of the proposed technology and to provide a brief opportunity to respond to reviewer comments.

a. SUCCESSFUL APPLICANTS

ARPA-E has discretion to select all or part of a proposed project for negotiation of an award. A notification letter selecting a Full Application for award negotiations does not authorize the Applicant to commence performance of the project. **ARPA-E selects Full Applications for award negotiations, not for award.** Applicants do not receive an award until award negotiations are complete and the Contracting Officer executes the funding agreement. ARPA-E may terminate award negotiations at any time for any reason.

Please refer to Section IV.F.2 of the FOA for guidance on pre-award costs.

b. POSTPONED SELECTION DETERMINATIONS

A notification letter postponing a final selection determination until a later date does not authorize the Applicant to commence performance of the project. ARPA-E may ultimately determine to select or not select the Full Application for award negotiations.

Please refer to Section IV.F.2 of the FOA for guidance on pre-award costs.

c. UNSUCCESSFUL APPLICANTS

By not selecting a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. ARPA-E hopes that unsuccessful Applicants will submit innovative ideas and concepts for future FOAs.

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

The following administrative and national policy requirements apply to Prime Recipients. The Prime Recipient is the responsible authority regarding the settlement and satisfaction of all contractual and administrative issues, including but not limited to disputes and claims arising out of any agreement between the Prime Recipient and a FFRDC contractor. Prime Recipients are required to flow down these requirements to their Subrecipients through subawards or related agreements.

- If a subaward is made to a DOE/NNSA National Laboratory, all Disputes and Claims will be resolved in accordance with the terms and conditions of the DOE/NNSA National Laboratory's management and operating (M&O) contract, as applicable, in consultation between DOE and the prime awardee.
- If a subaward is made to another Federal agency or its FFRDC contractor, all Disputes and Claims will be resolved in accordance with the terms and conditions of the interagency agreement in consultation between DOE and the prime awardee.

1. UNIQUE ENTITY IDENTIFIER AND SAM, FSRS, AND FEDCONNECT REGISTRATIONS

Prime Recipients must register with the System for Award Management (SAM) at www.sam.gov/SAM prior to submitting an application, at which time the system will assign (if newly registered) a Unique Entity Identifier (UEI). As of April 4, 2022, the UEI replaces the old Dun and Bradstreet Data Universal Numbering System (DUNS) number requirement.

Prime Recipients must:

- Maintain an active SAM registration with current information, including information on a its immediate and highest-level owner and subsidiaries, as well as on all predecessors that have been awarded a Federal contract or financial assistance award within the last three years, if applicable, at all times during which it has an active Federal award or an application or plan under consideration by a Federal awarding agency;
- Remain registered in the SAM database after the initial registration;
- Update its information in the SAM database as soon as it changes;

- Review its information in the SAM database on an annual basis from the date of initial registration or subsequent updates to ensure it is current, accurate and complete; andnot make a subaward to any entity unless the entity has provided its UEI.

Subrecipients are not required to register in SAM, but must obtain a UEI.

Prime Recipients and Subrecipients should commence this process as soon as possible in order to expedite the execution of a funding agreement. Registering with SAM and obtaining the UEI could take several weeks.

Prime Recipients are also required to register with the Federal Funding Accountability and Transparency Act Subaward Reporting System (FSRS) at https://www.fsrs.gov/.[19] Prime Recipients are required to report to FSRS the names and total compensation of each of the Prime Recipient's five most highly compensated executives and the names and total compensation of each Subrecipient's five most highly compensated executives. Please refer to https://www.fsrs.gov/ for guidance on reporting requirements. Prime Recipients are required to keep the FSRS data current throughout the duration of the project.

ARPA-E may not execute a funding agreement with the Prime Recipient until it has obtained a UEI and completed its SAM and FSRS registrations.

Finally, Prime Recipients are required to register with FedConnect in order to receive notification that their funding agreement has been executed by the Contracting Officer and to obtain a copy of the executed funding agreement. Please refer to https://www.fedconnect.net/FedConnect/ for registration instructions.

2. NATIONAL POLICY ASSURANCES

Project Teams, including Prime Recipients and Subrecipients, are required to comply with the National Policy Assurances attached to their funding agreement in accordance with 2 C.F.R. 200.300. Refer to Attachment 6 of ARPA-E's Model Cooperative Agreement (Https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/funding-agreements) for guidance on the National Policy Assurances.

3. ENVIRONMENTAL IMPACT QUESTIONNAIRE

By law, ARPA-E is required to evaluate the potential environmental impact of projects that it is considering for funding. In particular, ARPA-E must determine before funding a project whether the project qualifies for a categorical exclusion under 10 C.F.R. § 1021.410 or whether it requires further environmental review (i.e., an environmental assessment or an environmental impact statement).

[19] The Federal Funding Accountability and Transparency Act, P.L. 109-282, 31 U.S.C. 6101 note.

To facilitate and expedite ARPA-E's environmental review, Prime Recipients are required to complete an Environmental Impact Questionnaire during award negotiations. This form is available on ARPA-E eXCHANGE at https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/required-forms-and-templates. Each Prime Recipient must wait to complete the Environmental Impact Questionnaire (EIQ) until after ARPA-E has notified them that Attachment 3 Statement of Program Objectives is in final form. The completed EIQ is then due back to ARPA-E within 14 calendar days.

4. TECHNOLOGY-TO-MARKET PLAN

During award negotiations, Prime Recipients are required to negotiate and submit an initial Technology-to-Market Plan for Phase II and Phase IIS with the ARPA-E Program Director, and obtain the ARPA-E Program Director's approval prior to the execution of the award. Prime Recipients must show how any budgeted Technology Transfer and Outreach (TT&O) costs relate to furthering elements of the Technology-to-Market Plan. During the period of performance, Prime Recipients are required to provide regular updates on the initial Technology-to-Market plan and report on implementation of Technology-to-Market activities. Prime Recipients may be required to perform other actions to further the commercialization of their respective technologies. Prime Recipients are not required to negotiate a Technology-to-Market Plan for Phase I only awards.

ARPA-E may waive or modify this requirement, as appropriate.

5. INTELLECTUAL PROPERTY AND DATA MANAGEMENT PLANS

ARPA-E requires every Project Team to negotiate and establish an Intellectual Property Management Plan for the management and disposition of intellectual property arising from the project. The Prime Recipient must submit a completed and signed Intellectual Property Management plan to ARPA-E within six weeks of the effective date of the ARPA-E funding agreement. All Intellectual Property Management Plans are subject to the terms and conditions of the ARPA-E funding agreement and its intellectual property provisions, and applicable Federal laws, regulations, and policies, all of which take precedence over the terms of Intellectual Property Management Plans.

ARPA-E has developed a template for Intellectual Property Management Plans (https://arpa-e.energy.gov/technologies/project-guidance/post-award-guidance/project-management-reporting-requirements) so as to facilitate and expedite negotiations between Project Team members. ARPA-E does not mandate the use of this template. ARPA-E and DOE do not make any warranty (express or implied) or assume any liability or responsibility for the accuracy, completeness, or usefulness of the template. ARPA-E and DOE strongly encourage Project Teams to consult independent legal counsel before using the template.

Awardees are also required, post-award, to submit a Data Management Plan (DMP) that addresses how data generated in the course of the work performed under an ARPA-E award

will be preserved and, as appropriate, shared publicly. At that time ARPA-E may negotiate with the Prime Recipient a mutually agreeable list of data that may be released to the public and not be treated as SBIR/STTR data. The Prime Recipient must submit a completed and signed DMP - as part of the Team's Intellectual Property Management Plan - to ARPA-E within six weeks of the effective date of the ARPA-E funding agreement.

6. U.S. COMPETITIVENESS

A primary objective of DOE's multi-billion dollar research, development and demonstration investments – including ARPA-E awards - is advancement of new energy technologies, manufacturing capabilities, and supply chains for and by U.S. industry and labor. Therefore, in exchange for receiving taxpayer dollars to support an applicant's project, the applicant must agree to the following U.S. Competitiveness Provision as part of an award under this FOA.

U.S. Competitiveness

> The Contractor (Prime Recipient in ARPA-E awards) agrees that any products embodying any subject invention or produced through the use of any subject invention will be manufactured substantially in the United States unless the Contractor can show to the satisfaction of DOE that it is not commercially feasible. In the event DOE agrees to foreign manufacture, there will be a requirement that the Government's support of the technology be recognized in some appropriate manner, e.g., alternative binding commitments to provide an overall net benefit to the U.S. economy. The Contractor agrees that it will not license, assign or otherwise transfer any subject invention to any entity, at any tier, unless that entity agrees to these same requirements. Should the Contractor or other such entity receiving rights in the invention(s): (1) undergo a change in ownership amounting to a controlling interest, or (2) sell, assign, or otherwise transfer title or exclusive rights in the invention(s), then the assignment, license, or other transfer of rights in the subject invention(s) is/are suspended until approved in writing by DOE. The Contractor and any successor assignee will convey to DOE, upon written request from DOE, title to any subject invention, upon a breach of this paragraph. The Contractor will include this paragraph in all subawards/contracts, regardless of tier, for experimental, developmental or research work.
>
> A subject invention is any invention of the contractor conceived or first actually reduced to practice in the performance of work under an award. An invention is any invention or discovery which is or may be patentable. The contractor includes any awardee, recipient, sub-awardee, or sub-recipient.
>
> As noted in the U.S. Competitiveness Provision, at any time in which an entity cannot meet the requirements of the U.S. Competitiveness Provision, the entity may request a modification or waiver of the U.S. Competitiveness Provision. For example, the entity may propose modifying the language of the U.S. Competitiveness Provision in order to

change the scope of the requirements or to provide more specifics on the application of the requirements for a particular technology. As another example, the entity may request that the U.S. Competitiveness Provision be waived in lieu of a net benefits statement or U.S. manufacturing plan. The statement or plan would contain specific and enforceable commitments that would be beneficial to the U.S. economy and competitiveness. Commitments could include manufacturing specific products in the U.S., making a specific investment in a new or existing U.S. manufacturing facility, keeping certain activities based in the U.S. or supporting a certain number of jobs in the U.S. related to the technology. If DOE, in its sole discretion, determines that the proposed modification or waiver promotes commercialization and provides substantial U.S. economic benefits, DOE may grant the request and, if granted, modify the award terms and conditions for the requesting entity accordingly.

The U.S. Competitiveness Provision is implemented by DOE pursuant to a Determination of Exceptional Circumstances (DEC) under the Bayh-Dole Act and DOE Patent Waivers. See Section VIII.A, "Title to Subject Inventions", of this FOA for more information on the DEC and DOE Patent Waiver.

7. CORPORATE FELONY CONVICTIONS AND FEDERAL TAX LIABILITY

In submitting an application in response to this FOA, the Applicant represents that:

- It is not a corporation that has been convicted of a felony criminal violation under any Federal law within the preceding 24 months; and
- It is not a corporation that has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

For purposes of these representations the following definitions apply: A Corporation includes any entity that has filed articles of incorporation in any of the 50 states, the District of Columbia, or the various territories of the United States [but not foreign corporations]. It includes both for-profit and non-profit organizations.

8. APPLICANT RISK ANALYSIS

If selected for award negotiations, ARPA-E may evaluate the risks posed by the Applicant using the criteria set forth at 2 CFR §200.206(b)(ii). ARPA-E may require special award terms and conditions depending upon results of the risk analysis.

Further, as DOE invests in critical infrastructure and funds critical and emerging technology areas, DOE also considers possible vectors of undue foreign influence in evaluating risk. If high risks are identified and cannot be sufficiently mitigated, DOE may elect to not fund the

applicant. As part of the research, technology, and economic security risk review, DOE may contact the applicant and/or proposed project team members for additional information to inform the review.

ARPA-E will not make an award if ARPA-E has determined that:

- The entity submitting the proposal or application:
  - has an owner or covered individual that is party to a malign foreign talent recruitment program;
  - has a business entity, parent company, or subsidiary located in the People's Republic of China or another foreign country of concern; or
  - has an owner or covered individual that has a foreign affiliation with a research institution located in the People's Republic of China or another foreign country of concern; and

- The relationships and commitments described above:
  - interfere with the capacity for activities supported by the Federal agency to be carried out;
  - create duplication with activities supported by the Federal agency;
  - present concerns about conflicts of interest;
  - were not appropriately disclosed to the Federal agency;
  - violate Federal law or terms and conditions of the Federal agency; or

  pose a risk to national security.

9. RECIPIENT INTEGRITY AND PERFORMANCE MATTERS

Prior to making a Federal award, ARPA-E is required to review and consider any information about Applicants that is contained in the Office of Management and Budget's designated integrity and performance system accessible through SAM (currently the Federal Awardee Performance and Integrity Information System or FAPIIS) (41 U.S.C. § 2313 and 2 C.F.R. 200.206).

Applicants may review information in FAPIIS and comment on any information about itself that a Federal awarding agency previously entered into FAPIIS.

ARPA-E will consider any written comments provided by Applicants during award negotiations, in addition to the other information in FAPIIS, in making a judgment about an Applicant's integrity, business ethics, and record of performance under Federal awards when reviewing potential risk posed by Applicants as described in 2 C.F.R. §200.206.

10. NONDISCLOSURE AND CONFIDENTIALITY AGREEMENTS REPRESENTATIONS

In submitting an application in response to this FOA the Applicant represents that:

(1) **It does not and will not** require its employees or contractors to sign internal nondisclosure or confidentiality agreements or statements prohibiting or otherwise restricting its employees or contractors from lawfully reporting waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information.

(2) **It does not and will not** use any Federal funds to implement or enforce any nondisclosure and/or confidentiality policy, form, or agreement it uses unless it contains the following provisions:

a. *"These provisions are consistent with and do not supersede, conflict with, or otherwise alter the employee obligations, rights, or liabilities created by existing statute or Executive order relating to (1) classified information, (2) communications to Congress, (3) the reporting to an Inspector General of a violation of any law, rule, or regulation, or mismanagement, a gross waste of funds, an abuse of authority, or a substantial and specific danger to public health or safety, or (4) any other whistleblower protection. The definitions, requirements, obligations, rights, sanctions, and liabilities created by controlling Executive orders and statutory provisions are incorporated into this agreement and are controlling."*

b. The limitation above shall not contravene requirements applicable to Standard Form 312, Form 4414, or any other form issued by a Federal department or agency governing the nondisclosure of classified information.

c. Notwithstanding the provision listed in paragraph (a), a nondisclosure confidentiality policy form or agreement that is to be executed by a person connected with the conduct of an intelligence or intelligence-related activity, other than an employee or officer of the United States Government, may contain provisions appropriate to the particular activity for which such document is to be used. Such form or agreement shall, at a minimum, require that the person will not disclose any classified information received in the course of such activity unless specifically authorized to do so by the United States Government. Such nondisclosure or confidentiality forms shall also make it clear that they do not bar disclosure to congress, or to an authorized official of an executive agency or the Department of Justice, that are essential to reporting a substantial violation of law.

11. INTERIM CONFLICT OF INTEREST POLICY FOR FINANCIAL ASSISTANCE

The DOE interim Conflict of Interest Policy for Financial Assistance (COI Policy) can be found at https://www.energy.gov/management/financial-assistance-letter-no-fal-2022-02. This policy is applicable to all non-Federal entities applying for, or that receive, DOE funding by means of a

financial assistance award (e.g., a grant, cooperative agreement, or technology investment agreement or similar other transaction agreement) and, through the implementation of this policy by the entity, to each Investigator who is planning to participate in, or is participating in, the project funded wholly or in part under the DOE financial assistance award. DOE's interim COI Policy establishes standards that provide a reasonable expectation that the design, conduct, and reporting of projects funded wholly or in part under DOE financial assistance awards will be free from bias resulting from financial conflicts of interest or organizational conflicts of interest. The applicant is subject to the requirements of the interim COI Policy and within each application for financial assistance, the applicant must certify that it is, or will be by the time of receiving any financial assistance award, compliant with all requirements in the interim COI Policy. For applicants to any ARPA-E Funding Opportunity Announcement, this certification, disclosure of any managed or unmanaged conflicts of interest, and a copy of (or link to) the applicant's own conflict of interest policy must be included with the information provided in the Business Assurances & Disclosures Form. The applicant must also flow down the requirements of the interim COI Policy to any subrecipient non-Federal entities.

12. COMMERCIALIZATION PLAN AND SOFTWARE REPORTING

If your project is selected and it targets the development of software, you may be required to prepare a Commercialization Plan for the targeted software and agree to special provisions that require the reporting of the targeted software and its utilization. This special approach to projects that target software mirrors the requirements for reporting that attach to new inventions made in performance of an award.

C. REPORTING

Recipients are required to submit periodic, detailed reports on technical, financial, and other aspects of the project, as described in Attachment 4 to ARPA-E's Model Cooperative Agreement (https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/funding-agreements).

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

Upon the issuance of an Exploratory Topic, only the Contracting Officer may communicate with Applicants. ARPA-E personnel and our support contractors are prohibited from communicating (in writing or otherwise) with Applicants regarding the FOA. This "quiet period" remains in effect until ARPA-E's public announcement of its project selections.

During the "quiet period," Applicants are required to submit all questions regarding this FOA to ARPA-E-CO@hq.doe.gov. Questions and Answers (Q&As) about ARPA-E and the FOA are available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, please send an email with the FOA name and number in the subject line to ARPA-E-CO@hq.doe.gov. Due to the volume of questions received, ARPA-E will only answer pertinent questions that have not yet been answered and posted at the above link.

- ARPA-E will post responses on a weekly basis to any questions that are received that have not already been addressed at the link above. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- ARPA-E will cease to accept questions approximately 10 business days in advance of the Exploratory Topic submission deadline. Responses to questions received before this cutoff will be posted no later than three business days in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- Responses are published in a document specific to this FOA under "CURRENT FUNDING OPPORTUNITIES – FAQS" on ARPA-E's website (http://arpa-e.energy.gov/faq).

Applicants may submit questions regarding ARPA-E eXCHANGE, ARPA-E's online application portal, to ExchangeHelp@hq.doe.gov. ARPA-E will promptly respond to emails that raise legitimate, technical issues with ARPA-E eXCHANGE. ARPA-E will refer any questions regarding the FOA to ARPA-E-CO@hq.doe.gov.

ARPA-E will not accept or respond to communications received by other means (e.g., fax, telephone, mail, hand delivery). Emails sent to other email addresses will be disregarded.

During the "quiet period," only the Contracting Officer may authorize communications between ARPA-E personnel and Applicants. The Contracting Officer may communicate with Applicants as necessary and appropriate. As described in Section IV.A of the FOA, the Contracting Officer may arrange pre-selection meetings and/or site visits during the "quiet period."

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings. If authorized per Table 1, ARPA-E provides Applicants with reviewer comments on Full Applications before the submission deadline for Replies to Reviewer Comments.

VIII. OTHER INFORMATION

A. TITLE TO SUBJECT INVENTIONS

Ownership of subject inventions is governed pursuant to the authorities listed below.

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions;
- All other parties: The federal Non-Nuclear Energy Act of 1974, 42. U.S.C. 5908, provides that the government obtains title to new subject inventions unless a waiver is granted (see below):
- Class Patent Waiver for Domestic Large Businesses: DOE has issued a class patent waiver that applies to this FOA. Under this class patent waiver, domestic large businesses may elect title to their subject inventions similar to the right provided to the domestic small businesses, educational institutions, and nonprofits by law. In order to avail itself of the class patent waiver, a domestic large business must agree to the U.S. Competitiveness Provision in accordance with Section VI.B.6. of this FOA.
- Advance and Identified Waivers: For applicants that do not fall under the class patent waiver or the Bayh-Dole Act, those applicants may request a patent waiver that will cover subject inventions that may be made under the award, in advance of or within 30 days after the effective date of the award. Even if an advance waiver is not requested or the request is denied, the recipient will have a continuing right under the award to request a waiver for identified inventions, i.e., individual subject inventions that are disclosed to DOE within the time frames set forth in the award's intellectual property terms and conditions. Any patent waiver that may be granted is subject to certain terms and conditions in 10 CFR 784.
- DEC: On June 07, 2021, DOE approved a DETERMINATION OF EXCEPTIONAL CIRCUMSTANCES (DEC) UNDER THE BAYH-DOLE ACT TO FURTHER PROMOTE DOMESTIC MANUFACTURE OF DOE SCIENCE AND ENERGY TECHNOLOGIES. In accordance with this DEC, all awards, including sub-awards, under this FOA made to a Bayh-Dole entity (domestic small businesses and nonprofit organizations) shall include the U.S. Competitiveness Provision in accordance with Section VI.B.6 of this FOA. A copy of the DEC may be found on the DoE website. Pursuant to 37 CFR § 401.4, any Bayh-Dole entity affected by this DEC has the right to appeal it by providing written notice to DOE within 30 working days from the time it receives a copy of the determination.

B. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

Where Prime Recipients and Subrecipients retain title to subject inventions, the U.S. Government retains certain rights.

1. GOVERNMENT USE LICENSE

The U.S. Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world. This license extends to contractors doing work on behalf of the Government.

2. MARCH-IN RIGHTS

The U.S. Government retains march-in rights with respect to all subject inventions. Through "march-in rights," the Government may require a Prime Recipient or Subrecipient who has elected to retain title to a subject invention (or their assignees or exclusive licensees), to grant a license for use of the invention. In addition, the Government may grant licenses for use of the subject invention when Prime Recipients, Subrecipients, or their assignees and exclusive licensees refuse to do so.

The U.S. Government may exercise its march-in rights if it determines that such action is necessary under any of the four following conditions:

- The owner or licensee has not taken or is not expected to take effective steps to achieve practical application of the invention within a reasonable time;
- The owner or licensee has not taken action to alleviate health or safety needs in a reasonably satisfactory manner;
- The owner has not met public use requirements specified by Federal statutes in a reasonably satisfactory manner; or
- The U.S. Manufacturing requirement has not been met.

C. RIGHTS IN TECHNICAL DATA

Data rights differ based on whether data is first produced under an award or instead was developed at private expense outside the award.

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
- Generated Data: Pursuant to special statutory authority for SBIR/STTR awards, data generated under ARPA-E SBIR/STTR awards may be protected from public disclosure for twenty years from the date of award in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

Applicants may not include any Protected Personally Identifiable Information (Protected PII) in their submissions to ARPA-E. Protected PII is defined as data that, if compromised, could cause harm to an individual such as identity theft. Listed below are examples of Protected PII that Applicants must not include in their submissions.

- Social Security Numbers in any form;
- Place of Birth associated with an individual;
- Date of Birth associated with an individual;
- Mother's maiden name associated with an individual;
- Biometric record associated with an individual;
- Fingerprint;
- Iris scan;
- DNA;
- Medical history information associated with an individual;
- Medical conditions, including history of disease;
- Metric information, e.g. weight, height, blood pressure;
- Criminal history associated with an individual;
- Ratings;
- Disciplinary actions;
- Performance elements and standards (or work expectations) are PII when they are so intertwined with performance appraisals that their disclosure would reveal an individual's performance appraisal;
- Financial information associated with an individual;
- Credit card numbers;
- Bank account numbers; and
- Security clearance history or related information (not including actual clearances held).

E. FOAS AND FOA MODIFICATIONS

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA, including Exploratory Topic announcements, are also posted to these websites. You can receive an email when a modification or a new Exploratory Topics is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

F. OBLIGATION OF PUBLIC FUNDS

The Contracting Officer is the only individual who can make awards on behalf of ARPA-E or obligate ARPA-E to the expenditure of public funds. A commitment or obligation by any individual other than the Contracting Officer, either explicit or implied, is invalid.

ARPA-E awards may not be transferred, assigned, or assumed without the prior written consent of a Contracting Officer.

G. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

Applicants are required to make a full and complete disclosure of the information requested in the Business Assurances & Disclosures Form. Disclosure of the requested information is mandatory. Any failure to make a full and complete disclosure of the requested information may result in:

- The rejection of a Full Application, and/or Reply to Reviewer Comments;
- The termination of award negotiations;
- The modification, suspension, and/or termination of a funding agreement;
- The initiation of debarment proceedings, debarment, and/or a declaration of ineligibility for receipt of Federal contracts, subcontracts, and financial assistance and benefits; and
- Civil and/or criminal penalties.

H. RETENTION OF SUBMISSIONS

ARPA-E expects to retain copies of all Full Applications, Replies to Reviewer Comments, and other submissions. No submissions will be returned. By applying to ARPA-E for funding, Applicants consent to ARPA-E's retention of their submissions.

I. MARKING OF CONFIDENTIAL INFORMATION

ARPA-E will use data and other information contained in Full Applications, and Replies to Reviewer Comments strictly for evaluation purposes.

Full Applications, Replies to Reviewer Comments, and other submissions containing confidential, proprietary, or privileged information should be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

The cover sheet of the Full Application, Reply to Reviewer Comments or other submission must be marked as follows and identify the specific pages containing confidential, proprietary, or privileged information:

> Notice of Restriction on Disclosure and Use of Data:
>
> Pages [___] of this document may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

The header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure." In addition, every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

J. ADDITIONAL NOTICES

- This FOA is intended for informational purposes and reflects current planning. If there is any inconsistency between the information contained herein and the terms of any resulting SBIR or STTR funding agreement, the terms of the funding agreement are controlling.
- Before award of an SBIR or STTR funding agreement, ARPA-E may request the selectee to submit certain organizational, management, personnel, and financial information to assure responsibility of the Prime Recipient. In addition, selectees will be required to make certain legal commitments at the time of execution of funding agreements resulting from this FOA. ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement for SBIR/STTR Awards, which is available at https://arpa-e.energy.gov/?q=site-page/funding-agreements.
- Actual or suspected fraud, waste, or abuse may be reported to the DOE Office of Inspector General (OIG) at 1-800-541-1625.

K. EXPORT CONTROL INFORMATION

Do not include information subject to export controls in any submissions, including Concept Papers, Full Applications, and Replies to Reviewer Comments – whether marked as subject to US export control laws/regulations or otherwise. Such information may not be accepted by ARPA-E and may result in a determination that the application is non-compliant, and therefore not eligible for selection. This prohibition includes any submission containing a general, non-determinative statement such as "The information on this page [or pages _ to__] may be

subject to US export control laws/regulations", or similar. Under the terms of their award, awardees shall be responsible for compliance with all export control laws/regulations.

L. COMPLIANCE AUDIT REQUIREMENT

A prime recipient organized as a for-profit entity expending $750,000 or more of DOE funds in the entity's fiscal year (including funds expended as a Subrecipient) must have an annual compliance audit performed at the completion of its fiscal year. For additional information, refer to Subpart F of: (i) 2 C.F.R. Part 200, and (ii) 2 C.F.R. Part 910.

If an educational institution, non-profit organization, or state/local government is either a Prime Recipient or a Subrecipient, and has expended $750,000 or more of Federal funds in the entity's fiscal year, the entity must have an annual compliance audit performed at the completion of its fiscal year. For additional information refer to Subpart F of 2 C.F.R. Part 200.

M. PAYMENT OF FEE OR PROFIT

ARPA-E will pay a fee or profit to Prime Recipients in an amount not to exceed 7% of total project cost under any agreement resulting from this FOA, subject to negotiations. Any fee or profit paid by Prime Recipients to their sub-recipients (but not commercial suppliers, vendors, or contractors) must be paid from fee or profit paid to Prime Recipients by ARPA-E. Any fee or profit must be included in the budget submitted with Prime Recipients' Full Applications and will be payable to Prime Recipients upon: (i) completion of all work required by the agreement, (ii) submission and acceptance of all for-profit audit reports and resolution of all findings (if any) identified in the reports, (iii) submission and acceptance by the Government of all closeout documentation required by Attachment 4 to the agreement (refer to ARPA-E's Model Cooperative Agreement found at (https://arpa-e.energy.gov/?q=site-page/funding-agreements), and (iv) submission of an acceptable invoice.

IX. GLOSSARY

Applicant: The entity that submits the application to ARPA-E. In the case of a Project Team, the Applicant is the lead organization listed on the application.

Application: The entire submission received by ARPA-E, including the Preliminary Application, Full Application, Reply to Reviewer Comments, and Small Business Grant Application (if applicable).

ARPA-E: Is the Advanced Research Projects Agency – Energy, an agency of the U.S. Department of Energy.

Cost Sharing: Is the portion of project costs from non-Federal sources that are borne by the Prime Recipient (or non-Federal third parties on behalf of the Prime Recipient), rather than by the Federal Government.

Covered Individual: an individual who contributes in a substantive, meaningful way to the scientific development or execution of an R&D project proposed to be carried out with an award from ARPA-E. This includes, but is not limited to, the PI, Co-PI, Key Personnel, and technical staff (e.g., postdoctoral fellows/researchers and graduate students). ARPA-E may further designate covered individuals during award negotiations or the award period of performance.

Deliverable: A deliverable is the quantifiable goods or services that will be provided upon the successful completion of a project task or sub-task.

DOE: U.S. Department of Energy.

DOE/NNSA: U.S. Department of Energy/National Nuclear Security Administration

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

Foreign Affiliation: a funded or unfunded academic, professional, or institutional appointment or position with a foreign government or government-owned entity, whether full-time, part-time, or voluntary (including adjunct, visiting, or honorary).

Foreign Countries of Concern: the People's Republic of China, the Democratic People's Republic of Korea, the Russian Federation, the Islamic Republic of Iran, Burma, Eritrea, Pakistan, Saudi Arabia, Tajikistan, and Turkmenistan.

For-Profit Organizations (Other than Small Businesses) (or *large businesses*): Means entities organized for-profit other than small businesses as defined elsewhere in this Glossary.

GOCOs: U.S. Government Owned, Contractor Operated laboratories.

GOGOs: U.S. Government Owned, Government Operated laboratories.

Institutions of Higher Education (or *educational institutions*): Has the meaning set forth at 20 U.S.C. 1001.

Malign Foreign Talent Recruitment Program: the meaning given such term in section 10638 of the Research and Development, Competition, and Innovation Act (division B of Public Law 117–167) or 42 USC 19237, as of October 20, 2022.

Milestone: A milestone is the tangible, observable measurement that will be provided upon the successful completion of a project task or sub-task.

Nonprofit Organizations (or *nonprofits*): Has the meaning set forth at 2 C.F.R. § 200.70.

Prime Recipient: The signatory to the funding agreement with ARPA-E.

PI: Principal Investigator.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement

Small Business: Small businesses are domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards).

Standalone Applicant: An Applicant that applies for funding on its own, not as part of a Project Team.

Subject Invention: Any invention conceived or first actually reduced to practice under an ARPA-E funding agreement.

Subrecipient: An entity (not an individual) that receives a subaward from the Prime Recipient to carry out part of the ARPA-E award.

Exploratory Topic: A technical area of research that is detailed in a "Special Program Announcement" at the end of this FOA as an Appendix and visible on ARPA-E eXCHANGE as a supporting FOA document. Each Exploratory Topic will have its own deadline. Once the topic deadline has passed the notice will be taken down and ARPA-E will no longer be accepting applications in that area. ARPA-E will only review applications that are scientifically aligned with the Exploratory Topic(s) open at the time the application is submitted.

Task: A task is an operation or segment of the work plan that requires both effort and resources. Each task (or sub-task) is connected to the overall objective of the project, via the achievement of a milestone or a deliverable.

Total Project Cost: The sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs, FFRDCs, and GOCOs.

TT&O: Technology Transfer and Outreach. (See Section IV.F.8 of the FOA for more information)

X. APPENDIX A: LOW-ENERGY NUCLEAR REACTIONS

Special Program Announcement for
EXPLORATORY TOPICS (DE-FOA-0002785)
Low-Energy Nuclear Reactions

Topic Issue Date	September 13, 2022
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5 PM ET, Friday, November 4, 2022
Submission Deadline for Full Applications	9:30 AM ET, Tuesday, November 15, 2022
Submission Deadline for Replies to Reviewer Comments:	5:00 PM ET, Tuesday, December 20, 2022
Expected Date for Selection Notifications	February 2023
Anticipated Date of Awards	May 2023
Total Amount to be Awarded	Approximately $10,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between approximately $1,000,000–$2,500,000 for Category A and $500,000–$1,500,000 for Category B.
Maximum Period of Performance	30 Months

1. Introduction

This announcement describes an Exploratory Topic (ET) on Low-Energy Nuclear Reactions (LENR).[20] ARPA-E invites Full Applications for financial assistance in pursuit of hypotheses-driven approaches toward producing publishable evidence of LENR that is convincing to the wider scientific community. A goal of this Exploratory Topic is to establish clear practices to rigorously answer the question, "should this field move forward given that LENR could be a potentially transformative carbon-free energy source, or does it conclusively not show promise?". Program objectives, technical categories, and performance metrics are described further in Section 2.

ARPA-E acknowledges the complex, controversial history of LENR beginning with the announcement by Martin Fleischmann and Stanley Pons (FP) in 1989 that they had achieved

[20] We define LENR as a hypothetical energy-producing process (or class of processes) with system energy outputs characteristic of nuclear physics (>>1 keV/amu/reaction) and energy inputs characteristic of chemistry (~eV/atom). See further materials from the ARPA-E LENR workshop: https://arpa-e.energy.gov/events/low-energy-nuclear-reactions-workshop.

deuterium-deuterium (D-D) "cold fusion" in an electrochemical cell.[21] Multiple books[22] recount the history of "cold fusion" (now known as LENR). DOE reviews in 1989 and 2004 both concluded that the evidence did not support the claim of D-D fusion, but that research proposals on deuterated heavy metals should be evaluated under the standard peer-review process.[23] However, few such proposals were submitted, and none were funded by DOE.

Despite LENR being largely dismissed by the scientific research community by 1990, many groups from around the world (including the U.S., Japan, Russia, China, and the EU) continued to conduct varied LENR experiments and report evidence of excess heat and nuclear reactions (including neutrons, tritium, ^{3}He, ^{4}He, transmutation products, and isotopic shifts) in hundreds of reports/papers.[24] However, repeatability of the key evidence over multiple trials of seemingly the same experiment remains elusive to this day. This may be due to limitations in experimental or diagnostic techniques, a lack of awareness and/or control of the key triggers and independent variables of LENR experiments, and/or other reasons. Furthermore, results were typically not reported with the level of scientific rigor required by top-tier research journals. As a result, LENR as a field remains in a stalemate with uncertain prospects for scientific advances and impact.

Based on its claimed characteristics to date, LENR may support a form of nuclear energy with potentially low capital cost, high specific power and energy, and little-to-no radioactive byproducts. If LENR can be irrefutably demonstrated and scaled, it could potentially become a disruptive technology with myriad energy, defense, transportation, and space applications, all with strong implications for U.S. technological leadership. For energy applications, LENR could potentially contribute to decarbonizing sectors such as industrial heat and transportation (~50% of U.S. and global CO_2-equivalent emissions).

Within the past decade, there has been renewed interest in supporting LENR research activities in the U.S., with prominent sponsorship (e.g., Google, DARPA, NASA), that has advanced LENR-relevant state-of-the-art capabilities and methodologies.[25] Some of the teams are reporting preliminary evidence[26] of LENR that are possibly consistent with past observations but that do not yet meet the program metrics presented below in Section 2, the fulfillment of which could help break the stalemate surrounding LENR.

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[21] M. Fleischmann and S. Pons, "Electrochemically induced nuclear fusion of deuterium," *J. Electroanal. Chem. Int. Electrochem.* **261**, 201 (1989); https://doi.org/10.1016/0022-0728(89)80006-3.

[22] See, e.g., J. R. Huizenga, *Cold Fusion: The Scientific Fiasco of the Century* (University of Rochester Press, Rochester, NY, 1993); E. Storms, *The Science of Low Energy Nuclear Reaction* (World Scientific, Singapore, 2007); S. B. Krivit, *Hacking the Atom* (Pacific Oaks Press, San Rafael, CA, 2016); and S. B. Krivit, *Fusion Fiasco* (Pacific Oaks Press, San Rafael, CA, 2016).

[23] For the 1989 and 2004 DOE review reports, see https://www.lenr-canr.org/acrobat/ERABreportofth.pdf and https://www.lenr-canr.org/acrobat/DOEreportofth.pdf, respectively. For a summary presentation of the reviews, see https://arpa-e.energy.gov/sites/default/files/2021LENR_workshop_Greco.pdf.

[24] See, e.g., https://lenr-canr.org and the bibliographies of the Storms and Krivit books in footnote 4.

[25] See, e.g., C. P. Berlinguette et al., "Revisiting the cold case of cold fusion," *Nature* **570**, 45 (2019); https://doi.org/10.1038/s41586-019-1256-6.

[26] See talks from the ARPA-E LENR workshop: https://arpa-e.energy.gov/events/low-energy-nuclear-reactions-workshop.

This ARPA-E Exploratory Topic aims to build on the recent progress with strong emphases on testing/confirming specific hypotheses (rather than focusing only on replication), identifying and verifying control of experimental variables and triggers, supporting more comprehensive diagnostics and analysis, improving access to broader expertise and capabilities on research teams, and insisting on peer review and publication in top-tier scientific journals.

2. Topic Description

This Exploratory Topic invites Full Applications to advance LENR research by identifying and testing well-articulated hypotheses on how to activate/control LENR and their accompanying empirical signatures. A key goal of the ET is to obtain convincing empirical evidence of nuclear reactions[27] in an LENR experiment and publication of the evidence in a top-tier peer-reviewed research journal (see Section 2A for specific suggested criteria for what constitutes "convincing empirical evidence"). ARPA-E is seeking Full Applications that successfully address the highest-priority elements described in the sub-sections immediately below and in greater detail in the Technical Volume (TV) template, which is available for download at the ARPA-E: Funding Opportunity Exchange website (https://arpa-e-foa.energy.gov/).

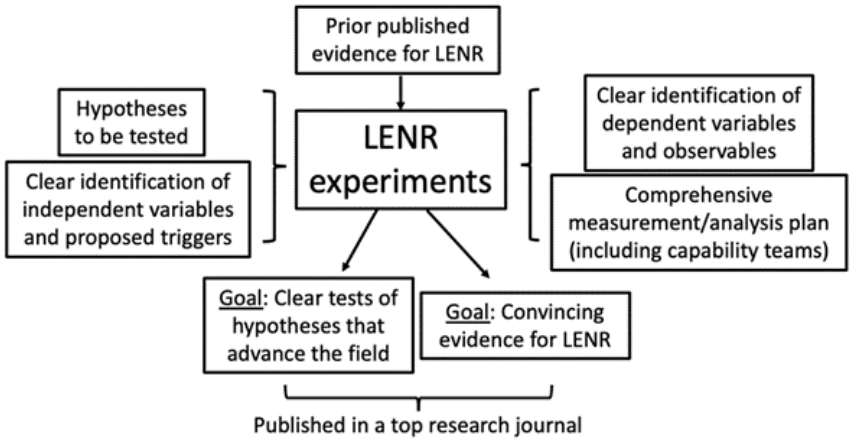
Additional overarching goals of this Exploratory Topic are to bring together new perspectives and participants, modern state-of-the-art scientific and technical capabilities, and the experiences of long-time LENR practitioners..

Applicants must select only one of the following technical categories, discussed further below:

A. LENR experiments
B. Capability teams.

A. Technical Category A: LENR experiments

The figure below summarizes Category A logic and goals.



[27] ARPA-E is agnostic at this time regarding the existence of LENR as a physical phenomenon (as defined in footnote 20), the underlying mechanism(s) of LENR, and the specific nuclear process(es) involved, if any (e.g., fusion, neutron capture, alpha or beta decay, neutronization, etc.).

For Category A, Applicants must comprehensively address the following:

- Select and justify LENR experimental platform(s) and design (i.e., methods for H and/or D loading and LENR activation/trigger; materials structure/composition; control experiments; background/contaminant characterization, etc.) with a clearly articulated connection to prior published research claiming evidence of LENR
- Articulate specific hypothesis or hypotheses to be tested, including justification at a phenomenological level of the importance and relevance of the hypothesis or hypotheses
- Identify key independent and dependent variables and their desired quantitative ranges that the proposed research will emphasize and rigorously characterize
- Propose a comprehensive diagnostic and analysis plan that minimizes the probability of inconclusive outcomes (whether the results are positive or negative); the expectation is a strong focus on detection of both prompt and secondary/delayed nuclear-reaction products, specifying the particle(s) and prompt energy ranges anticipated (and why)
- Account for uncertainties in both background and signal in the statistical analysis with all assumptions explicitly defined and justified; the correlation among all measurements should be analyzed in a single comprehensive statistical framework with all assumptions explicitly defined in mathematical terms. If multiple simultaneous measurements are made, a unified statistical framework is required with clear identification of correlated or orthogonal measurements
- Demonstrate access to the needed broad discipline expertise and the embodied knowledge of long-time LENR researchers, corresponding to the chosen experimental approach, hypotheses to be tested, and statistical analysis methodologies
- Commit to the standard peer-review process and demonstrate a willingness to submit findings to leading research journals;
- As stated in section IV.F.3, for Subject Inventions disclosed to DOE under an award, ARPA-E will reimburse the Prime Recipient – in addition to allowable costs associated with Subject Invention disclosures - up to $30,000 of expenditures for filing and prosecution of United States patent applications;
- Technology-to-Market (T2M) considerations, including
    - Plausibility of proposed LENR approach to realize net energy gain and scalability to devices with useful levels of power
    - Potential first markets for a commercial system
    - Other barriers, such as obtaining IP protection, consideration for publication by top-tier journals, etc.
- Serious evaluation and mitigation/control of potential hazards (mechanical, electrical, radiological, and otherwise) associated with the proposed LENR experiments, and plans for protecting human health and property.

Please refer to the Technical Volume template (available for download at the ARPA-E: Funding Opportunity Exchange website (https://arpa-e-foa.energy.gov/)), which provides further guidance for preparing your Full Application.

To constitute convincing empirical evidence for LENR, each Applicant must describe how they will meet the following:

- Conduct experiments that demonstrably satisfy the definition of LENR given in footnote 20
- Achieve statistically significant diagnostic evidence of nuclear reactions above background and relative to control experiments, at a level greater than 99.7% (3s) statistical confidence level
- Carefully identify and eliminate "prosaic" explanations, e.g., rogue chemical reactions resulting in excess heat, material and/or environmental contaminants, natural radiation background, etc.
- Publish results in a top-tier research journal.

B. Technical Category B: Capability Teams

Applicants seeking to contribute an expert/specialist capability that could assist multiple Category-A LENR experimental teams in fulfilling program objectives should consider selecting Category B. Capabilities of interest include but are not limited to

- Diagnostic instruments expertise (e.g., detection of nuclear-reaction products, pre- and post-experimental materials elemental/isotopic analysis, etc.)
- Relevant analyses expertise, including statistical analysis and Bayesian inference techniques of "multi-messenger" datasets in low-count, high-background environments[28]
- Relevant computational codes/expertise to aid in experimental design and data interpretation
- Precision materials fabrication, handling, characterization.

The primary objectives for Category B is to bring state-of-the-art instruments and capabilities to the program and to Category-A projects that may not otherwise have access to the resources and/or expertise to quickly achieve an equivalent capability. A goal is to avoid expending time and resources in establishing capabilities/expertise that already exist elsewhere. Capability teams bring a neutral, independent perspective that will bolster the credibility of any reported evidence for LENR. ARPA-E has experience with Capability Teams in other programs.[29]

ARPA-E strongly encourages interactions between potential Category-A and Category-B Applicants throughout the application process, so that Submissions are coordinated and complementary to the extent possible. However, Category-A and Category-B Submissions will be evaluated independently.

[28] See, e.g., J. L. Alvarez, "Poisson-based detection limit and signal confidence intervals for few total counts," Health Phys. **93**, 120 (2007); https://doi.org/10.1097/01.hp.0000261331.73389.bd.

[29] See, e.g., https://arpa-e.energy.gov/news-and-media/blog-posts/fusing-further-advancement-introducing-arpa-e-fusion-capability-teams.

Category-A Applicants are especially encouraged to partner with Category-B Applicants on capabilities requiring lengthy/nuanced experience and/or expensive instruments/diagnostics. It is acceptable for Category-A Applicants to either include a team member to fulfill the needed capability or to state that they expect to work with a known Category-B Applicant. The latter is encouraged to improve efficiency and avoid unnecessary expenses in duplicating Category-B capabilibities . If the proposed capabilities are clearly articulated/justified, including appropriate quantitative technical requirements, ARPA-E will identify and encourage collaborations between Category-A and B teams during technical milestone negotiations.

ARPA-E prohibits the same person or persons being on both a Category-A and Category-B Applicant team. In order to ensure objectivity in the measurements taken by Category-B teams, Category A and Category B teams interested in partnering should ensure that there are no actual or apparent conflicts of interest within or between the the teams.

Per Section VI.B.7 of the FOA, every Project Team must negotiate and establish an Intellectual Property Management Plan for the management and disposition of intellectual property arising from the project. Every project that involves a Category-A awardee partnering with a Category-B awardee will be required to have a similar plan for the management and disposition of intellectual property arising from such a collaboration. Such a Plan will need to at least address the limtations, if any, on the use and disclosure of any data exchanged between the parties and the rights of the collaborating parties to any newly arising technology for commercialization purposes. If a Category-B awardee is partnering with more than one Category-A awardee, then both the ARPA-E award to the Category-B awardee and the Plan between the collaborating parties shall include a prohibition on the Category-B awardee sharing any data provided to it or produced by it to any other Category-A awardee without the express written permission of the partnering Category-A awardee.

C. Criteria and Metrics

Category A: LENR Experiments

Table 1 summarizes the key criteria/metrics for Category A: LENR Experiments. Applicants should clearly and concisely articulate how their Submission meets each of the criteria.

Table 1. Summary of criteria/metrics for Category A: LENR experiments.

Criteria	Metrics
Maximum input energy or voltage	• ≤ 500 eV per directly energized particle, or ≤ 500 V applied voltage anywhere in the experiment
Proposed LENR experimental platform	• Past evidence of nuclear reactions (preferred) and/or excess heat in a peer-reviewed journal paper (cite papers, show/discuss key data) • Preferably, related corroboration of key results by at least one independent group (cite papers, show/discuss key data)

	• Recognition and discussion of potential hazards to property and human safety, and demonstrated commitment and ability to develop a hazard mitigation/control plan
Hypotheses to be tested	• Phenomenological justification of the significance/relevance of the chosen hypothesis (hypotheses) with respect to LENR • Clear statement of independent and dependent variables to be characterized and their allowable measurement uncertainties, as well as a statement of uncontrolled/uncontrollable variables (e.g., average loading fraction may be a controllable variable, but the loading process introduces uncontrollable and possibly uncharacterized morphological changes to the sample)

Detection of nuclear-reaction products	• Justification of particles and energy ranges to be measured, and desired temporal/spatial resolutions
	• Plan for achieving statistically significant diagnostic evidence of nuclear reactions above background and relative to control experiments, at a level greater than 99.7% (3s) statistical confidence level, including
	  ○ Real-time detection of prompt/secondary nuclear-reaction products, including multiple detectors and positioning, etc., as appropriate, and/or pre- and post-experiment materials elemental/isotopic analysis
	  ○ Background/contaminant characterization with sufficient sensitivity, resolution, and time correlation to achieve the required statistical confidence
	• Inclusion of or access to state-of-the-art detectors and expertise

Calorimetry	• Calorimetry cannot be the only nor primary diagnostic, but it can be part of the diagnostic suite, provided that labor and hardware expenditures associated with calorimetry are ≤10% of the total project cost of a Category-A application • Category-A teams are encouraged to work with a Category-B Capability Team that has demonstrated capability in calorimetry • A comprehensive energy-balance model that accounts for all possible sources and sinks must be available or developed as part of the proposed work • State quantitative requirements on calorimetry detection thresholds and resolution based upon analysis of experimental uncertainty
Control experiments	• Identify and justify the control experiments needed to support a clear test of the hypotheses under consideration, and to build confidence in empirical evidence for LENR if it is observed • Describe how control experiments are not introducing new or uncontrolled variables, or how these are accounted for in reaching conclusions
Controlling impurities and contaminants	• Plan for pre- and post-experimental sample characterization for all materials, electrolytes, and/or gases • Articulation of required characterization resolution/uncertainties based on hypotheses being tested

Teaming	• Team composition includes first-hand knowledge of a past LENR experiment that is directly related to the selected experimental platform and hypotheses • PI of this Submission has a demonstrated track record of publishing in top-tier journals

Category B: Capability Teams

Several capabilities are needed for LENR experiments to fulfill the program objectives. Classes of anticipated capabilities and their desired attributes are summarized in Table 2. Category-B Applicants should clearly state the capability or capabilities they are providing (with quantitative targets wherever possible) and the class or classes of LENR experimental platforms that they envision supporting..

Table 2. Summary of criteria/attributes for Category B: Capability Teams.

Capability	Desired attributes and quantitative targets
Detection of prompt and secondary nuclear-reaction products	• Description of particles (e.g., ^{3}He, ^{4}He, tritium, neutrons, transmutation/decay products) and energy ranges that can be measured • State achievable temporal, spatial, and energy resolutions, as well as detection sensitivities and thresholds • Type of selected detectors and their strengths/weaknesses in the context of common LENR experimental platforms • Plans for placing detectors in a suitable position relative to the presumed source, including within challenging liquid or high-temperature/pressure environments
Materials fabrication and pre/post-experimental structural and elemental analysis	• Ability to fabricate materials samples with controlled microstructure (specify feature sizes, morphology, defect uniformity, etc.) • Materials handling protocols to control the introduction of contaminants • Elemental/isotopic detection thresholds and resolution • Structural and/or morphological analysis/imaging resolution, including direct measurement of H/D-loading capable of resolving spatiotemporal variations
Mass balance and spectroscopy	• Ability to provide an inventory of all species present in an LENR experiment, with mass or fractional molar resolutions adequate to differentiate from control experiments and the environmental background
Calorimetry	• Budget devoted to calorimetry should be ≤25% of total project cost[30] • Previous calorimetry data/results and calibrations by team appear in peer-reviewed publications

[30] Note that the limit for calorimetry is ≤10% of total project cost for Category-A applications that include calorimetry, but calorimetry can be up to ≤25% of the budget for a Category-B application.

	• Achieved detection thresholds, resolutions, uncertainties of relevance to leading LENR experimental platforms • Validated energy balance model of calorimeter and all sensors with uncertainty analysis
Modeling/computation	• Relevant capabilities /codes to support the experimental design of promising classes of LENR experiments and control experiments • Relevant capabilities/codes to support diagnostic design, specification of diagnostic requirements, and data/scientific interpretations

3. Submissions Specifically Not of Interest

Submissions that propose the following may be deemed non-responsive and may not be merit-reviewed:

- Experiments with input energies >500 eV per directly energized particle, or >500 V of applied voltage anywhere in the experiment
- No clear hypotheses to be tested
- No articulated connection to prior published evidence for LENR and of how this work builds on the earlier work
- Calorimetry as the only or primary diagnostic
- Lack of a plan for obtaining direct empirical evidence of nuclear reactions
- Purely theoretical or computational studies
- Research plans requiring substantial diagnostic or code development beyond their adaptation to specific experiments.

4. Content and Form of Full Applications

The content and form of Applicants' Technical Volumes shall follow the instructions and be consistent with the template titled Technical Volume: Appendix A, LENR. All other instructions set forth at FOA Section IV.C remain unchanged.

Templates for preparing Full Applications under this Exploratory Topic may be found on ARPA-E Exchange at https://arpa-e-foa.energy.gov/.

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XI. Appendix B: RESERVED

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XII. APPENDIX C: CREATING REVOLUTIONARY ENERGY AND TECHNOLOGY ENDEAVORS

Special Program Announcement for
Exploratory Topics (DE-FOA-0002785)
Creating Revolutionary Energy And Technology Endeavors

Topic Issue Date	February 17, 2023
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5 PM ET, Friday, March 10, 2023
Submission Deadline for Full Applications	9:30 AM ET, Tuesday, March 21, 2023
Submission Deadline for Replies to Reviewer Comments:	Not Applicable
Expected Date for Selection Notifications	June, 2023
Anticipated Date of Awards	September, 2023
Total Amount to be Awarded	Approximately $10,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between approximately $200,000 and $500,000. Awards are issued as Phase I or Phase I/II grants, with a go/no-go milestone after Phase I, as applicable.
Maximum Period of Performance	24 Months

1. Introduction

The objective of CREATE is to identify and support disruptive energy-related technologies. Projects funded through CREATE should have the potential for large-scale impact. If successful, projects should create new paradigms in energy technology and have the potential to achieve significant advances in any of the following ARPA-E Mission Areas:

- reducing energy imports
- improving energy efficiency of all economic sectors
- reducing energy-related emissions, including GHG emissions
- improving management, clean-up and disposal of radioactive waste and spent nuclear fuel
- improving resilience, reliability and security of infrastructure to produce, deliver and store energy

Awards under this program will support research projects that establish potential new areas of technology development and provide ARPA-E with information that could lead to new focused funding programs. Awards may support exploratory research to establish viability, proof-of-concept demonstration for new energy technology and/or modeling and simulation efforts to guide development of new energy technologies.

2. Areas of Interest

Applications that address one or more of ARPA-E's Mission Areas (see above and Section I.A.). Applicants must explain how the proposed concept represents a transformative approach. Applicants may propose technology development efforts with the potential for high impact in any of the ARPA-E Mission Areas.

3. ARPA-E Funding Agreement

ARPA-E anticipates awarding fixed-amount grants resulting from this Exploratory Topic. ARPA-E will only award a fixed-amount grant in instances where it can be assured that the prospective awardee will not realize any increment above the actual cost of performing work (other than any fee or profit as described in the FOA Section VIII.L). Equal payments will be made, one following grant award, one each upon submission and acceptance by ARPA-E of the quarterly report demonstrating sufficient technical progress, and final payment upon submission and acceptance by ARPA-E of the final technical report. The final payment also requires certification to ARPA-E that all project activity has been completed. For additional information about fixed-amount awards refer to 2 C.F.R. § 200.45 and 2 C.F.R. § 200.201.

In addition to the aforementioned certification, awardees will be required, inter alia, to obtain prior approval of the ARPA-E Contracting Officer for changes in principal investigator, project partner, or scope of project effort.

The maximum amount of any grant awarded under this Exploratory Topic is $500,000. Cost share is not required nor will be accepted for awards resulting from Exploratory Topic, Topic C: CREATE SBIR/STTR.

4. Content and Form of Full Applications

Not withstanding the instructions at FOA Section IV.C, "Topic C: Technical Volume (Fixed-Amount Grant)" is replacing the "Technical Volume Template" and "Topic C: SF-424A (Fixed amount Grant)" is replacing the "Budget Justification Workbook/SF-424A" provided.

Component	Required Format	Description and Information
Topic C: Technical Volume (Fixed-Amount Grant)	PDF	The centerpiece of the Full Application. Provides a detailed description of the proposed R&D project and Applicant Team. A Technical Volume template is available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/). **Note – Section and page maximums for this Topic's Technical Volume differ from the standard Technical Volume Template under this FOA.**

Topic C: SF-424A (Fixed-Amount Grant)	XLS	Budget Information – Non-Construction Programs (https://arpa-e-foa.energy.gov/)

Templates for preparing Full Applications under this Exploratory Topic may be found on ARPA-E Exchange at https://arpa-e-foa.energy.gov/.

An award that targets the development of software, algorithms or data bases that are intended for use by others and not just intended for internal use by the awardee may be required to develop a Commercialization Plan as a milestone during performance of their award. A Commercialization Plan must include a commitment to report to ARPA the targeted item and address how software, algorithms or data sets that are the intended target of the award will be commercialized and which Intellectual Property rights will be asserted. ARPA-E will be open to considering modification of the license retained by the government in copyright to support acceptable Plans. An Awardee may request a modification of the Commercialization Plan from ARPA-E at any time.

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XIII. APPENDIX D: PREDICTIVE REAL-TIME EMISSIONS TECHNOLOGIES REDUCING AIRCRAFT INDUCED LINES IN THE SKY (PRE-TRAILS)

Special Program Announcement for Exploratory Topics (DE-FOA-0002785)
"Predictive Real-time Emissions Technologies Reducing Aircraft Induced Lines in the Sky (PRE-TRAILS)"

Topic Issue Date	February 23, 2023
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5 PM ET, April 14, 2023
Submission Deadline for Full Applications	9:30 AM ET, April 25, 2023
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, June 1, 2023
Expected Date for Selection Notifications	July 2023
Anticipated Date of Awards	November 2023
Total Amount to be Awarded	Approximately $10,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic
Anticipated Awards	ARPA-E may issue one, multiple, or no reimbursable grants under this FOA. Awards may vary between approximately $500,000 and $2,500,000.
Maximum Period of Performance	18 Months

1. Introduction

This announcement describes an Exploratory Topic (ET): Predictive Real-time Emissions Technologies Reducing Aircraft Induced Lines in the Sky (PRE-TRAILS). The purpose of this announcement is (1) to solicit Full Applications for the development of new technologies and tools related to improving the prediction of contrails that form Aircraft Induced Cirrus (AIC) clouds to reduce the environmental impact of aviation, (2) to focus the attention of the scientific and technical community on the specific area of interest and encourage dialogue amongst those interested, and (3) to provide a timetable for the submission of full applications.

2. Topic Description

Aviation is an important part of our domestic and international transportation networks. Fuel consuming aircraft emit a range of emissions. From a climate-forcing standpoint, the most significant are carbon dioxide and water vapor. The Schmidt-Appleman criterion describes specific temperature, pressure and humidity conditions where the mixing of aircraft exhaust

water with colder ambient humid air can result in the formation of condensation trails (contrails).[31] Fortunately, most contrails dissipate in under 10 minutes and are of no concern.

However, when nucleation sites and specific atmospheric conditions exist (such as Ice Super-Saturated Regions (ISSR)), engine exhaust can cause the formation of persistent contrails, which can in turn produce persistent cirrus clouds known as aircraft-induced cirrus (AIC). These upper atmospheric clouds can last for hours and may grow to span several hundreds of kilometers. Recent studies have indicated that contrails likely contribute to global radiative forcing at a level that is roughly equivalent to that of the CO_2 emissions from the entire aviation sector, which is estimated to be about 2% of total global CO_2 emissions.[32] Submissions funded under this ET will focus on the following ARPA-E mission area:

1. **Reduce Energy-Related Emissions**: Projects will develop the diagnostics and predictive tools needed to explore further mitigation of contrail-related global warming. If successful, a total radiative forcing emission equivalent to all CO_2 emissions from aviation could potentially be mitigated.[32]

Unfortunately, at present, pilots, air traffic controllers, and aerospace system designers have little to no information on whether a specific flight may result in persistent cirrus clouds. ARPA-E envisions the development of a system to predict aviation contrails (hereinafter referred to as an "Aviation Contrail Predictive System") that would be capable of informing pilots and ground controllers in real-time whether an airplane is likely to produce persistent AIC. This new system could foster the development of a) avoidance strategies – allowing re-direction of airplanes by ground control to more favorable (non-AIC) flight trajectories – and/or b) on-board mitigation technologies.

The development of an Aviation Contrail Predictive System will be particularly challenging – in part because AIC can form several hours after the passage an aircraft. Thus, these predictive models will need to consider both dynamic atmospheric conditions and engine emissions. This may require, for example, the assimilation of *in-situ* data from onboard sensor systems as well as off-aircraft observational data from ground- and/or satellite-based sources and previous flight reports.

[31] Schumann, U., 1996. On conditions for contrail formation from aircraft exhausts. Meteorologische Zeitschrift, 5, pp.4-23.

[32] Lee, D.S., Fahey, D.W., Skowron, A., Allen, M.R., Burkhardt, U., Chen, Q., Doherty, S.J., Freeman, S., Forster, P.M., Fuglestvedt, J. and Gettelman, A. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment*, 244, p.117834 (2021).

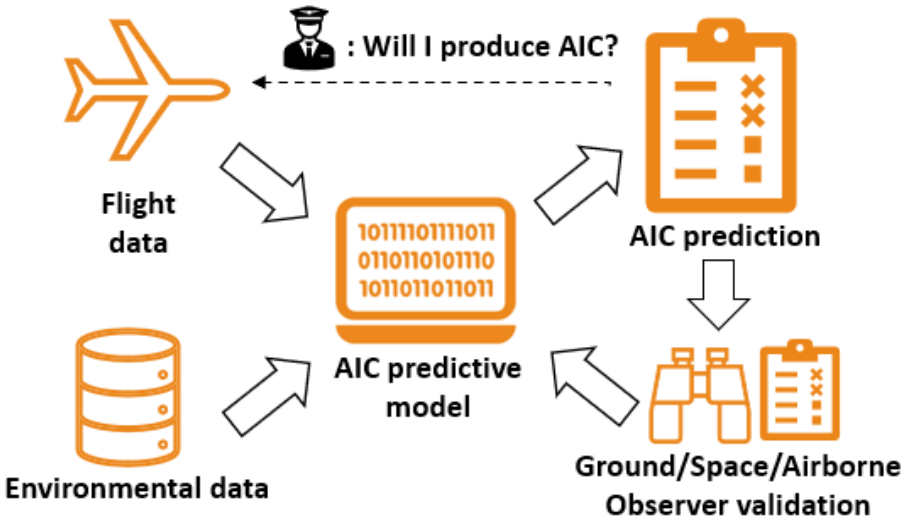

Figure 1. An envisioned use of a near real-time AIC predictive model. Flight data and other environmental data sources are assimilated into a best-guess AIC predictive model during flight planning. Further *in-situ* data from the current flight, *in-situ* data from previous or following flights, and observational data from satellite or ground-based sources would constrain and improve the model output, resulting in improved predictions and better in-flight decision support either via simple monitoring and reporting to the pilot/flight operator or via continuously optimized tactical flight routing. The program outcome is the AIC predictive model and data or sensors needed to make an accurate AIC prediction validated using observations.

One potential approach to explore is the use of predictive modeling through machine learning to analyze data on past and present contrail formation, atmospheric conditions, and onboard sensor systems. A computationally inexpensive, continually updated AIC predictive model could improve forecast accuracy and thus provide feedback and decision support to flight planners, whether prior to takeoff or while underway (Figure 1).

This ARPA-E ET aims to fund project teams that will improve the prediction of AIC resulting from contrail formation. It is hoped that these efforts will provide valuable tools for airlines and other stakeholders in the aviation industry to create and improve detailed techno-economic analyses, quantify efficiencies, and more accurately estimate the environmental impacts associated with the adoption of alternative fuels such as SAF or hydrogen.

3. Technical Areas of Interest

The aim of this new Exploratory Topic is to support the development of a predictive capability that in "real-time" and with high confidence could inform a pilot or flight operator whether an aircraft is likely to produce persistent aircraft induced cirrus clouds (AIC), even hours before they are fully developed. Each submission must address the following three technology areas to develop an Aviation Contrail Predictive System:

- **Aircraft, Environmental Data, and Sensor Development:** New sensors or environmental data sources may be needed to provide sufficient training and validation data for the envisioned predictive capabilities. Contrail forming conditions are identified by the Schmidt-Appleman criterion: where water vapor content reaches liquid saturation under

specific temperature and saturation conditions in the presence of nucleation sites.[33,34,35] Especially important are persistent contrails formed when airplanes travel through atmospheric Ice Super-Saturated Regions (ISSR), leading to AIC.[34] As the persistent contrail formation regime is a combination of Schmidt-Appleman and ISSR criteria, sensors capable of identifying these parameters accurately in real-time are of particular interest, *e.g.* sensor systems capable of measuring upper atmospheric humidity at or below 10 ppm.

- **Predictive Modeling:** Advanced machine learning computational methods developed in the past decade allow the exploration of larger sets of input data and explore complex multivariate correlations to solve more complex problems than ever before. ARPA-E is interested in project teams that explore whether such methods can be leveraged to develop a real-time predictive system for AIC development. To inform avoidance and mitigation strategies, it is important that any predictive model gives reasonably accurate results, minimizing false positive (type I) and false negative (type II) errors. For the purposes of this Exploratory Topic, this can be captured in the balanced F-score (F_1-score) which is the harmonic mean of precision and recall. It is important that sufficient confidence in the model exists to inform avoidance and mitigation solutions, while minimizing unnecessary and burdensome rerouting.
- **Observer Data**: A predictive model needs to be trained and validated. For an Aircraft Contrail Predictive System, this will likely require observers and additional sensors. It is anticipated that teams will need to obtain sufficient relevant flight and observer data from available sources or dedicated flight tests to provide true AIC observations and validation, rather than theoretical studies alone. Additionally, ARPA-E envisions a contrail reporting and observational data aggregation mechanism that mimics current tools for turbulence reporting and could further serve to continuously refine and improve AIC predictive modeling capabilities going forward.

[33] Appleman, H., 1953: The formation of exhaust condensation trails by jet aircraft. Bull. Amer. Meteor. Soc., 34, 14–20.
[34] Kärcher, B. 2018. Formation and radiative forcing of contrail cirrus. Nature Communications, 9, 1824.
[35] Teoh, R., Schumann, U., Majumdar, A. and Stettler, M.E., 2020. Mitigating the climate forcing of aircraft contrails by small-scale diversions and technology adoption. Environmental Science & Technology, 54(5), pp.2941-2950.

4. Technical Performance Targets

A. *Model F_1-score of at least 0.8*: The developed models should be able to forecast persistent aircraft induced cirrus (AIC) cloud with an accuracy (as defined by the F_1-score) of at least 0.8 for a period of at least 5-12 hours after the passage of an aircraft.

Additionally, proposed AIC predictive model frameworks should be able to provide forecasts for a wide range of atmospheric conditions, including both clear and cloudy skies, and will prove their ability to provide real-time updates to pilots and flight controllers. While the feedback mechanism is undefined for the purpose of this Exploratory Topic, applicants are strongly encouraged to define in their application how these model predictions will be used to inform the pilot or air traffic control to allow for in-flight tactical decisions. This will allow airlines to adjust their flight routes and altitudes to avoid contrail formation and minimize their environmental impact.

B. Final demonstration of the AIC predictive model to achieve a minimum of five (5) true positive predictions of persistent aircraft induced cirrus (AIC) cloud for relevant flights at cruise altitude while satisfying the F_1-score criterion.

The performance of the developed AIC predictive models must be demonstrated before the end of project via a minimum of five (5) true positive predictions of persistent aircraft induced cirrus (AIC) cloud while satisfying the F_1-score criterion. For this target, persistence is defined as greater than five (5) hours and a cirrus cloud as a cloud system which spans ≥ 1 km in width at relevant cruise altitude. This will require observer validation, whether using onboard test flights, ground- or satellite-based.

C. Enabling technologies/Transformational Sensors: if novel sensors are proposed as enabling technologies, describe how they are transformational and relevant for the AIC predictive model to reach the outcome listed above

Any additional sensors that are needed beyond existing sensors on aircraft need to have size, weight, and power requirements that allow them to be easily integrated with existing airframes.

5. Criteria and Metrics

ARPA-E has an ambitious technical target: model performance with a validated F_1-score of at least 0.8. There are several other criteria of interest in each of the relevant areas that support that target:

1. **Aircraft and environmental data and sensor development:** relevant data factors need to be identified and measured with sufficient accuracy. This might be a combination of aircraft speed, altitude, aircraft and engine model, fuel type, humidity, pressure, weather

forecast, or other relevant atmospheric data. If current sensors are insufficient, new sensors might need to be explored. Target sensor performance metrics should be described in the submitted application within the context of meeting the F_1-score ≥ 0.8 metric.

2. **Predictive modeling approaches:** it is anticipated that advanced predictive analytical methods are required to identify relevant parameters and develop correlations which can yield a reasonably high accuracy, *e.g.* F_1-score ≥ 0.8, strongly reducing the number of false positives and false negatives. These predictive models require validation of their performance by identifying probable AIC ≥ 1 km in width, persisting for no fewer than five (5) hours at relevant cruise flight altitude.

3. **Observer data to validate and train the predictive model:** relevant observer methods need to be deployed, developed, or invented to provide feedback on whether aircraft contrails lead to AIC, and will play a critical role in validating model predictions. This can be a set of ground observer systems near relevant flight corridors, aircraft mounted observing sensors, or space-based observer data, as well as any other available aviation data sources. For the purposes of this new Exploratory Topic, limited relevant test flights for data gathering and model validation might be required.

Successful projects will develop a single AIC predictive model, and will incorporate two interim Go/No-Go decision points at intermediate steps, delimitating three distinct project performance focus periods:

Period 1: Development of sensors and predictive model framework: identify any sensor data sources, sensor development needs, and flight and/or other data requirements and explicitly state them with Pass/Fail metrics for each. These Pass/Fail metrics must be directly attributable to successfully meeting the overall model prediction metric of F_1-score of at least 0.8.

Period 2: Gathering of test and observer data and development of AIC predictive model: effective training of the AIC predictive model using the gathered data and exploration on how to integrate such systems within the aircraft to provide feedback to pilot, air traffic control, and other relevant aerospace system design teams.

Period 3: AIC predictive model demonstration: flight testing or other demonstration in relevant conditions of the proposed approach, including a minimum of 5 successful true positive AIC predictions, while satisfying the F_1-score criterion. This can include flight tests or demonstration on available and validated datasets. The criterion for validation is prediction of contrail cirrus and observation of the resultant AIC persisting for no fewer than 5 hours and spanning at least 1 km in width.

6. Submissions Specifically Not of Interest

Submissions that propose the following may be deemed non-responsive and may not be merit-reviewed:

- *Incomplete solutions:* any system or systems that do not result in a predictive capability that meets the aforementioned F_1-score criterion. This includes sensors solely for atmospheric measurement, or models for a single component of the AIC forming conditions (*e.g.,* models of single parameters such as convection, temperature, humidity, *etc.*).
- *Solutions not relevant to majority of commercial flights:* any technologies that operate solely outside of currently accepted flight commercial flight paths (whether altitude, aircraft or flight path) are not of interest.

7. Content and Form of Full Applications

The content and form of Applicants' Technical Volumes shall follow the instructions and be consistent with the template titled Technical Volume: DE-FOA-0002785. All other instructions set forth at FOA Section IV.C remain unchanged.

Templates for preparing Full Applications under this Exploratory Topic may be found on ARPA-E Exchange at https://arpa-e-foa.energy.gov/.

Commercialization Plan and Software Reporting

All projects funded under this ET target the development of a software model. Therefore, if your project is selected and awarded following award negotiations, you will be required, as a milestone, to prepare a Commercialization Plan for the targeted software and agree to special provisions that require the reporting of the targeted software and its utilization. This special approach to projects that target software mirrors the requirements for reporting that attach to new inventions made in performance of an award. Because the Plan is called a Commercialization Plan does not mean that an awardee will be required to make the software publicly available. An acceptable Plan may indicate that the awardee will use the software internally within its own enterprises.

XIV. Appendix E: RESERVED

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XV. Appendix F: Novel Superconducting Technologies for Conductors

Special Program Announcement for
Exploratory Topics (DE-FOA-0002785)
Novel Superconducting Technologies for Conductors

Topic Issue Date	May 25, 2023
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5 PM ET, Friday, June 30, 2023
Submission Deadline for Full Applications	9:30 AM ET, Tuesday, July 11, 2023
Submission Deadline for Replies to Reviewer Comments:	5:00 PM ET, Friday August 11, 2023
Expected Date for Selection Notifications	September, 2023
Anticipated Date of Awards	December, 2023
Total Amount to be Awarded	Approximately $10,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between approximately $1,000,000–$10,000,000.
Maximum Period of Performance	36 Months

1. Introduction

This announcement describes a research and development thrust titled "Novel Superconducting Technologies for Conductors." The purpose of this announcement is to (1) focus the attention of the scientific and technical community on specific areas of interest related to the manufacturing processes of high-performance, rapidly produced superconducting tapes, (2) encourage dialogue among those interested in this area, and (3) provide a timetable for the submission of full applications.

2. Topic Description

Widely available low-cost high-temperature superconducting (HTS) tapes would encourage their use into several energy-related applications that could have major implications in the energy transition. The superconductors targeted in this FOA are expected to help enable the market growth and proliferation of nuclear fusion,[36] superconducting cables for the electric grid,[37,38] electric aviation,[39] and superconductor-based electric generators/motors.[40,41]

[36] X. Wang, S. A. Gourlay, and S. O. Prestemon, "Dipole magnets above 20 Tesla: research needs for a path via high-temperature superconducting REBCO conductors," *Instruments*, vol. 3, no. 4, 62, 2019, doi: 10.3390/instruments3040062.
[37] T. Stamm, P. Cheetham, C. Park, C. H. Kim, L. Graber, and S. Pamidi, "Novel gases as electrical insulation and a new design for gas-cooled superconducting power cables," IEEE Electr. Insul. Mag., vol. 36, no. 5, pp. 32–42, 2020, doi: 10.1109/MEI.2020.9165697.
[38] B. Marchionini et al., "High temperature superconductivity application readiness map - energy delivery - transmission, substation and distribution," IEEE Trans. Appl. Supercond., vol. 33, no. 5, 5401405 , 2023, doi: 10.1109/TASC.2023.3242226.
[39] https://arpa-e.energy.gov/technologies/exploratory-topics/aviation-power-distribution
[40] L. Ybanez et al., "ASCEND: The first step towards cryogenic electric propulsion," IOP Conf. Ser.: Mater. Sci. Eng., vol. 1241, no. 1, 012034, 2022, doi: 10.1088/1757-899X/1241/1/012034.
[41] https://arpa-e.energy.gov/technologies/programs/ascend

Superconductors are materials that have zero electrical resistance when operated at temperature T, electrical current I, and magnetic field B below a critical temperature T_c, a critical current I_c, and a critical field B_c, respectively. This triad of critical parameters are interdependent such that, at lower temperatures, superconductors may be able to operate at higher currents or under a higher magnetic field before quenching occurs, i.e., before they lose their superconducting properties. HTS such as $YBa_2Cu_3O_{7-x}$, which is part of a larger family of compounds known as Rare Earth Barium Copper Oxides (REBCO), are a particularly attractive technology because if they are processed appropriately they can maintain high critical current in high magnetic fields (i.e., > 20 T) at low temperatures (i.e., 20 K with LH_2) for applications such as high-energy physics and nuclear fusion,[36] or can work at higher temperatures (i.e., up to 77 K with LN_2) in lower magnetic fields (< 2 T) for applications such as electric motors and generators, transformers, high-speed maglev transportation, and electric power transmission.[37,38,42]

Although they have superior performance, HTS are more difficult to manufacture than low-temperature superconductors (LTS). LTS such as niobium–titanium are simple metal alloys which are malleable and are easily and cheaply manufactured into wires or tapes. However, they generally have critical temperatures less than 30 K, use liquid helium cooling (i.e., ≈ 4 K) to improve their critical current I_c, and are not capable of operating in very high magnetic fields.[36] Conversely, the most promising high-temperature superconductors, such as REBCO, are brittle ceramics which often require a combination of multiple sequential processing steps, multiple layers of sequential deposition, and highly controlled growth processes. These factors lead to difficult and costly manufacturing for HTS tapes.

The manufacturing process of REBCO tapes starts with a substrate layer which typically consist of a thin, long, flexible, metal foil that provides mechanical support as well as thermal stability (see Fig. 3a of Ref.[43], for example). The width and thickness of the substrate can vary depending on manufacturing process capabilities and customer requirements. Currently, the substrates are ≈ 30-150 µm thick and 12 mm wide. Wider substrates could be an area for manufacturing improvement. In terms of customer requirements, thicker substrates may allow for higher proof strength which could be needed when tapes experience large electromagnetic forces during operation, while thinner substrates can allow for smaller bending radii before critical current degradation which is a consideration when wrapping HTS tapes onto formers for cables.[44,45] The substrate is processed to provide a smooth, aligned crystalline structure for the REBCO layer epitaxial growth through the use of various oxide buffer layers combined with ion-beam assisted deposition (IBAD), inclined substrate deposition (ISD), or a rolling assisted biaxially textured substrate (RABiTS) method.

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[42] K. Mizuno, M. Sugino, M. Tanaka, and M. Ogata, "Development of a real-scale REBCO Coil for the demonstration of a magnetomotive force of 700 kA," Q. rep. RTRI, vol. 58, no. 4, pp. 318–323, 2017, doi: 10.2219/rtriqr.58.4_318.

[43] L. MacManus-Driscoll and S. C. Wimbush, "Processing and applications of high temperature superconducting coated conductors," Nature Review Materials, vol.6, pp. 587-604, 2021, doi: 10.1038/s41578-021-00290-3.

[44] G. Jiang et al., "Recent development and mass production of high Je 2G-HTS tapes by using thin hastelloy substrate at Shanghai Superconductor Technology," Supercond. Sci. Technol., vol. 33, no. 7, 074005, 2020, doi: 10.1088/1361-6668/ab90c4.

[45] X. Wang, D. Arbelaez, S. Caspi, S. O. Prestemon, G. Sabbi, and T. Shen, "Strain distribution in REBCO-coated conductors bent with the constant-perimeter geometry," IEEE Trans. Appl. Supercond., vol. 27, no. 8, 6604010, 2017, doi: 10.1109/TASC.2017.2766132.

Once the substrate is ready, the REBCO is then applied with several passes through deposition processes such as Pulsed Laser Deposition (PLD), reactive sputtering/evaporation, metal organic deposition (MOD), or metal organic chemical vapor deposition (MOCVD) with precise temperature, chemical, and dopant controls. As the REBCO layer gets thicker, high-quality growth is difficult to maintain and control. Thus, the critical current density J_c – defined as the ratio of I_c to the cross-sectional area of the REBCO layer – generally decreases with each pass of the tape through the deposition process. Preventing degradation in J_c as the REBCO layer gets thicker is an active area of research. [46,47] Outcomes of this research and development could result in less chemical species needed, fewer or faster passes through the deposition processes, and longer lengths of tape without critical current dropouts leading to cost savings, faster production, or improved capability to meet customer performance requirements such as uniform current density over long lengths to eliminate end tape connections and improve current balancing in parallel tapes. Other process adjustments in the buffer and HTS layer to improve J_c can also relate to the creation of field pinning defects for high magnetic field operation.[43,48,49,50,51]

Once the REBCO layer is complete, the sheet can be slit into narrower tapes typically 1-6 mm wide. Burrs or cracks resulting from the mechanical slitting of these wider tapes into narrower widths for specific applications can lead to a reduction in I_c. Laser slitting is becoming more common and generally causes less degradation though could still have a small heat-affected zone (HAZ) of a few tens of micrometers where the tape can be damaged.[52,53] A few micrometers thick silver layer is generally deposited to protect the HTS layer before and/or after slitting. Finally, the entire conductor is usually coated with a copper stabilization layer that can be as thick as 50 µm depending on customer specifications which are often related to quenching requirements.

The performance of the HTS can be defined by (i) its critical current per unit width, $I_{c/w}$ (in A/cm-width) and/or (ii) its engineering current density J_e (in A/mm^2) defined as the ratio of I_c at a given temperature and magnetic field and the cross-sectional area A of the completed tape including all layers, i.e., $J_e = I_c/A$. The engineering current density J_e is an important parameter particularly for high-density magnets as it indicates how tightly coils can be packed.[54] The reported tape length achieving a given $I_{c/w}$ or J_e is also a key metric as it indicates if uniformity can be maintained

[46] S. Chen et al., "Scale Up of high-performance REBCO tapes in a pilot-scale advanced MOCVD tool with In-line 2D-XRD system," IEEE Trans. Appl. Supercond., vol. 31, no. 5, 6600205, 2021, doi: 10.1109/TASC.2021.3058868.

[47] A. Markelov *et al.*, "2G HTS wire with enhanced engineering current density attained through the deposition of HTS layer with increased thickness," *Progress in Superconductivity and Cryogenics*, vol. 21, no. 4, pp. 29–33, 2019, doi: 10.9714/PSAC.2019.21.4.029.

[48] K. Tsuchiya et al., "Critical current measurement of commercial REBCO conductors at 4.2 K," Cryogenics, vol. 85, pp. 1–7, 2017, doi: 10.1016/j.cryogenics.2017.05.002.

[49] W. O'Neill, "Ultrafast machining of high temperature superconductor nanostructures for novel mesoscale physics," Final Technical Report. AFRL-AFOSR-UK-TR-2023-0012.

[50] N. M. Strickland et al., "Tunable dimensionality of pinning centers from silver-ion irradiation of REBCO coated conductors," IEEE Trans. Appl. Supercond., vol. 33, no. 5, 8000205, 2023, doi: 10.1109/TASC.2023.3240384.

[51] M. Paidpilli et al., "Growth of high-performance 4-5µm thick film REBCO tapes doped with hafnium using advanced MOCVD," IEEE Trans. Appl. Supercond., vol. 31, no. 5, 6600405, 2021, doi: 10.1109/TASC.2021.3060366.

[52] Z. Yang, Y. Li, P. Song, M. Guan, F. Feng, and T. Qu, "Effect of edge cracks on critical current degradation in REBCO tapes under tensile stress," *Superconductivity*, vol. 1, 100007, 2022, doi: 10.1016/j.supcon.2022.100007.

[53] W. N. Hartnett *et al.*, "Characterization of edge damage induced on REBCO superconducting tape by mechanical slitting," *Eng. Res. Express*, vol. 3, no. 3, 035007, 2021, doi: 10.1088/2631-8695/ac0fc3.

[54] R. C. Duckworth *et al.*, "Conceptual design and performance considerations for superconducting magnets in the material plasma exposure experiment," *IEEE Trans. Plasma Sci.*, vol. 48, no. 6, pp. 1421–1427, 2020, doi: 10.1109/TPS.2020.2985948.

over a substantial length of tape through the manufacturing process. Various state-of-the-art metrics have been reported in recent literature. While statistical uniformity between batches is also a very important metric, data is sparse. The reader is also referred to recent publications as cited in this Topic for further review of state-of-the-art HTS fabrication and manufacturing trends.

While there are many areas of improvement and investigation associated with HTS that may be inextricably related, **the primary focus of this FOA is on novel fabrication methods for HTS tape or wire that can concurrently (i) increase the continuous tape or wire length, (ii) reduce the electrical variation along the tape or wire, and (iii) increase the overall production rate while (iv) significantly reducing the production costs and (v) maintaining a high level of tape performance characterized by $I_{c/w}$ and J_e**. Therefore, ARPA-E seeks proposals for novel scalable superconducting manufacturing methods that can increase the production rate of high-quality superconducting tapes or wires with uniform performance parameters.

A. Technical Areas of Interest

Technical areas of interest could include methods to improve the speed and quality of manufacturing with faster deposition, fabricate higher quality tapes with higher $I_{c/w}$ or J_e, reduce processing steps, increase tape width, and/or reduce required chemical species and verifiably translate these improvements to tape production with clear reductions in cost by a factor of 10x, per the Topic metrics, and an increase in production speed for a single production line. Applicants must discuss limiting factors that exist in today's production processes in their technical volume as well as how they propose to greatly improve those processes. In order to achieve the ambitious cost metric, such improvements should be for a single HTS tape or wire production line rather than counting on economies of scale with multiple production lines. Other manufacturing aspects such as reducing performance degradation due to axial strains, improving slitting processes and cable production methods, or expanding fabrication into multi-tape or multi-wire structures are also important for the overall performance in the different applications and should be considered as they relate to the Topic objectives or proving out the metrics; however, they should not be the singular focus of any proposal.

The areas of interest include novel manufacturing techniques and processes such as those discussed above that will demonstrably increase superconducting tape output from a single production line for tape operation either:

A. at high magnetic fields (10-20 T) in the temperatures range of 20-40 K, or
B. at low magnetic fields (< 1 T) in the temperatures range of 65-77 K accessible to liquid nitrogen.

B. Technical Performance Targets

Superconductor tape metrics and goals of this Topic are outlined in the Table below. Every submission must describe how the proposed technology will be able to comply with metrics A.1-A.6 and report the remaining metrics in Table A. In addition, each submission must specify the intended application(s) and the associated, relevant metrics for the proposed technology and support these metrics via justifications in the body of their technical volume. The applicant should also describe how the tape will be handled and used in producing the final product(s) in the

application of interest. In particular, the pathway to achieving the aggressive cost metric in metric A.1 must be described in detail. If a metric is not considered or is changed from the Topic suggested goal, the applicant must describe in detail the reason for the omission or change, respetively. For example, if a tape has exceptional performance at 77 K, the applicant may be able to provide justification as to why a tape with lower critical current density at 20 T, 20 K should be acceptable or if the proposed solution is for wider tapes and/or those with higher ampacity, the applicant may be able to justify a lower production rate per year.

Table A. Comparison of the HTS tape manufacturing Topic goals and proposed solution.

ID	Performance parameter	Production-level SOA	Topic goals	Proposed solution and justification
A.1	Production Cost (in $/kA m)	100	< 10	
A.2	Continuous tape or wire length (m)	500	>500	
A.3	Variation along continuous length of 300 m as percentage of A.5 or A.6	-	< 10%	
A.4	J_e (A/mm^2)*	~600	> 600	
A.5	$I_{c/w}$ (A/cm-width)*	~500	> 500	
A.6	Tape fabrication width pre-slitting (mm)	12	> 12	
A.7	Projected production rate for single process line (in km/year)	-	Applicant specified	
A.8	Magnetic Field (T)	0.01-20	Applicant specified	
A.9	Temperature (K)	20-77	Applicant specified	
A.10	Allowed compressive strain without degradation to I_c	1.25%	Applicant specified	
A.11	J_e consistency between 3 lots of 300 m (%)	-	Applicant specified	
A.12	HAZ, crack, or burr size due to slitting (µm)	10-50	Applicant specified	
A.13	SC epitaxial film growth rate (nm/s)	3-50	Applicant specified	
A.14	SC epitaxial layer thickness (µm)	1-5	Applicant specified	
A.15	Substrate thickness (µm)	30-50	Applicant specified	
A.16	Copper plating thickness (µm)	5-50	Applicant specified	

*at the temperatures and magnetic fields specified by the application in A.8 and A.9.

XVI. Appendix G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes

Special Program Announcement for
Exploratory Topics (DE-FOA-0002785)
Production of Geologic Hydrogen Through Stimulated Mineralogical Processes

Topic Issue Date	September 7, 2023
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5 PM ET, October 13, 2023
Submission Deadline for Full Applications	9:30 AM ET, October 24, 2023
Submission Deadline for Replies to Reviewer Comments:	5:00 PM ET, November 27, 2023
Expected Date for Selection Notifications	January 2024
Anticipated Date of Awards	April 2024
Total Amount to be Awarded	Approximately $10,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between approximately $1,000,000–$2,500,000.
Maximum Period of Performance	24 Months

1. Introduction

It is anticipated that hydrogen (H_2) will be critical to our efforts to mitigate the climate impact of our energy system through its use as a reductant or energy source in applications that have typically been served by fossil fuels. However, to have the desired climate impact, hydrogen must be produced via climate-neutral means. Current global hydrogen demand is approximately 100 million tonnes (Mt)/year, but the International Energy Agency's (IEA) Net Zero by 2050 Roadmap requires 500 Mt/year of hydrogen by 2050.[55] At present, steam methane reforming (SMR) is used to produce "gray" hydrogen at low cost ($1.50/kg) but generates ~10 kg CO_2/kg H_2. "Blue" (SMR with carbon capture) and "green" (renewable energy powered water electrolysis) hydrogen are more climate-neutral alternatives to "gray" hydrogen. "Blue" and "green" hydrogen are being actively pursued and estimated to cost $2.00+/kg and $3.00+/kg, respectively. In addition to producing hydrogen at a higher cost than traditional SMR, both have approach-specific challenges:

"Blue" Hydrogen:

- Storage of gigatonnes (Gt) of CO_2/year;
- Greenhouse gas (GHG) emissions through losses in carbon capture and upstream methane leaks corresponding to about 10% of that of "gray" hydrogen.

[55] Inflation Reduction Act of 2022

"Green" Hydrogen:

- Competition for carbon-free electricity with other decarbonization efforts, and overall emission mitigation will depend on the electricity supply;
- Critical mineral availability to meet requirements for both electrolyzer production and the wind/solar generation capacity to power it.

Thus, it is important to develop alternate routes to low cost (<$1/kg H_2) and low emissions (<0.45 kg CO_2e/kg H_2) hydrogen.[56]

The subsurface continuously generates and consumes hydrogen through natural geochemical and biological processes.[57] There has been recent interest in the discovery of naturally accumulating deposits of subsurface hydrogen, such as efforts by the United States Geologic Survey (USGS).[58] Estimates vary from as little as 500,000 tonnes/year[59] to as much as billions of tonnes/year[60,61,62] of hydrogen being produced in the subsurface and accumulating in areas where mineralogical production processes are faster than consumptive biological processes. While the supply of naturally accumulating hydrogen, in and of itself, is potentially impactful on the U.S. energy economy, iron in the earth's crust has the theoretical potential to produce around 150,000 Gt H_2 from the reaction of Fe(II) within 3 km of the surface.[63] Exploiting a small percentage of this source through stimulated mineralogical processes could yield larger quantities of hydrogen than what are produced naturally. For reference, 1 Gt H_2 has enough energy to power the entire U.S. for a year.[64] Thus, engineering the production of subsurface hydrogen could potentially enable the production of substantial amounts of clean energy.

ARPA-E, under a combination of Exploratory Topics (ETs) G and H (hereinafter referred to as the Geologic H_2 effort), seeks to fund the development and validation of technologies that can stimulate the generation of hydrogen within the subsurface by enhancing/accelerating natural mineralogical processes. *Given the substantial resource potential of materials in the earth's crust, successful technologies developed under this new effort will lead to hydrogen production with the lowest cost (<$1 kg/$H_2$), emissions (<0.45 kg CO_2e/H_2), and resource consumption with*

[56] Hydrogen Shot | Department of Energy
[57] N. Dopffel, B.A. An-Stepec, J.R. de Rezende, D.Z. Sousa and A. Koerdt, Editorial: Microbiology of underground hydrogen storage, (2023).
[58] G.S. Ellis and S.E. Gelman, A preliminary model of global subsurface natural hydrogen resource potential, Geological Society of America Annual Meeting October 9-12, 2022, Denver, Colorado, Geological Society of America Abstracts with Programs, v. 54, no. 5. https://doi.org/10.1130/abs/2022AM-380270.
[59] B. Sherwood Lollar, T.C. Onstott, G. Lacrampe-Coulome, C.J. Ballantine. The contribution of Precambrian continental lithosphere to global H_2 production. *Nature.* **516**, 379–382 (2014).
[60] E. Hand, Hidden hydrogen. *Science*. **379**, 630–636 (2023).
[61] F. Klein, J.D. Tarnas, W. Bach, Abiotic sources of molecular hydrogen on earth. *Elements.* **16**, 19–24 (2020).
[62] V. Zgonnik, The occurrence and geoscience of natural hydrogen: A comprehensive review. *Earth Sci Rev.* **203**, 103140 (2020).
[63] G.S. Ellis and S.E. Gelman, A preliminary model of global subsurface natural hydrogen resource potential, Geological Society of America Annual Meeting October 9-12, 2022, Denver, Colorado, Geological Society of America Abstracts with Programs, v. 54, no. 5. https://doi.org/10.1130/abs/2022AM-380270.
[64] The lower heating value of H_2 is ~33 kWh/kg, 1 Gt of H would yield ~33,000 TWh (~112.6 quads, greater than U.S. energy consumption (EIA))

minimal disruption to the surrounding environment. This outcome supports the goals set for ARPA-E under 42 U.S.C. § 16538(c) to (1) reduce imports by minimizing the need for critical minerals for "green" hydrogen; (2) improve efficiency by utilizing hydrogen as a primary energy source for electricity (as opposed to as an energy carrier with a 30% energy loss); and (3) reduce emissions via the provision of ultra-low-GHG emission H_2.

ARPA-E seeks Full Applications to develop technologies that can lead to the production of stimulated geologic hydrogen at low cost and with low emissions. The Agency is specifically interested in:

1. *ET G: Technologies that stimulate hydrogen production from mineral deposits found in the subsurface* including developing our understanding of hydrogen-producing geochemical reactions (*e.g.*, serpentinization) and of how to enhance or control the rate of hydrogen production through external stimuli (*e.g.*, physical, chemical, or biological), and
2. *ET H: Technologies relevant to the extraction of geologic hydrogen* including improvements in subsurface transport methods and engineered containment, reservoir monitoring and/or modeling during production and extraction (*e.g.*, strain, leakage, and/or other risks).

ARPA-E targets for geologic hydrogen production for this effort are provided in **Table 1**, with a more in-depth discussion of technological metrics that applicants must address in Section 4 of this ET.

Table 1. Overall ARPA-E Geologic H_2 targets for geologic hydrogen production.

Metric	Geologic H_2 Target
H_2 cost at the well-head	*<$1/kg H_2*
H_2 GHG *(from production)*	*<0.45 kg CO_2e/kg H_2*
Hydrogen purity	*>20% (volumetric) at the well-head*
Deposit potential	*>10 Mt H_2*
Deposit production *(from formation)*	*>1 million m^3/day H_2 (>30,000 tonnes/year H_2)*

2. Topic Description

Under the Geologic H_2 effort, ARPA-E seeks to fund the development and validation of technologies that can lead to the lowest cost and lowest GHG emission hydrogen from the subsurface. These ETs are interested in supporting the development of upstream technologies to the well-head.

This ET includes Category 1, understanding and controlling the stimulation process, and Category 2, developing tools to model, monitor, or mitigate geological processes and risks. Engineering methods to economically extract the hydrogen through containment or separations is the focus of ET H: Subsurface Engineering for Hydrogen Reservoir Management. If successful, this effort could potentially enable the production of enough hydrogen to decarbonize the most challenging industries.

A. Topics of Interest

The following is a non-exhaustive list of technologies that are of interest for ET G. Applications can address one or more technologies:

- *Stimulation and generation:* Technologies which enhance the natural rate of serpentinization or other equivalent hydrogen producing geochemical reactions (*e.g.*, reduction of iron bearing minerals in banded iron formations, clinkers).
- *Modeling approaches:* Methods and tools to predict the viability of subsurface resources for stimulated hydrogen generation, inform reservoir management, or assist with stimulation efforts.
- *Characterization:* Methods and tools to map subsurface and ocean floor resources (*e.g.*, ultramafic formations or other candidate formations) and quantify physiochemical properties of interest, specifically total Fe content, Fe(II) concentration, Fe(II)/Fe(III) ratio, specific surface area, permeability, or other parameters relevant to stimulated hydrogen generation.

B. Topics Not of Interest

Applications that propose the following technology concepts may be deemed nonresponsive and may not be reviewed or considered:

- Methods focused on identifying, managing, and monitoring hydrogen reservoirs, as well as assessing the risk of hydrogen reservoir development. Proposals of this focus should apply to ET H: Subsurface Engineering for Hydrogen Reservoir Management.
- Gasification of existing hydrocarbon reserves in the subsurface (*e.g.*, coal, oil reserves).
- Subsurface conversion of methane into hydrogen.
- Technologies focused solely on extraction of naturally occurring/accumulating hydrogen.
- Methods of producing hydrogen that require carbon sequestration to meet the overall Geologic H_2 GHG target.
- Applications focused on generating subsurface hydrogen through electrolysis of water.
- Technologies that are fully mature in other sectors (*e.g.*, geothermal or oil and gas) and do not require substantial innovation to support subsurface hydrogen production.
- Subsequent applications and uses of hydrogen downstream of the well-head.
- Applications that do not address Category 1 (see Section 3. Technical Categories).

C. Technology-To-Market (T2M)

Current domestic hydrogen production is predominantly via SMR through merchant hydrogen producers. If the overall Geologic H_2 target of \$1/kg H_2 can be reached, geologically produced hydrogen would be competitive in those markets.[65] Hydrogen demand could also evolve from

[65] Inflation Reduction Act of 2022

local use opportunities to regional gathering, or as an input to other regional market opportunities (*e.g.*, petrochemical, ammonia, steelmaking).

For this ET, applicants should:

1. Identify a potential commercial pathway and commercial transition partners for their proposed work.
2. Show how their proposed technology contributes to meeting the overall Geologic H_2 targets for cost and emissions. The applicant should clearly identify the boundaries of their technology and provide a preliminary techno-economic assessment (TEA) and Life Cycle Assessment (LCA) in their Full Application. In their analysis or justification, applicants must show which current or conventional technologies can be directly implemented (known costs), as well as which novel technologies need to be developed (unknown costs).

3. Technical Categories

ARPA-E has identified two major technical categories. Category 1 is related to the investigation of stimulation methods to rapidly enhance the natural rate of hydrogen production from mineral sources. Category 2 is centered around the technology needed to manage the production of hydrogen through reaction modeling and monitoring.

Applications must address Category 1 and are also encouraged to address Category 2 as a complementary category to Category 1.

A. Category 1 – Stimulation

This category is focused on developing methods to enhance, control, and sustain serpentinization or other relevant processes for the generation of hydrogen, and is open to any approaches to do so in an economically feasible and sustainable way. Approaches of interest may be physical, chemical, thermal, or biological in nature, or any other approach. The final deliverable must include experimental data to show that the technology meets the overall Geologic H_2 and Category 1-specific performance targets. Computational models or simulation data are optional and encouraged.

The stimulation of subsurface hydrogen production represents a potentially much larger hydrogen source than the passive exploration/exploitation of naturally occurring hydrogen. With an average yield of 2-4 kgH_2/m^3 upon complete oxidation, the 10^{20} kg of ultramafic peridotites in the earth's upper 7-km[66] of crust can generate up to 100 trillion tons of hydrogen,

[66] P. B. Kelemen, J. Matter, E. E. Streit, J. F. Rudge, W. B. Curry, J. Blusztajn, Rates and Mechanisms of Mineral Carbonation in Peridotite: Natural Processes and Recipes for Enhanced, in situ CO_2 Capture and Storage. *Annu. Rev. Earth Planet. Sci.* **39**, 545–576 (2011).

sufficient for 250,000 years at a rate of 400 Mt/yr.[67] Additionally, these formations are annually refreshed at a rate of 10^{12} kg/yr through tectonic activity.[68] To stimulate the serpentinization for hydrogen production, water is injected *in situ* in identified reactive formations, from which hydrogen-saturated water can be collected from recovery wells surrounding the injection point.[69] It is estimated and supported by laboratory scale experiments that a rate of 0.1-3 MtH_2/yr for 1 km^3 of peridotite can be achieved with >5 wt% Fe(II) concentration.[70] Furthermore, this process can be expanded to other rock formations that contain valuable elements (Li, Ni, Co) or *ex situ* sources (Fe-rich mine wastes and steel slags), as well as using seawater or wastewater for natural oxidation of iron. However, the engineering of serpentinization in ultramafic rocks and other hydrogen producing mineralogical processes is not well understood. Recent research has evaluated the equilibrium and kinetic dynamics of this process.[71,72]

B. Category 2 – Modeling and Characterization

This category is focused on methods to understand, predict, and monitor stimulated hydrogen using innovative modeling and characterization approaches. Proposals focused on predicting and evaluating the yield and scale of stimulation methods, as well as methods to monitor, characterize, and confirm stimulation production, are of particular interest for this category.

The subsurface dynamics of hydrogen are poorly understood. In addition, existing technologies and methods for characterizing the subsurface were originated in the oil and gas sector, where the needs are very different than stimulated H_2 generation. Oil and gas characterization and modeling methods are focused on interpreting fluid flow (*e.g.*, hydrocarbons, brine) in porous rocks (*e.g.*, sandstones, shales).[73] The subsurface generation mechanism of hydrogen is typically a mineralogical reaction, likely within crystalline rock, in which iron bearing minerals react with water to create gaseous phase hydrogen.[74] These processes are most observable in

[67] P. B. Kelemen, J. Matter, E. E. Streit, J. F. Rudge, W. B. Curry, J. Blusztajn, Rates and Mechanisms of Mineral Carbonation in Peridotite: Natural Processes and Recipes for Enhanced, in situ CO ₂ Capture and Storage. *Annu. Rev. Earth Planet. Sci.* **39**, 545–576 (2011).
[68] P. B. Kelemen, J. Matter, E. E. Streit, J. F. Rudge, W. B. Curry, J. Blusztajn, Rates and Mechanisms of Mineral Carbonation in Peridotite: Natural Processes and Recipes for Enhanced, in situ CO ₂ Capture and Storage. *Annu. Rev. Earth Planet. Sci.* **39**, 545–576 (2011).
[69] F. Osselin, C. Soulaine, C. Fauguerolles, E. C. Gaucher, B. Scaillet, M. Pichavant, Orange hydrogen is the new green. *Nat. Geosci.* **15**, 765–769 (2022).
[70] F. Osselin, C. Soulaine, C. Fauguerolles, E. C. Gaucher, B. Scaillet, M. Pichavant, Orange hydrogen is the new green. *Nat. Geosci.* **15**, 765–769 (2022).
[71] T. M. McCollom, W. Bach, Thermodynamic constraints on hydrogen generation during serpentinization of ultramafic rocks. *Geochim. Cosmochim. Acta*. **73**, 856–875 (2009).
[72] F. Klein, W. Bach, T. M. McCollom, Compositional controls on hydrogen generation during serpentinization of ultramafic rocks. *Lithos*. **178**, 55–69 (2013).
[73] https://wiki.aapg.org/Overview_of_routine_core_analysis
[74] F. Osselin, C. Soulaine, C. Fauguerolles, E. C. Gaucher, B. Scaillet, M. Pichavant, Orange hydrogen is the new green. *Nat. Geosci.* **15**, 765–769 (2022).

extreme environments, such as tectonic subduction zones, but are still being investigated.[75] The nature of ultramafic rocks is very different from that of porous clastic rocks, necessitating new approaches to characterization and modeling.

Serpentinization (or an alternative hydrogen producing geochemical reaction) necessitates a focus on different physiochemical properties, such as total iron content, Fe(II)/Fe(III) ratio, and specific surface area. Methods to characterize and map these properties that pertain to the proposed stimulation methods as well as methods to model and predict engineered mineralogical processes of interest are needed to make stimulated geologic hydrogen a viable and responsibly exploited energy source.

4. Technical Performance Targets

Under the Geologic H_2 effort, ARPA-E intends to support the development of technologies that can lead to future hydrogen production safely and responsibly at lower cost and GHG emissions when compared to current state of the art (*e.g.*, hydrogen produced from SMR, SMR with sequestration, electrolysis). Proposed methods and technologies are required to meet the overall Geologic H_2 targets (**see items Pa-Pe below**).

In addition to the overall Geologic H_2 targets *(i.e.*, those targets applicable to both ET G and ET H), proposed methods and technologies will also be required to meet category-specific targets:

Geologic H_2 Effort

The proposed model, method, or technology must be able to do one or more of the following:

Pa. Produce H_2 with a cost at the well-head of *$1/kg H_2.*

Pb. Produce H_2 with GHG/kg H_2 of *<1 kg CO_2e/kg H_2.*

Pc. Produce H_2 with a purity of *>20% at the well-head (note – alternates can be proposed if an easy-to-separate sweeping gas is employed and justified in the Application).*

Pd. Enable H_2 deposit exploitation with a potential of *>10 Mt H_2.*

Pe. Enable H_2 deposit production of *>1 million m^3 H_2.*

[75] Worman, S. L., Pratson, L. F., Karson, J. A., and Schlesinger, W. H. (2020). Abiotic hydrogen (H2) sources and sinks near the Mid-Ocean Ridge (MOR) with implications for the subseafloor biosphere. PNAS 117, 13283–13293. doi:10.1073/pnas.2002619117

ET G Category 1. Stimulation
The proposed method or technology must be able to do one or more of the following:

1a. Increase serpentinization rate by *>10^5×* over the rate found in the native ore being evaluated at an equivalent starting *T* and *P* (*e.g.*, rate from the Samail ophiolite, Oman reported as 8×10^{-14} s^{-1}).[76]

1b. Increase the rate of other target H_2 producing mineralogical processes to produce a *comparable amount of H_2 to* ***1a.***

ET G Category 2. Modeling/Characterization
The proposed model, method, or technology must be able to do one or more of the following:

2a. Experimentally show ways to accurately quantify Fe(II), the Fe(II)/Fe(III) ratio, and the total Fe of target candidate formations.

2b. Experimentally show models that can predict H_2 stimulation using methods proposed in **Cat. 1**.

5. Data Rights and Sharing

Awardees under this ET will be strongly encouraged to share data with one or more select ARPA-E awardees who will use the data as inputs to generate publicly available models or tools that can be used to generate outputs such as life cycle analysis that will facilitate commercial acceptance of the technologies in this ET. Shared data may include, but is not limited to, mineral composition, conditions of the reaction, kinetics of hydrogen formation, and any underlying components or inputs for a technoeconomic or life-cycle analysis.

An awardee that receives data from another awardee will be required to treat any data provided to them as confidential information unless this requirement is altered by written agreement between them and the awardee that provided the data. The awardee receiving data will be required to treat all data generated under their award as trade secret-like for 10 years subject to a mutually agreed upon list of data that may be publicly released at any time. Such a publicly releasable list will not include data that is specifically identifiable with an awardee that provided data. Data provided by one awardee to another will not be shared by the awardee receiving the data with any other awardee. Similarly, an awardee that receives data from another awardee will not share with any other awardee data they generate that is related to the awardee that provided the data.

[76] J. A. Leong, M. Nielsen, N. McQueen, R. Karolyte, D. J. Hillegonds, C. Ballentine, T. Darrah, W. McGillis, P. B. Kelemen, H_2 and CH_4 outgassing rates in the Samail ophiolite, Oman: Implications for low-temperature, continental serpentinization rates. *Geochim. Cosmochim. Acta* **347**, 1–15 (2023).

6. Content and Form of Full Applications

The content and form of Applicants' Technical Volumes shall follow the instructions and be consistent with the template titled Technical Volume: Topic G. All other instructions set forth at FOA Section IV.C remain unchanged.

Templates for preparing Full Applications under this Exploratory Topic may be found on ARPA-E Exchange at https://arpa-e-foa.energy.gov/.

XVII. Appendix H: Subsurface Engineering for Hydrogen Reservoir Management

Special Program Announcement for
Exploratory Topics (DE-FOA-0002785)
Subsurface Engineering for Hydrogen Reservoir Management

Topic Issue Date	September 7, 2023
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5 PM ET, October 13, 2023
Submission Deadline for Full Applications	9:30 AM ET, October 24, 2023
Submission Deadline for Replies to Reviewer Comments:	5:00 PM ET, November 27, 2023
Expected Date for Selection Notifications	January 2024
Anticipated Date of Awards	April 2024
Total Amount to be Awarded	Approximately $10,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between approximately $1,000,000–$2,500,000.
Maximum Period of Performance	24 Months

1. Introduction

It is anticipated that hydrogen (H_2) will be critical to our efforts to mitigate the climate impact of our energy system through its use as a reductant or energy source in applications that have typically been served by fossil fuels. However, to have the desired climate impact, hydrogen must be produced via climate-neutral means. Current global hydrogen demand is approximately 100 million tonnes (Mt)/year, but the International Energy Agency's (IEA) Net Zero by 2050 Roadmap requires 500 Mt/year of hydrogen by 2050.[77] At present, steam methane reforming (SMR) is used to produce "gray" hydrogen at low cost ($1.50/kg) but generates ~10 kg CO_2/kg H_2. "Blue" (SMR with carbon capture) and "green" (renewable energy powered water electrolysis) hydrogen are more climate-neutral alternatives to "gray" hydrogen. "Blue" and "green" hydrogen are being actively pursued and estimated to cost $2.00+/kg and $3.00+/kg, respectively. In addition to producing hydrogen at a higher cost than traditional SMR, both have approach-specific challenges:

"Blue" Hydrogen:

- Storage of gigatonnes (Gt) of CO_2/year;
- Greenhouse gas (GHG) emissions through losses in carbon capture and upstream methane leaks corresponding to about 10% of that of "gray" hydrogen.

[77] Inflation Reduction Act of 2022

"Green" Hydrogen:

- Competition for carbon-free electricity with other decarbonization efforts, and overall emission mitigation will depend on the electricity supply;
- Critical mineral availability to meet requirements for both electrolyzer production and the wind/solar generation capacity to power it.

Thus, it is important to develop alternate routes to low cost (<$1/kg H_2) and low emissions (<0.45 kg CO_2e/kg H_2) hydrogen.[78]

The subsurface continuously generates and consumes hydrogen through natural geochemical and biological processes.[79] There has been recent interest in the discovery of naturally accumulating deposits of subsurface hydrogen, such as efforts by the United States Geologic Survey (USGS).[80] Estimates vary from as little as 500,000 tonnes/year[81] to as much as billions of tonnes/year[82,83,84] of hydrogen being produced in the subsurface and accumulating in areas where mineralogical production processes are faster than consumptive biological processes. While the supply of naturally accumulating hydrogen, in and of itself, is potentially impactful on the U.S. energy economy, iron in the earth's crust has the theoretical potential to produce around 150,000 Gt H_2 from the reaction of Fe(II) within 3 km of the surface.[85] Exploiting a small percentage of this source through stimulated mineralogical processes could yield larger quantities of hydrogen than what are produced naturally. For reference, 1 Gt H_2 has enough energy to power the entire U.S. for a year.[86] Thus, engineering the production of subsurface hydrogen could potentially enable the production of substantial amounts of clean energy.

ARPA-E, under a combination of Exploratory Topics (ETs) G and H (hereinafter referred to as the Geologic H_2 effort), seeks to fund the development and validation of technologies that can stimulate the generation of hydrogen within the subsurface by enhancing/accelerating natural mineralogical processes. *Given the substantial resource potential of materials in the earth's crust, successful technologies developed under this new effort will lead to hydrogen production with the lowest cost (<$1 kg/$H_2$), emissions (<0.45 kg CO_2e/H_2), and resource consumption with*

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[78] Hydrogen Shot | Department of Energy

[79] N. Dopffel, B.A. An-Stepec, J.R. de Rezende, D.Z. Sousa and A. Koerdt, Editorial: Microbiology of underground hydrogen storage, (2023).

[80] G.S. Ellis and S.E. Gelman, A preliminary model of global subsurface natural hydrogen resource potential, Geological Society of America Annual Meeting October 9-12, 2022, Denver, Colorado, Geological Society of America Abstracts with Programs, v. 54, no. 5. https://doi.org/10.1130/abs/2022AM-380270.

[81] B. Sherwood Lollar, T.C. Onstott, G. Lacrampe-Coulome, C.J. Ballantine. The contribution of Precambrian continental lithosphere to global H_2 production. *Nature.* **516**, 379–382 (2014).

[82] E. Hand, Hidden hydrogen. *Science*. **379**, 630–636 (2023).

[83] F. Klein, J.D. Tarnas, W. Bach, Abiotic sources of molecular hydrogen on earth. *Elements.* **16**, 19–24 (2020).

[84] V. Zgonnik, The occurrence and geoscience of natural hydrogen: A comprehensive review. *Earth Sci Rev.* **203**, 103140 (2020).

[85] G.S. Ellis and S.E. Gelman, A preliminary model of global subsurface natural hydrogen resource potential, Geological Society of America Annual Meeting October 9-12, 2022, Denver, Colorado, Geological Society of America Abstracts with Programs, v. 54, no. 5. https://doi.org/10.1130/abs/2022AM-380270.

[86] The lower heating value of H_2 is ~33 kWh/kg, 1 Gt of H would yield ~33,000 TWh (~112.6 quads, greater than U.S. energy consumption (EIA))

minimal disruption to the surrounding environment. This outcome supports the goals set for ARPA-E under 42 U.S.C. § 16538(c) to (1) reduce imports by minimizing the need for critical minerals for "green" hydrogen; (2) improve efficiency by utilizing hydrogen as a primary energy source for electricity (as opposed to as an energy carrier with a 30% energy loss); and (3) reduce emissions via the provision of ultra-low-GHG emission H_2.

ARPA-E seeks Full Applications to develop technologies that can lead to the production of stimulated geologic hydrogen at low cost and with low emissions. The Agency is specifically interested in:

1. *ET G: Technologies that stimulate hydrogen production from mineral deposits found in the subsurface* including developing our understanding of hydrogen-producing geochemical reactions (*e.g.*, serpentinization) and of how to enhance or control the rate of hydrogen production through external stimuli (*e.g.*, physical, chemical, or biological), and
2. *ET H: Technologies relevant to the extraction of geologic hydrogen* including improvements in subsurface transport methods and engineered containment, reservoir monitoring and/or modeling during production and extraction (*e.g.*, strain, leakage, and/or other risks).

ARPA-E targets for geologic hydrogen production for this effort are provided in **Table 1**, with a more in-depth discussion of technological metrics that applicants must address in Section 4 of this ET.

Table 1. Overall ARPA-E Geologic H_2 targets for geologic hydrogen production.

Metric	Geologic H_2 Target
H_2 cost at the well-head	*<$1/kg H_2*
H_2 GHG *(from production)*	*<0.45 kg CO_2e/kg H_2*
Hydrogen purity	*>20% (volumetric) at the well-head*
Deposit potential	*>10 Mt H_2*
Deposit production *(from formation)*	*>1 million m^3/day H_2 (>30,000 tonnes/year H_2)*

2. Topic Description

Under the Geologic H_2 effort, ARPA-E seeks to fund the development and validation of technologies that can lead to the lowest cost and lowest GHG emission hydrogen from the subsurface. These ETs are interested in supporting the development of upstream technologies to the well-head.

This ET includes Category 1, engineering of methods to economically extract the hydrogen through containment or separations; Category 2, developing tools to model, monitor, or mitigate geological processes; and Category 3, understanding environmental risks associated with geologic H_2 production (see Section 3, Technical Categories, for full details).

Understanding and controlling the hydrogen stimulation process is the focus of ET G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes. If successful, this effort could potentially enable the production of enough hydrogen to decarbonize the most challenging industries.

A. Topics of Interest

The following is a non-exhaustive list of technologies that are of interest for ET H. Applications can address one or more technologies:

- *Subsurface engineering:* Technologies which are related to engineering or creating subsurface hydrogen reservoirs, or technologies which can achieve a higher concentration/pressure of hydrogen prior to the well-head.
- *Down-hole gas separation:* Down-hole/upstream-of-well-head systems capable of separating gases to enable transport of higher purity hydrogen (in the case of production of coevolved or liberated gases). An example includes low cost, high flux, high selectivity membrane systems.
- *Risk mitigation methods:* Technologies that can predict, model, or prevent harmful side effects associated with enhanced stimulation of hydrogen generating mineralogical processes (*e.g.*, serpentinization of ultramafic rocks). Focus should be given to understanding and addressing volumetric expansion, seismicity, hydrogen leakage and associated impact on GHG emissions, biological effects, and subsurface contamination.
- *Modeling approaches:* Methods to predict the viability of subsurface resources for stimulated hydrogen generation, inform reservoir management, or assist with stimulation efforts.
- *Characterization:* Methods to map subsurface and ocean floor resources (*e.g.*, ultramafic formations or other candidate formations) and quantify physiochemical properties of interest, specifically total Fe content, Fe(II) concentration, Fe(II)/Fe(III) ratio, specific surface area, permeability, or other parameters relevant to stimulated hydrogen generation.

B. Topics Not of Interest

Applications that propose the following technology concepts may be deemed nonresponsive and may not be reviewed or considered:

- Methods focused on stimulation methods, such as enhanced serpentinization or other hydrogen generating processes, as well as modeling and characterization methods focused on predicting and monitoring the yield of these stimulation methods. Applications of this focus should apply to ET G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes.
- Gasification of existing hydrocarbon reserves in the subsurface (*e.g.*, coal, oil reserves).
- Subsurface conversion of methane into hydrogen.
- Technologies focused solely on extraction of naturally occurring/accumulating hydrogen.

- Methods of producing hydrogen that require carbon sequestration to meet the overall Geologic H_2 GHG target.
- Applications focused on generating subsurface hydrogen through electrolysis of water.
- Technologies that are fully mature in other sectors (*e.g.*, geothermal or oil and gas) and do not require substantial innovation to support subsurface hydrogen production.
- Subsequent applications and uses of hydrogen downstream of the well-head.
- Applications that only address Category 2 and/or 3 (see Section 3. Technical Categories).

C. Technology-To-Market (T2M)

Current domestic hydrogen production is predominantly via SMR through merchant hydrogen producers. If the overall Geologic H_2 target of \$1/kg H_2 can be reached, geologically produced hydrogen would be competitive in those markets.[87] Hydrogen demand could also evolve from local use opportunities to regional gathering, or as an input to other regional market opportunities (*e.g.*, petrochemical, ammonia, steelmaking).

For this ET, applicants should:

1. Identify a potential commercial pathway and commercial transition partners for their proposed work.
2. Show how their proposed technology contributes to meeting the overall Geologic H_2 targets for cost and emissions. The applicant should clearly identify the boundaries of their technology and provide a preliminary techno-economic assessment (TEA) and Life Cycle Assessment (LCA) in their Full Application. In their analysis or justification, applicants must show which current or conventional technologies can be directly implemented (known costs), as well as which novel technologies need to be developed (unknown costs).

3. Technical Categories

ARPA-E has identified three technical categories for this ET. Technical Category 1 deals with technologies in subsurface engineering, including ways to contain, concentrate, and economically transport hydrogen to the well-head. Category 2 is centered around the technologies needed to manage the production of hydrogen through monitoring, and Category 3 is centered around understanding and managing environmental risks associated with geologic hydrogen production. Applications must address Category 1 and are also encouraged to address Category 2 and Category 3 as complementary categories to Category 1.

A. Category 1 – Economic Extraction and Subsurface Engineering

Category 1 is focused on developing ways to effectively extract and manage hydrogen production. Applications to this category should focus on developing innovative ways to support

[87] Inflation Reduction Act of 2022

hydrogen reservoir management, including hydrogen containment, production, and extraction/transport to the surface.

Stimulating hydrogen generation from mineral deposits is very different from the production of hydrocarbons or geothermal resources. How to manage subsurface generation, containment, and extraction will require the development of new technologies—the priorities of which are so far undefined. Consequently, there is an identified need for engineering solutions that enable geologic hydrogen to be a viable and impactful energy resource.

Obtaining a high enough pressure of hydrogen at the well-head may be a critical factor governing the economics of stimulated geologic hydrogen if gas separations are required on the surface. Depending on the rate of hydrogen production, the extraction of hydrogen to the surface may not be straightforward. For example, steam could be one of the proposed stimulation methods and could ideally act as a hydrogen carrier. However, gaseous hydrogen solubility in water is very low, even at the high pressures and elevated temperatures found in the subsurface (<1 mol H_2/kg H_2O at pressures >1000 atm).[88] This solubility is further decreased by the addition of brines or salts, which would be in waste streams or leached during the pumping process. As an example, it would require >1 tonne of water for every kilogram of hydrogen, making it an unattractive transport modality.[89] Pumped-water transport would most likely only be economical in an enhanced geothermal operation where the pumped hot water or steam is already used to generate electricity and the hydrogen can be captured as an additional product. Thus, depending on the rates of stimulation, it may be necessary to concentrate and purify the hydrogen before the well-head, which can then be extracted on-demand when it is needed for energy.

Concentration of hydrogen may involve the identification, engineering, and/or creation of new geologic reservoirs to work with stimulated hydrogen generation. Several known geologic features are currently being explored for geologic hydrogen storage, but stimulated geologic hydrogen ideally would be agnostic to the existence of geologic features. This may be in the form of creating artificial subsurface reservoirs, like those currently deployed for pumped hydroelectric storage,[90] with engineered channels to control the flow of stimulated hydrogen. In addition, these efforts are critical to the mitigation of hydrogen or other GHGs produced from leaking into the atmosphere, as discussed in Category 3.1. In addition, it is possible that there can be some synergy with H_2 stimulation and CO_2 sequestration in ultramafic rocks and may aid in releasing reactive Fe(II) species.[91] However, mineralization of CO_2 may create

[88] Z. Zhu, Y. Cao, Z. Zheng, D. Chen, An Accurate Model for Estimating H2 Solubility in Pure Water and Aqueous NaCl Solutions. *Energies*. **15**, 5021 (2022).
[89] F. Osselin, C. Soulaine, C. Fauguerolles, E. C. Gaucher, B. Scaillet, M. Pichavant, Orange hydrogen is the new green. *Nat. Geosci.* **15**, 765–769 (2022).
[90] Quidnetenergy.com
[91] P. B. Kelemen, J. Matter, E. E. Streit, J. F. Rudge, W. B. Curry, J. Blusztajn, Rates and Mechanisms of Mineral Carbonation in Peridotite: Natural Processes and Recipes for Enhanced, in situ CO ₂ Capture and Storage. *Annu. Rev. Earth Planet. Sci.* **39**, 545–576 (2011).

geologic barriers to hydrogen diffusion, and the interaction between to-be mineralized CO_2 and hydrogen in the reservoir area can be significant.

Increasing the purity of the hydrogen at the well-head may require the development of down-hole separation systems where the hydrogen is separated from any other gaseous species (geology dependent, *e.g.*, CO_2, CH_4, N_2, H_2S, *etc.*). This can be in the form of a down-hole membrane system that accepts hydrogen as a permeate gas and rejects the other retentate gases into a separate reservoir (to not dilute the stimulated hydrogen further). Other methods which can economically extract the stimulated hydrogen with high enough purity and pressure would be of interest, including any chemical or material methods which can bind and release hydrogen.

B. Category 2 – Modeling and Characterization

Category 2 is focused on methods to monitor stimulated hydrogen production and inform reservoir management through the use of innovative modeling and characterization approaches. Applications focused on the preliminary identification of target reservoirs, characterization of ultramafic rocks or other formations of interest, geophysics-informed modeling and ongoing monitoring methods to manage risk assessment or inform management decisions are of particular interest for this category.

The subsurface dynamics of hydrogen are poorly understood. In addition, existing technologies and methods for characterizing the subsurface were originated in the oil and gas sector, where the needs are very different than stimulated H_2 generation. Oil and gas characterization and modeling methods are focused on interpreting fluid flow (*e.g.*, hydrocarbons, brine) in porous rocks (*e.g.*, sandstones, shales).[92] The subsurface generation mechanism of hydrogen is typically a mineralogical reaction, likely within crystalline rock, in which iron bearing minerals react with water to create gaseous phase hydrogen.[93] These processes are most observable in extreme environments, such as tectonic subduction zones, but are still being investigated.[94] The nature of ultramafic rocks is very different from that of porous clastic rocks, necessitating new approaches to characterization and modeling. Serpentinization (or an alternative hydrogen-producing geochemical reaction) necessitates a focus on different physiochemical properties, such as total iron content, Fe(II)/Fe(III) ratio, and specific surface area. Methods to characterize and map these properties for hydrogen producing reservoir management and methods to monitor and predict production are needed to make stimulated geologic hydrogen a viable and responsibly exploited energy source. In addition to informing subsurface engineering efforts aimed at producing hydrogen, monitoring and predicting the side effects (*e.g.*, hydrogen leakage, subsurface contamination, volume expansion, development of

[92] https://wiki.aapg.org/Overview_of_routine_core_analysis

[93] F. Osselin, C. Soulaine, C. Fauguerolles, E. C. Gaucher, B. Scaillet, M. Pichavant, Orange hydrogen is the new green. *Nat. Geosci.* **15**, 765–769 (2022).

[94] Worman, S. L., Pratson, L. F., Karson, J. A., and Schlesinger, W. H. (2020). Abiotic hydrogen (H2) sources and sinks near the Mid-Ocean Ridge (MOR) with implications for the subseafloor biosphere. PNAS 117, 13283–13293. doi:10.1073/pnas.2002619117x

geomechanical stress and seismicity) of the processes used to stimulate hydrogen production are also necessary to help ensure the success of this effort.

C. Category 3 – Risk Management

The nascent nature of geologic hydrogen leads to potential risks, which may require new technological development for mitigation and monitoring. Some identified risks stem from the geophysical changes that occur, while others may be from unintended releases of materials/hydrogen through leaks caused by physical and chemical reactions.

1. Category 3.1 – Leakage/Greenhouse Gas Effects

This sub-category seeks to fund research associated with understanding and developing mitigation strategies to prevent the unintended release of hydrogen to the atmosphere.

Hydrogen is a GHG and its uncontrolled release into the atmosphere is a critical concern.[95] Hydrogen's small size, coupled with the natural stress areas in geologic structures, makes it such that leakage is impossible to contain completely. However, as the amount of hydrogen leakage is driven by the pressure of subsurface hydrogen, monitoring and controlling it will be critical to acceptable environmental and economic performance. This concentration and pressure of hydrogen in the subsurface needs to be economic for extraction and further purification/use, but also cannot be so large that a high amount of leakage is found at the surface. Mitigating the release of stimulated geologic hydrogen or other natural accumulations of hydrogen into the atmosphere requires low leakage containment reservoirs (previously discussed in **Cat. 1**) and/or bio-remediation efforts for microbial consumption of any leaking hydrogen. The mitigation of hydrogen leakage may also require development of sensitive downhole sensors.

2. Category 3.2 – Subsurface Contamination

This sub-category is focused on understanding, preventing, and mitigating the threat of subsurface contamination resulting from stimulated hydrogen production. Applications should focus on subsurface contamination issues specific to the production of stimulated hydrogen through serpentinization of ultramafic rocks or proposed in complementary ET G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes.

The serpentinization and flushing of the subsurface with water (or other fluids) has the potential to leech out toxic metals or radioactive materials previously mineralized within a target formation.[96] If pumped water is used as a partial carrier of hydrogen gas, sensing technologies are needed to detect low concentrations of contaminants. If the pumped fluid is

[95] Environmental Defense Fund, 2022, (STUDY: Emissions of Hydrogen Could Undermine Its Climate Benefits). https://www.edf.org/media/study-emissions-hydrogen-could-undermine-its-climate-benefits-warming-effects-are-two-six

[96] Environmental Protection Agency, (Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)). https://www.epa.gov/radiation/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm

recycled back into the ground, interference with aquifers will need to be closely monitored to ensure that there is no contamination. In contrast, if stimulation uses an alternative mechanism that does not involve pumping water to the surface, the containment technology must prevent the migration of contaminants to aquifers or other sources which can lead to the surface. It may also be possible for toxic metals to be re-mineralized with CO_2 in areas that are not being stimulated.

3. Category 3.3 – Seismicity

This sub-category is focused on understanding, preventing, and mitigating the risk associated with volume expansion and associated seismicity resulting from enhanced serpentinization or other proposed mechanisms for stimulated hydrogen, as proposed in ET G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes.

Research focused on this subcategory should develop understanding of this risk and, where possible, propose and develop risk mitigation approaches.

Current literature reports that the serpentinization reaction can cause a volume expansion in the oxidized state by as much as 50%.[97,98] Thus, it is necessary for both safety (induced seismicity) but also for the well-controlled production of hydrogen to continuously monitor the volume changes associated with any stimulated reaction. This can be partially mitigated at the laboratory-scale by determining the conditions at which excess strain is generated within ore bodies. In addition, new methods and technologies need to be developed to predict volumetric expansion and associated risks. These advances may come in the form of new sensors (such as optimized distributed fiber optic sensing) that can measure the strain tensor or modeling efforts to predict volume expansion in advance of stimulated hydrogen production efforts. The development of any technology addressing this should be highly correlated with efforts that seek to model the stimulation process.

4. Category 3.4 – Biological Effects

This sub-category is focused on understanding, preventing, and mitigating the risks posed to the microbiome, and near surface ecology more generally, associated with enriched or depleted hydrogen concentrations.

Hydrogen is an electron donor for subsurface bacteria and archaea, henceforth called microorganisms.[99] Thus, elevated hydrogen concentrations, through artificial stimulation, can promote the growth of these microbial communities, which can result in adverse effects on gas injectivity and extraction, reduction in hydrogen volume, and corrosion of metal

[97] E.B. Alexander, J. DuShey, Topographic and soil differences from peridotite to serpentinite, Geomorphology, 135(3–4), 2011, 271-276.
[98] Malvoisin et al., Control of serpentinisation rate by reaction-induced cracking. Earth and Planetary Science Letters, 476, 2017, 143–152.
[99] N. Dopffel, B.A. An-Stepec, J.R. de Rezende, D.Z. Sousa and A. Koerdt, Editorial: Microbiology of underground hydrogen storage, (2023).

infrastructure.[100] Additionally, the supply of hydrogen via natural serpentinization can lead to the growth of previously absent microbial communities and lead to adverse, unintended ecological effects.[101,102,103] Consequently, new research is needed to fully understand and determine the relation of these microbial communities to subsurface hydrogen dynamics with a focus on minimizing the ecological and microbial impacts from stimulated hydrogen production.

4. Technical Performance Targets

Under the Geologic H_2 effort, ARPA-E intends to support the development of technologies that can lead to future hydrogen production safely and responsibly at lower cost and GHG emissions when compared to current state of the art (*e.g.*, hydrogen produced from SMR, SMR with sequestration, electrolysis). Proposed methods and technologies are required to meet the overall Geologic H_2 targets (**see items Pa-Pe below**).

In addition to the overall Geologic H_2 targets (*i.e.*, those targets applicable to both ET G and ET H), proposed methods and technologies will also be required to meet category-specific targets:

Geologic H_2 Effort

The proposed model, method, or technology must be able to do one or more of the following:

Pa. Produce H_2 with a cost at the well-head of *$1/kg H_2.*

Pb. Produce H_2 with GHG/kg H_2 of *<1 kg CO_2e/kg H_2.*

Pc. Produce H_2 with a purity of *>20% at the well-head (note – alternates can be proposed if an easy-to-separate sweeping gas is employed and justified in the Application).*

Pd. Enable H_2 deposit exploitation with a potential of *>10 Mt H_2.*

Pe. Enable H_2 deposit production of *>1 million m^3 H_2.*

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[100] E. M. Thaysen, S. McMahon, G. J. Strobel, I. B. Butler, B. T. Ngwenya, N. Heinemann, M. Wilkinson, A. Hassanpouryouzband, C. I. McDermott, K. Edlmann, Estimating microbial growth and hydrogen consumption in hydrogen storage in porous media. *Renew. Sustain. Energy Rev.* **151**, 111481 (2021).

[101] D. S. Kelley, J. A. Karson, G. L. Früh-Green, D. R. Yoerger, T. M. Shank, D. A. Butterfield, J. M. Hayes, M. O. Schrenk, E. J. Olson, G. Proskurowski, M. Jakuba, A. Bradley, B. Larson, K. Ludwig, D. Glickson, K. Buckman, A. S. Bradley, W. J. Brazelton, K. Roe, M. J. Elend, A. Delacour, S. M. Bernasconi, M. D. Lilley, J. A. Baross, R. E. Summons, S. P. Sylva, A Serpentinite-Hosted Ecosystem: The Lost City Hydrothermal Field. *Science*. **307**, 1428–1434 (2005).

[102] W. J. Brazelton, M. O. Schrenk, D. S. Kelley, J. A. Baross, Methane- and Sulfur-Metabolizing Microbial Communities Dominate the Lost City Hydrothermal Field Ecosystem. *Appl. Environ. Microbiol.* **72**, 6257–6270 (2006).

[103] M. O. Schrenk, W. J. Brazelton, S. Q. Lang, Serpentinization, Carbon, and Deep Life. *Rev. Mineral. Geochem.* **75**, 575–606 (2013).

ET H Category 1. Economic Extraction and Subsurface Engineering

The proposed method or technology must be able to do one or more of the following:

1a. Experimentally show the potential to transport H_2 to the well-head with a purity of *>20% by volume* (or at a justified concentration that is economical for conventional gas separation methods).

1b. Enable the subsurface enhancement of H_2 concentration from natural accumulations up to *66% H_2 at ~10 atm* (based on proposed geologic hydrogen storage targets).[104]

1c. Experimentally show sustained and controlled production from target stimulation method with a *loss of output <25% over 1 month* (equivalent to hypothetical production loss of ~3 months of unconventional natural gas production).[105]

ET H Category 2. Modeling/Characterization

The proposed model, method, or technology must be able to do one or more of the following:

2a. Increase the success of finding enhanced serpentinization candidate formations.

2b. Decrease field work for delineating enhanced serpentinization candidate formations by *10× (e.g., 10× reduction in time, labor, cost, or other relevant parameter as interpreted by the applicant).*

2c. Increase the success of finding other H_2 producing stimulation candidate formations that do not proceed through serpentinization.

2d. Decrease field work for delineating other target H_2 producing stimulation candidate formations *comparable to **3b.***

2e. Experimentally show ways to accurately characterize pore spaces of ultramafic rocks, such as the quantification of porosity and specific surface area *(i.e., porosity<8%).*

2f. Experimentally show ways to accurately measure matrix permeability of ultramafic rocks *(i.e., $<10^{-15}$ m^2).*

2g. Experimentally show ways to accurately quantify Fe(II), Fe(II)/Fe(III) ratio, and total Fe of target candidate formations.

[104] R.K. Ahluwali, D.D. Papadias, J-K. Peng, H.S. Roh, System Level Analysis on Hydrogen Storage Options, U.S. DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting. Project ID: ST001, (2019).

[105] https://geology.com/royalty/production-decline.shtml

ET H Category 3. Risk Management

The proposed model, method, or technology must be able to do one or more of the following:

3a. Predict volume expansion for enhanced H_2 producing mineralogical processes based on stimulation methods proposed in ET G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes (enhanced serpentinization of ultramafic rocks or *other* proposed method).

3b. Model induced seismicity associated with H_2 stimulation methods proposed in ET G: Production of Geologic Hydrogen Through Stimulated Mineralogical Processes (enhanced serpentinization of ultramafic rocks or other proposed method).

3c. Develop a list of critical ecological indicators (*i.e.*, microbiomes, flora, fauna) and quantify how each of them is impacted from hydrogen leakage and depletion in situ and at surface environments. Develop methods for determining the impact range of hydrogen leakage, monitoring the ecological indicators, and mitigating biotic effects on hydrogen yield and leakage.

3d. Investigate ways to mitigate subsurface contamination associated with methods proposed in **Cat. 1** or **2.1** (enhanced serpentinization of ultramafic rocks or other proposed method).

5. Data Rights and Sharing

Awardees under this ET will be strongly encouraged to share data with one or more select ARPA-E awardees who will use the data as inputs to generate publicly available models or tools that can be used to generate outputs such as life cycle analysis that will facilitate commercial acceptance of the technologies in this ET. Shared data may include, but is not limited to, hydrogen concentration, purification, containment, and extraction (including any input data for technoeconomic and life-cycle analyses, such as efficiency, energy, kinetics, etc.).

An awardee that receives data from another awardee will be required to treat any data provided to them as confidential information unless this requirement is altered by written agreement between them and the awardee that provided the data. The awardee receiving data will be required to treat all data generated under their award as trade secret-like for 10 years subject to a mutually agreed upon list of data that may be publicly released at any time. Such a publicly releasable list will not include data that is specifically identifiable with an awardee that provided data. Data provided by one awardee to another will not be shared by the awardee receiving the data with any other awardee. Similarly, an awardee that receives data from another awardee will not share with any other awardee data they generate that is related to the awardee that provided the data.

6. Content and Form of Full Applications

The content and form of Applicants' Technical Volumes shall follow the instructions and be consistent with the template titled Technical Volume: Topic H. All other instructions set forth at FOA Section IV.C remain unchanged.

Templates for preparing Full Applications under this Exploratory Topic may be found on ARPA-E Exchange at https://arpa-e-foa.energy.gov/.

XVIII. Appendix I: RESERVED

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XIX. Appendix J: RESERVED

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XX. Appendix K: RESERVED

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XXI. Appendix L: Plant Hyperaccumulators TO MIne Nickel-Enriched Soils (PHYTOMINES)

Special Program Announcement for
Exploratory Topics (DE-FOA-0002785)
Plant HYperaccumulators TO MIne Nickel-Enriched Soils (PHYTOMINES)

Topic Issue Date	March 21, 2024
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5 PM ET, April 26, 2024
Submission Deadline for Full Applications	9:30 AM ET, May 7, 2024
Submission Deadline for Replies to Reviewer Comments:	5:00 PM ET, June 12, 2024
Expected Date for Selection Notifications	July 2024
Anticipated Date of Awards	October 2024
Total Amount to be Awarded	Approximately $10,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between approximately $1,000,000–$2,500,000.
Maximum Period of Performance	36 months

1. Introduction

This announcement describes the exploratory research effort Plant HYperaccumulators TO MIne Nickel-Enriched Soils (PHYTOMINES). The purpose of this announcement is to (1) evaluate the feasibility of systems that use plants to extract nickel from soils, and (2) encourage partnerships between farmers, agronomists, plant scientists, microbiologists, engineers, data scientists, soil scientists, battery manufacturers, and those working in the mining and steel industries.

2. Topic Description

ARPA-E is interested in funding research projects that investigate the feasibility of cost-competitive and low carbon-footprint extraction of nickel by terrestrial plants. The nickel-rich bio-ore derived from such plants could establish a competitive domestic supply chain to supplement conventional mining methods and reduce nickel imports. The targeted outcomes of this topic are:

i. The development of phytomining technologies that optimize the biotic systems which regulate the availability and uptake of nickel by hyperaccumulator (HA) plants.[106]

[106] Nicoletta Rascio and Flavia Navari-Izzo, "Heavy Metal Hyperaccumulating Plants: How and Why Do They Do It? And What Makes Them so Interesting?," *Plant Science* 180, no. 2 (February 2011): 169–81, https://doi.org/10.1016/j.plantsci.2010.08.016.

Technologies could be interventions in the soil or plant microbiome or the development of plant traits that enable the accumulation of nickel at an enhanced rate. We envision these projects as early-stage proof-of-concepts likely to take place in closed or open-air laboratories, greenhouses, or confined fields where light, humidity, and temperature regimes can be fully programmed. Open field trials are outside the scope of this FOA.

ii. Understanding the interrelationships of the geologic, ecological and economic factors that affect the potential of phytomining to complement traditional mining as a source of nickel and other critical materials for energy listed in the DOE's 2023 Critical Materials Assessment (CMA).[107] Possible projects include mapping HA species of interest, scaling phytomining opportunities, and technoeconomic and lifecycle analyses (TEAs and LCAs) of phytomining projects.

3. Background

As the United States expands its investment in clean energy technology, the demand for clean energy minerals from viable sources will increase. Among the critical materials named by the DOE CMA, nickel serves as an ideal target to validate the viability of phytomining in the U.S. due to the large number of documented nickel HA plants globally (more than 500 species).[108] Nickel is used in the cathodes of lithium-ion batteries present in electric vehicles, consumer electronics, stationary storage, stainless steel, metallurgy, coatings, electroplating, and other alloys. Nickel is crucial to global clean energy technology supply chains and future demand is expected to grow considerably due to nickel's use in batteries for electric vehicles and stationary storage and for solid oxide electrolyzers and fuel cells.[109,110] The DOE CMA found the supply risk for nickel is moderate in the short term and high in the long term, given the challenges of matching rapid demand increases, the presence of some sensitive countries among the list of global suppliers, and the reliance of the U.S. market on imports to meet domestic demand.[111] At present, nickel is only mined in the U.S. at Eagle Mine in Champion, Michigan.

[107] https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals.
[108] Roger D. Reeves, Alan J. Backer, Tanguy Jaffré, Peter D. Erskine, Guillaume Echevarria, and Antony van der Ent, "A global database for plants that hyperaccumulate metal and metalloid trace elements", *New Phytologist* 218:407–411 (2018), https://doi.org/10.1111/nph.14907.
[109] US DOE, "2023 Critical Materials Assessment," 2023.
[110] IEA, "The Role of Critical Minerals in Clean Energy Transitions," 2022.
[111] US DOE, "2023 Critical Materials Assessment."

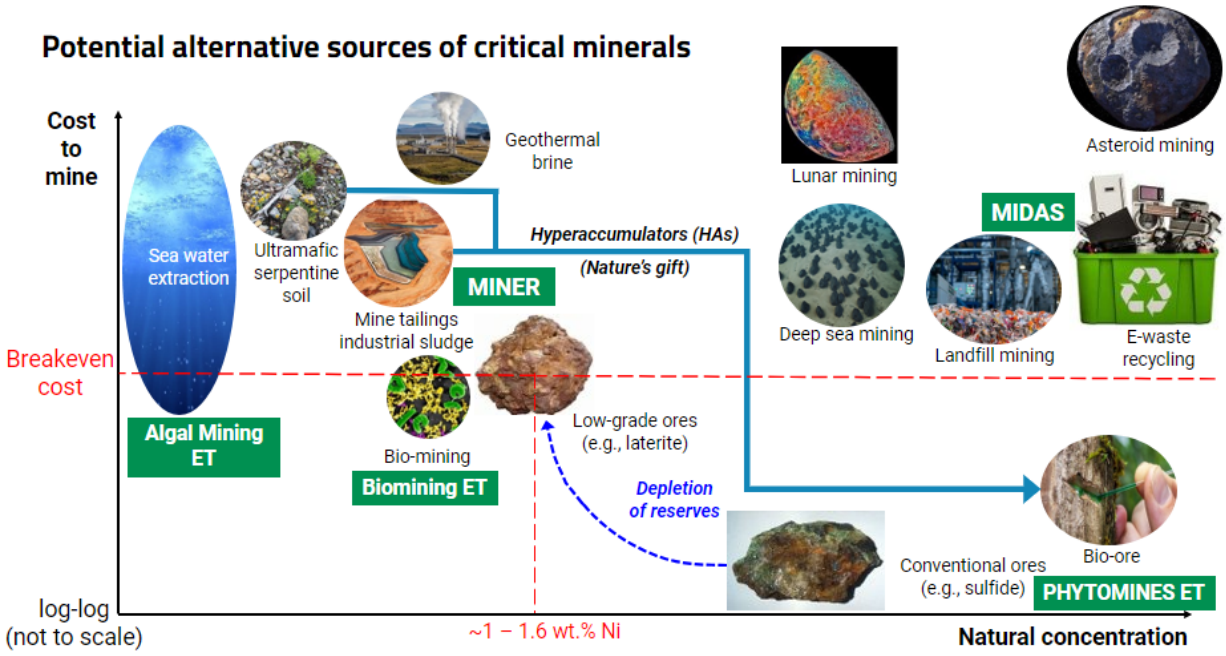

Figure 1. Alternative sources of critical minerals and ARPA-E programs to develop these sources.

Traditionally, agriculture has been deployed to produce food, fuel, or fiber. However, plants also accumulate minerals from the soils in which they grow. The ability of plants to accumulate metals is used currently to detoxify soils and water in a process known as phytoremediation.[112] Phytoremediation, however, has not focused on the deployment of plants to accumulate and collect minerals for downstream use—a possibility that is described as 'phytomining'.[113] ARPA-E seeks applications for extracting dilute terrestrial nickel in soils using phytomining which are sub-economic for conventional mining (Figure 1).[114]

[112] Sumira Jan and Javid Ahmad Parray, "Heavy Metal Uptake in Plants," in *Approaches to Heavy Metal Tolerance in Plants*, by Sumira Jan and Javid Ahmad Parray (Singapore: Springer Singapore, 2016), 1–18, https://doi.org/10.1007/978-981-10-1693-6_1.

[113] Rufus Chaney, J. Scott Angle, C. Leigh Broadhurst, Carinne Peters, Ryan Tappero, and Donald Sparks, "Improved Understanding of Hyperaccumulation Yields: Commercial Phytoextraction and Phytomining Technologies," *Journal of Environmental Quality* 36: 1429-1443 (2007), doi.org/10.2134/jeq2006.0514.

[114] Antony Van Der Ent et al., eds., *Agromining: Farming for Metals: Extracting Unconventional Resources Using Plants*, Mineral Resource Reviews (Cham: Springer International Publishing, 2021), https://doi.org/10.1007/978-3-030-58904-2.

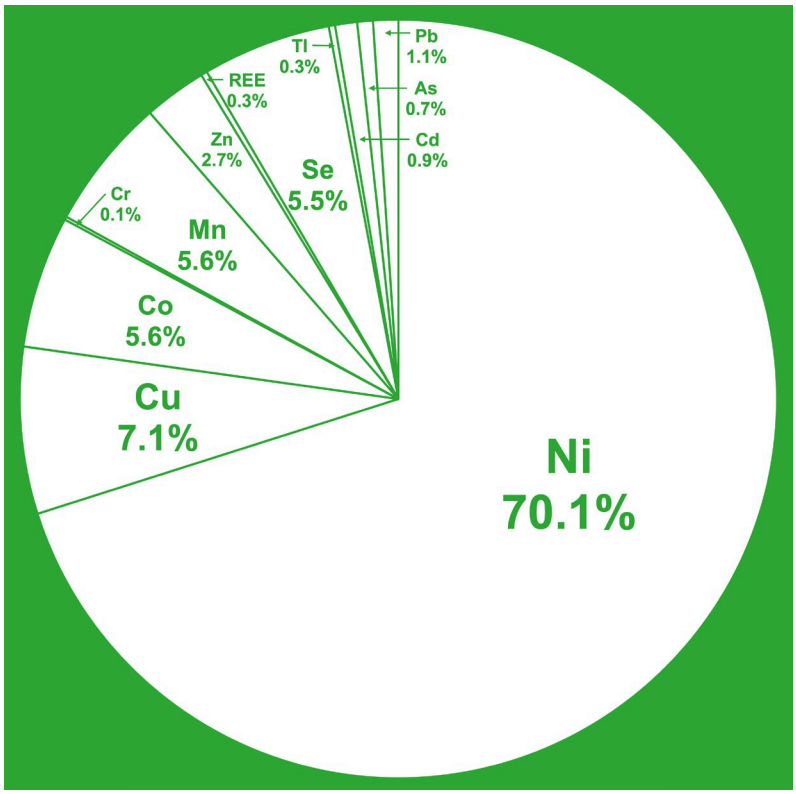

Figure 2. Most known hyperaccumulators accumulate nickel, but plants that hyperaccumulate other critical materials have also been identified.[115]

As shown in Figure 2, over 500 species of plants have been documented to 'hyperaccumulate' nickel, which is generally defined as accumulating greater than 1 milligram of nickel per gram of total dry plant biomass (mg Ni/gdpb). Plants such as *Berkheya coddii* are reported to accumulate more than 30 mg Ni/gdpb in dry leaves.[116] Initial experiments to harvest nickel at small scale from HA plants have been conducted in Asia.[117] In Europe, several companies seek to produce and market nickel-rich bio-ore[118]. In the U.S., phytomining is not currently pursued commercially.[119]

[115] A. van der Ent, ARPA-E Workshop, 2023.

[116] Marie Rue, Adrian L D Paul, Guillaume Echevarria, Antony van der Ent, Marie-Odile Simonnot, and Jean Louis Morel "Uptake, translocation and accumulation of nickel and cobalt in *Berkheya coddii*, a 'metal crop' from South Africa" *Metallomics*, 12(8): 1278–1289 (2020), https://doi.org/10.1039/d0mt00099j.

[117] Philip Nkrumah, Romane Tisserand, Rufus L. Chaney, Alan Baker, Jean-Louis Morel, Romain Goudon, Peter Erskine, Guillaume Echevarria, and Antony van der Ent, "The first tropical 'metal farm': Some perspectives from field and pot experiments," *Journal of Geochemical Exploration* 198: 114-122 (2019), https://doi.org/10.1016/j.gexplo.2018.12.003.

[118] "Bani, A. et al. (2021). Element Case Studies in the Temperate/Mediterranean Regions of Europe: Nickel. In: van der Ent, A., Baker, A.J., Echevarria, G., Simonnot, MO., Morel, J.L. (eds) *Agromining: Farming for Metals. Mineral Resource Reviews*. Springer, Cham. https://doi.org/10.1007/978-3-030-58904-2_16.

[119] Philip Nti Nkrumah et al., "Current Status and Challenges in Developing Nickel Phytomining: An Agronomic Perspective," *Plant and Soil* 406, no. 1–2 (September 2016): 55–69, https://doi.org/10.1007/s11104-016-2859-4.

This Exploratory Topic supports the technological development of phytomining in the U.S. that could complement current and future domestic sources of nickel and catalyze phytomining for critical minerals beyond nickel.[120] ARPA-E seeks to de-risk future investments in the improvement of phytomining systems technologies, to optimize nickel accumulation rates in plants that could grow in nickel-rich soils, and to improve awareness of phytomining's potential utility in underutilized and nonagricultural lands.

Both the concentration and bioavailability (or phytoavailability) of nickel within soils are key drivers of the productivity and economic viability of phytomining.[121]Between these two factors, nickel's bioavailability is variable and governed by the combined outcomes of natural biotic systems.[122] At present, knowledge of those systems is insufficient to optimize their management. Activity and composition of rhizobial communities, including nematodes, mycorrhizal fungi, and the microbiome, have been shown to affect the availability and uptake of metals of interest in harvestable plants.[123] Endophyte and viral activity in above-ground plant tissues can alter hyperaccumulation activity. Plant traits, such as root or gene expression phenotypes, and plant exudates interact and alter the system.[124] ARPA-E seeks to reduce the scientific uncertainty associated with the technologies used to optimize biotic systems that regulate nickel availability to HA plants. Such understanding and control of biological systems would potentially improve future phytomining economics such that they are competitive with traditional mining.

4. Technical Areas of Interest

The goal of this topic is to support the investigation of nickel phytomining to complement existing U.S. mining of nickel ore. To achieve this, ARPA-E seeks to fund projects in the following Technical Area:

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[120] A. Joseph Pollard and Alan J.M. Baker, "Quantitative Genetics of Zinc Hyperaccumulation in *Thlaspi caerulescens*," *New Phytologist* 132, no. 1 (January 1996): 113–18, https://doi.org/10.1111/j.1469-8137.1996.tb04515.x; V Bert et al., "Genetic Basis of Cd Tolerance and Hyperaccumulation in *Arabidopsis halleri*," n.d.; A. G. L. Assunção et al., "Elevated Expression of Metal Transporter Genes in Three Accessions of the Metal Hyperaccumulator *Thlaspi Caerulescens*: Zinc Transporters of *Thlaspi Caerulescens*," *Plant, Cell & Environment* 24, no. 2 (February 2001): 217–26, https://doi.org/10.1111/j.1365-3040.2001.00666.x.

[121] Petra Susan Kidd et al., "Developing Sustainable Agromining Systems in Agricultural Ultramafic Soils for Nickel Recovery," *Frontiers in Environmental Science* 6 (June 8, 2018): 44, https://doi.org/10.3389/fenvs.2018.00044; Yin-M Li et al., "Development of a Technology for Commercial Phytoextraction of Nickel: Economic and Technical Considerations," n.d.

[122] Adrian L. D Paul and Rufus L. Chaney, "Influence of Subsoil and Soil Volume on the Accumulation of Nickel by *Odontarrhena corsica* Grown on a Serpentine Soil," *International Journal of Phytoremediation*, November 28, 2023, 1–8, https://doi.org/10.1080/15226514.2023.2282055.

[123] Jianfeng Hua et al., "Interactions between Arbuscular Mycorrhizal Fungi and Fungivorous Nematodes on the Growth and Arsenic Uptake of Tobacco in Arsenic-Contaminated Soils," *Applied Soil Ecology* 84 (December 2014): 176–84, https://doi.org/10.1016/j.apsoil.2014.07.004.

[124] Michael W. Persans, Ken Nieman, and David E. Salt, "Functional Activity and Role of Cation-Efflux Family Members in Ni Hyperaccumulation in *Thlaspi goesingense*," *Proceedings of the National Academy of Sciences* 98, no. 17 (August 14, 2001): 9995–10000, https://doi.org/10.1073/pnas.171039798.

Technical Area 1 (TA1): Systemic approaches to improve the phytomining of nickel on U.S. marginal lands

ARPA-E is interested in supporting proof-of-concept studies that utilize biotic phytomining systems to recover nickel from soils. These biotic systems include HA plants, their associated microorganisms, and the soil environment.[125] ARPA-E would consider modifications in system components, including plants as well as biota within rhizobial or above-ground biomes, that lead to increased collection of nickel and enhance the economic viability of phytomining.[126] Projects should take a systems approach that investigates interactions between underlying soil geochemistry, HA plants, and the organisms that mediate interactions between the plant and soil environment.[127] Technologies of interest could include those that introduce additions or deletions to the activity and composition of rhizobial, endophyte, viral, or multicellular communities or that alter activity or traits in plant tissues that increase plant hyperaccumulation activity.[128] Technologies at the biome, organismal, or metagenomic scale will be considered. While research using model organisms/systems could be a complementary work stream, applications that focus on non-model organisms or have potential to translate to non-model organisms with strong commercialization pathways are encouraged. Aquatic hyperaccumulators in fresh water will be considered.

Applications should identify the molecular mechanism through which the phytomining system is expected to enhance plant hyperaccumulation of nickel. Further, applicants should indicate the mechanisms through which the phytomining system will alter the existing biota and soil geochemistry and the likely duration of that alteration. Applications should provide information on the prevalence of the environments in which the phytomining system is potentially applicable and the potential relevance of that system to nickel accumulation at commercial scale. While scalability is a critical factor to long-term commercial potential, risk management is an equally critical consideration. As such, from their initial design, applicants should consider the environmental impacts of the proposed phytomining system. The applicants should explain methods for containing the system to a geographic area of interest. Designing phytomining systems to be self-containing (e.g., self-regulating microbe accumulation or plant sterility) will be a key consideration to project funding decisions.

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[125] Paul and Chaney, "Influence of Subsoil and Soil Volume on the Accumulation of Nickel by *Odontarrhena corsica* Grown on a Serpentine Soil."

[126] Assunção et al., "Elevated Expression of Metal Transporter Genes in Three Accessions of the Metal Hyperaccumulator *Thlaspi caerulescens*"; Martina Becher et al., "Cross-Species Microarray Transcript Profiling Reveals High Constitutive Expression of Metal Homeostasis Genes in Shoots of the Zinc Hyperaccumulator *Arabidopsis halleri*: Transcript Profiling in Shoots of *A. halleri*," *The Plant Journal* 37, no. 2 (January 2004): 251–68, https://doi.org/10.1046/j.1365-313X.2003.01959.x.

[127] Aida Bani et al., "The Effect of Plant Density in Nickel-Phytomining Field Experiments with *Alyssum murale* in Albania," *Australian Journal of Botany* 63, no. 2 (2015): 72, https://doi.org/10.1071/BT14285.

[128] Jitendra Mishra, Rachna Singh, and Naveen K. Arora, "Alleviation of Heavy Metal Stress in Plants and Remediation of Soil by Rhizosphere Microorganisms," *Frontiers in Microbiology* 8 (September 6, 2017): 1706, https://doi.org/10.3389/fmicb.2017.01706.

Genetic modification is within the scope of this Technical Area. Should a new genetically modified material arise from the performance of an award, it must be reported in iEdison, the government-wide portal for reporting new inventions. iEdison allows for the reporting of biological materials that are going to be either patented by the awardee or not patented. If not patented, the new genetically modified material may be reported in iEdison as "Designated as Unpatented Biological Material or Research Tool." Awards made under TA1 will require that such new materials that the awardee does not intend to patent be so reported in iEdison, and will also require follow-on reporting on the utilization of such materials.

Applications should specifically address the present accumulation rate of nickel in the proposed plant-soil system, the targeted enhanced accumulation rate proposed, and the biological hypothesis through which the accumulation rate will be increased. Optionally, applicants can indicate the likely methodology or methodologies that will be used to extract nickel from biomass and the cost and greenhouse gas (GHG) emissions associated with these extraction processes; projects will be expected to not exceed and, ideally, reduce both cost and emissions versus current nickel mining technologies. Trials are expected to take place in highly controlled lab or greenhouse environments, where light, humidity, and temperature regimes can be programmed, and the characteristics of the soil system (either native or artificial) are fully defined. Applicants shall explain the relevance of laboratory metrics to nickel accumulation rates that would be observed in situ. ARPA-E seeks to fund multiple projects in TA1 where each project is between $1 million to $2.5 million and has a period of performance of no more than 36 months. To support TEA/LCA in TA2 in the standard version of this FOA (DE-FOA-0002784), TA1 teams may share information with such TA2 teams, such as cost information and process details.

5. Metrics and Technical Performance Criteria

Table 1. Description of primary metrics for Technical Area 1.

Technical Area 1 (TA1): Systems approaches to improve the phytomining of nickel on U.S. marginal lands	
Phytomining system development: hypothesis and description (must be included in the Application)	• Description of system initial conditions and the prevalence of the system in U.S. (ultra)mafic soils. • Molecular-level mechanism of action to enhance phytomining is proposed.

Target Effectiveness of phytomining system (must be verified by experimentation)	• Improved (experimental) phytomining system produces 200% of nickel yield of unimproved system and is greater than 30 mg Ni/gdpb. • ~~At lab or confined field scale of no less than 1,000 cubic feet of soil, phytomining system should accumulate more than 250 kg of nickel per hectare per year (kg Ni/hectare/year) in harvestable plant biomass.~~ • At the end of the proposed project, the improved phytomining system should accumulate more than 250 kg of nickel per hectare per year (kg Ni/hectare/year) in harvestable plant biomass in the lab or in a confined field at a sample scale that is no less than 250 square feet of soil at an appropriate depth for that plant's root system. In case of aquatic plants in a freshwater system, an equivalent scale testing environment is required. • Project also describes a technology pathway to accumulation of greater than 500 kg Ni/hectare/year.
Information from selected downstream processing (must be included in the Application)	• Description of likely methodology for extraction of nickel from the HA plant, including an estimate of GHG emissions associated with the extraction of 1,000 kg of nickel from plant biomass using the indicated methodology.

If responding to TA1, applicants are required to submit:

1. An initial discussion of the relevance and likely robustness of the proposed technology system to phytomining of nickel in diverse ecosystems.
2. A description of likely changes to the geographic range of the system that may result from changes introduced within the project.
3. Current accumulation rate of nickel in the proposed system, the targeted accumulation rate, and the biological hypothesis through which the accumulation rate will be increased.
4. Description of likely downstream processing methodologies to yield bio-ore and estimates of the TEA/LCA of the proposed bio-ore generation process.
5. Target nickel production cost and a plan to conduct TEA/LCA studies of the combined phytomining/bio-ore generation and selected downstream processing method.

6. Submissions Specifically Not of Interest

- Applications that envision field testing HA plant systems. Trials are expected to take place in highly controlled lab or greenhouse environments, where light, humidity, and temperature regimes can be fully programmed.
- To maintain focus on the soil-plant interface, projects that focus exclusively on modification of above-ground endophytes and their interactions with plants.
- Submissions aimed solely at growing and cultivating terrestrial plants, without consideration of extracting and refining metals from hyperaccumulated plant biomass.

- Submissions aimed solely at processing of hyperaccumulated plant biomass to extract and refine metals.
- Submissions that include species listed as Federal noxious weeds or invasive species by the U.S. Department of Agriculture.[129]
- Projects under Technical Area 1 that anticipate nickel extraction that will produce GHG emissions greater than the emissions associated with nickel mining technology (approximately 20 kg carbon dioxide equivalent (CO2e) per kg nickel).
- Submissions that clearly compete with existing land use for food and fuel crops
- Approaches that cannot be scaled up at a reasonable cost and time.

[129] Noxious weeds: www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/weedlist.pdf.
Invasive species: www.invasivespeciesinfo.gov/species-profile-list

XXII. Appendix M: H2SENSE

Special Program Announcement for
Exploratory Topics (DE-FOA-0002785)
H2SENSE

Topic Issue Date	April 25, 2024
Deadline for Questions to ARPA-E-CO@hq.doe.gov	5:00 PM ET, May 28, 2024
Submission Deadline for Full Applications	9:30 AM ET, June 7, 2024
Submission Deadline for Replies to Reviewer Comments:	5:00 PM ET, July 12, 2024
Expected Date for Selection Notifications	August 2024
Anticipated Date of Awards	November 2024
Total Amount to be Awarded	Approximately $20,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002784 and DE-FOA-0002785 for this Exploratory Topic.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between approximately $1,000,000–$3,000,000.
Maximum Period of Performance	36 Months

1. Introduction

Hydrogen (H_2) can be used as a chemical fuel to produce energy via combustion and as a reductant to produce electricity in fuel cells. The growth of the hydrogen economy, wherein hydrogen replaces fossil fuels in a variety of applications, is anticipated to play a crucial role in global decarbonization efforts as hydrogen does not directly produce greenhouse gas (GHG) emissions at its point of use. However, hydrogen is an indirect GHG because, through chemical reactions in the atmosphere, it can extend the lifetime of other GHGs. Therefore, the movement towards a low-carbon, hydrogen economy presents the need for a new class of atmospheric hydrogen sensing technologies. The goal of the H2SENSE Exploratory Topic is to support the development of innovative approaches for hydrogen gas emissions detection and quantification. The focus is on the full supply chain of hydrogen for energy systems from production to end use. Cost-effective, accurate measurements of hydrogen gas will facilitate detection and mitigation of direct emissions. New technologies to improve hydrogen emissions detection are needed to maximize the climate benefits of hydrogen production.

2. Topic Description

Under Exploratory Topic M, ARPA-E seeks to fund the development and validation of technologies that can detect the release of hydrogen from production, transportation, and storage infrastructure. Given the substantial anticipated increase in hydrogen use in the U.S., successful technologies developed under this new effort will allow for the expansion of hydrogen use without deleterious climate or economic impacts. This outcome supports ARPA-E's statutory goals under 42 U.S.C. § 16538(C) to (1) reduce imports, (2) improve efficiency, and

(3) reduce emissions by preserving hydrogen for domestic use and preventing its release into the atmosphere.

ARPA-E seeks Full Applications to develop technologies that can lead to hydrogen emissions detection at costs that will enable widespread deployment. Technologies of interest should comprise of fully integrated systems that incorporate sensors, data transmission, dispersion and quantification analyses, and any peripheral components and modeling necessary for operation and calibration. Hydrogen emissions detection systems may rely on a single or multiple sensors. Both active sensors and passive sensors are permitted. Active sensors are defined as those which involve the projection of energy (e.g., light or sound) into the environment and detect changes caused by the presence of hydrogen, whereas passive sensors monitor the environment without emitting energy into the monitored area.

3. Background

Hydrogen is expected to play a critical role in the decarbonization of industry and transportation. The current global production of hydrogen is roughly 100 million metric tonnes per year (Mt/yr), most of which is used for petroleum refining and ammonia production for fertilizer.[130] Future hydrogen production is projected to increase by a factor of 5 to 8 (between 470 Mt/yr[131] and 800 Mt/yr[132]) by 2050, as hydrogen use expands to include energy storage, long-distance transportation, and industrial processes. The hydrogen market is projected to grow to $1.4 trillion per year by 2050.[133] In the U.S. and globally, large investments have been made in hydrogen infrastructure and safety to support the growth of the future hydrogen economy. The 2021 Bipartisan Infrastructure Law allocated $8 billion to develop the Hydrogen Hub program. In 2023, seven Regional Clean Hydrogen Hubs (H2Hubs) were announced across the country to establish a network for clean hydrogen production, storage, delivery, and end use. The H2Hubs are expected to produce 3 Mt/yr H_2, roughly one third of the 2030 U.S. hydrogen production target.[134]

Hydrogen does not absorb infrared (IR) light and therefore does not act as a direct GHG in the atmosphere. However, hydrogen is considered an indirect GHG due to its ability to extend the lifetime of other GHGs. The majority (70-80%) of atmospheric hydrogen is removed via biological soil uptake. The remaining 20-30% is removed via tropospheric oxidation by hydroxyl

[130] IEA, *Global Hydrogen Review 2023*, (Paris: International Energy Agency, 2023).
[131] IEA, *Net zero roadmap: a global pathway to keep the 1.5 °C goal in reach*. (Paris: International Energy Agency, 2023).
[132] Energy Transitions Commission. *Making mission possible: delivering a net-zero economy*. (London: Energy Transitions Commission 2020).
[133] Deloitte, *Emerging green hydrogen market to set to help reshape global energy map by end of decade creating US $1.4 trillion market by 2050.* (2023).
[134] "Biden-Harris Administration Announces $7 Billion For America's Fist Clean Hydrogen Hubs, Driving Clean Manufacturing and Delivering New Economic Opportunities Nationwide," Department of Energy, October 13, 2023, https://www.energy.gov/articles/biden-harris-administration-announces-7-billion-americas-first-clean-hydrogen-hubs-driving/

radicals ($OH^{\bullet}$).[135] The same oxidation mechanism is the primary method of methane (CH_4) removal from the atmosphere. Since hydrogen reacts with hydroxyl radicals more quickly than methane, increases in atmospheric hydrogen concentrations may decrease hydroxyl radical concentrations available to react with methane, thereby extending the atmospheric lifetime of methane.[136,137] This is significant because methane is the second most-emitted GHG after carbon dioxide (CO_2) and has a 20-year global warming potential (GWP-20) of 83 ± 26 .[138] By comparison, the GWP-20 of hydrogen is 40 ± 24.[139] The atmospheric concentration of hydrogen has risen over the last century and is now 530 parts per billion (ppb).[140] In addition to hydrogen's traditional role as an energy carrier, geological hydrogen production offers the possibility of hydrogen serving as a primary energy source.[141] Given the projected growth of the hydrogen economy and potential near-term warming effects of atmospheric hydrogen,[142,143,144] detection and mitigation of hydrogen emissions is essential for ensuring the safe, efficient, and economic use of hydrogen in the future. To limit fugitive methane emissions, the Environmental Protection Agency requires a minimum detection threshold of 0.4 kilograms per hour (kg/hr) for continuous sensing technologies.[145] To limit commensurate warming from hydrogen emissions, ARPA-E is seeking technologies capable of a minimum detection threshold of 10 kg/hr across a 100 meters (m) x 100 m area for a cost of no more than $10,000. These

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[135] Ehhalt, D.H. and Rohrer F., "The Tropospheric Cycle of H_2: A Critical Review," *Tellus. Series B, Chemical and Physical Meteorology 61*, no. 3 (January 1, 2009): 500, https://doi.org/10.1111/j.1600-0889.2009.00416.x.

[136] Bertagni, M.B., Pacala, S.W., Paulot, F. *et al.* Risk of the hydrogen economy for atmospheric methane. *Nat Commun* **13**, 7706 (2022). https://doi.org/10.1038/s41467-022-35419-7

[137] Warwick, N., Griffiths, P., Keeble, J., Archibald, A., and Pyle, J. (2022). Atmospheric implications of increased hydrogen use. https://www.gov.uk/government/publications/atmospheric-implications-of-increased-hydrogen-use

[138] Forster, P., T. Storelvmo, K. Armour, W. Collins, J.-L. Dufresne, D. Frame, D.J. Lunt, T. Mauritsen, M.D. Palmer, M. Watanabe, M. Wild, and H. Zhang, 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054, doi: 10.1017/9781009157896.009.

[139] Hauglustaine, D., Paulot, F., Collins, W. *et al.* Climate benefit of a future hydrogen economy. *Commun Earth Environ* **3**, 295 (2022). https://doi.org/10.1038/s43247-022-00626-z

[140] Patterson J. D., Aydin, M., Crotwell, A.M., Petron G., Severinghaus J. P., &Saltzman, E. S. (2020). Atmospheric history of H_2 over the past century reconstructed from South Pole firn air. *Geophys. Res. Lett.*,47, e2020GL087787. https://doi.org/10.1029/2020GL0877878.

[141] Hand E., Hidden hydrogen. *Science*. **379**, 630–636 (2023).

[142] Derwent, R., Simmonds, P., O'doherty, S., Manning, A., Collins, W., and Stevenson, D. (2006). Global environmental impacts of the hydrogen economy. Int. J. Nucl. Hydrogen Prod. Appl. 1, 57–67. doi:10.1504/IJNHPA.2006.009869

[143] Derwent, R. G., Stevenson, D. S., Utembe, S. R., Jenkin, M. E., Khan, A. H., and Shallcross, D. E. (2020). Global modelling studies of hydrogen and its isotopomers using STOCHEM-CRI: Likely radiative forcing consequences of a future hydrogen economy. Int. J. Hydrogen Energy 45, 9211–9221. doi: 10.1016/j.ijhydene.2020.01.125

[144] Field, R. A., and Derwent, R. G. (2021). Global warming consequences of replacing natural gas with hydrogen in the domestic energy sectors of future low-carbon economies in the United Kingdom and the United States of America. *Int. J. Hydrogen Energy*, 46, 30190–30203. doi: 10.1016/j.ijhydene.2021.06.120

[145] EPA, 40 CFR Park 60, Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Reviews. 2023. https://www.epa.gov/system/files/documents/2023-12/eo12866_oil-and-gas-nsps-eg-climate-review-2060-av16-final-rule-20231130.pdf

performance targets, described in more detail below, will enable a systems-level approach to large-area monitoring of hydrogen emissions.

Improved large-area detection technologies may also facilitate prospecting for geologic hydrogen. Geologic hydrogen may play an important role in the hydrogen supply chain of the future, as geologic production is potentially cheaper and more abundant than other hydrogen production methods. However, as relatively few geologic hydrogen deposits have been identified in the U.S., better remote sensing of hydrogen emissions from the subsurface would facilitate the location of resource deposits.

Atmospheric hydrogen detection poses unique challenges compared to other gases, like methane, due to the distinct chemical and physical properties of hydrogen. Hydrogen is a linear, diatomic molecule with a single vibrational mode and very weak polarizability. In contrast, methane has a rich spectrum of vibrational modes, and the polar carbon-hydrogen bond is IR active. Many methods developed for atmospheric methane detection rely on IR activity. The lack of an IR stretch makes atmospheric hydrogen detection much more challenging than methane detection.

Nonetheless, many hydrogen detection methods have been developed.[146,147,148] Prior leak detection efforts have been focused on safety due to the flammable nature of hydrogen. A variety of safety codes and standards have been developed to detect and monitor leaks that pose a fire hazard for which the limit is typically greater than or equal to 4% by volume (40,000 parts per million by volume).[149] The detection of significantly lower concentration leaks (i.e., ppb level) that may have a climate impact without posing a safety hazard is much more difficult. Detection and quantification of hydrogen emissions at the ppb level requires the development of new hydrogen detection technologies that can survey larger areas. The Department of Transportation's Pipeline and Hazardous Materials Safety Administration is currently considering performance standards for advanced leak detection programs for gas pipelines and underground gas storage facilities, and whether hydrogen gas pipeline-specific provisions should be made.[150]

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[146] Chauhan, P.S. & Bhattacharya S. (2019). Hydrogen gas sensing methods, materials, and approach to achieve parts per billion level detection: A review. *Int. J. Hydrogen Energy,* 44 (47), 26076-26099, doi.org/10.1016/j.ijhydene.2019.08.052.

[147] Wang, L. & Song, J. (2024). Review—Recent Progress in the Design of Chemical Hydrogen Sensors. *J. Electrochem. Soc.*

[148] "Surveillance and Monitoring for Hydrogen Storage," Subsurface Hydrogen Assessment, Storage and Technology Acceleration, accessed April 18, 2024, https://edx.netl.doe.gov/sites/shasta/surveillance-and-monitoring-for-hydrogen-storage/

[149] Rivkin, C., Burgess, R., Buttner W. (2015). Hydrogen Technologies Safety Guide. *National Renewable Energy Laboratory.*

[150] Pipeline and Hazardous Materials Safety Administration (PHMSA), Department of Transportation. "Pipeline Safety: Gas Pipeline Leak Detection and Repair." *Federal Register* 88, No. 96 (May 18, 2023): 31926. https://www.govinfo.gov/content/pkg/FR-2023-05-18/pdf/2023-09918.pdf.

4. Technical Performance Targets

Applications must present a well-justified, technologically feasible concept capable of meeting ambitious performance criteria as follows:

1. Emissions Rate Estimation Accuracy: The system must accurately estimate a hydrogen leak rate of 10 kg/hr within a specified area of 100 m by 100 m. The accuracy error of the measurement must be less than or equal to 20%. This estimation should be completed within a 24-hour period.
2. Operational Conditions: The accuracy goal stated in Performance Target 1 must be achieved under all reasonable operational conditions, including but not limited to variations in atmospheric and environmental conditions, and in the presence of common contaminants that could be expected in the operational or surrounding measurement area.
3. Leak Detection Alarm: The system must be capable of detecting and alerting on a total hydrogen emission rate of 10 kg/hr within the conditions outlined in Performance Target 1. The detection mechanism should have a probability of detection at or above 90%, with a false positive rate of less than 1%.
4. Leak Localization: If a single leak is found to emit at a rate of 10 kg/hr or more, the system must provide a means to locate the leak source to within 10 m of its actual location. The methodology employed for leak localization may differ from the primary leak estimation method. There is no localization requirement for leaks emitting at rates less than 10 kg/hr.
5. Cost Constraints: The total cost for a single survey that fulfills the leak measurement criteria outlined in Performance Targets 1–4 must not exceed $10,000.

Additionally, applications are invited to meet one non-mandatory target described below:

- Low Leak Rate Detection: This optional target aims to enhance a system's sensitivity and precision capabilities. The system should aim to estimate a hydrogen leak rate as low as 1 kg/hr with an accuracy error less than or equal to 50% and at a 90% probability of detection with a false positive rate of less than 1%.

5. Submissions Specifically Not of Interest

Submissions that propose the following may be deemed non-responsive and may not be merit-reviewed:

- Technologies outside the specified technical parameters
- Technologies not scientifically distinct from pending applications to ARPA-E FOAs
- Basic research without application to the H2SENSE objectives
- Large-scale demonstration projects of existing technologies
- Incremental improvements to existing technologies
- Technologies not based on sound scientific principles

- Technologies that do not align with ARPA-E's statutory goals or are not potentially disruptive
- Funded activities supported elsewhere within the Department of Energy

6. Content and Form of Full Applications

The content and form of Applicants' Technical Volumes shall follow the instructions and be consistent with the template titled Technical Volume: Topic M. All other instructions set forth at FOA Section IV.C remain unchanged.

Templates for preparing Full Applications under this Exploratory Topic may be found on ARPA-E Exchange at https://arpa-e-foa.energy.gov/.