

**FINANCIAL ASSISTANCE  
FUNDING OPPORTUNITY ANNOUNCEMENT**



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

***SOLICITATION ON TOPICS INFORMING NEW PROGRAM AREAS  
SBIR/STTR***

Announcement Type: **Modification 08 09**  
Funding Opportunity No. DE-FOA-0001954  
CFDA Number 81.135

|                                   |   |
|-----------------------------------|---|
| <b>FOA Issue Date:</b>            | December 20, 2018   |
| <b>FOA Close Date:</b>            | Open continuously until otherwise amended.  |
| <b>Application Due Date:</b>      | See Targeted Topics Table for topic-specific application due dates.   |
| <b>Total Amount to Be Awarded</b> | Approximately <b>\$59.25 \$49.5</b> million, subject to the availability of appropriated funds to be shared between FOAs DE-FOA-0001953 and DE-FOA-0001954. See Targeted Topics Table for topic-specific information. |
| <b>Anticipated Awards</b>         | ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between \$100,000 and \$3.67-million. See Targeted Topics Table for topic-specific award amount requirements.                            |

- For eligibility criteria, see Section III.A – III.D 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.F.1 of the FOA.
- Applicants are responsible for meeting the submission deadline associated with each Targeted Topic. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the Targeted 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](mailto: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](mailto: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.

| <b>Mod. No.</b> | <b>Date</b> | <b>Description of Modifications</b>  |
|-----------------|-------------|--|
| 01              | 2/13/2019   | <ul style="list-style-type: none"> <li>Revised Full Application Deadlines for Topics A, B, &amp; C. See Table 1. Targeted Topics and Appendices A, B &amp; C.</li> <li>Inserted information regarding Renewal Awards. See Section II.B of the FOA.</li> </ul>  |
| 02              | 2/15/2019   | <ul style="list-style-type: none"> <li>Revised Full Application Deadlines for Topics A, B, &amp; C. See Table 1. Targeted Topics and Appendices A, B &amp; C.</li> </ul>   |
| 03              | 5/21/2019   | <ul style="list-style-type: none"> <li>Inserted new Targeted Topic. Topic F: <a href="#">High Value Methane Pyrolysis</a>. See Table 1. Targeted Topics, Appendix F and Total Amount to be awarded on Cover Page.</li> </ul>   |
| 04              | 7/12/2019   | <ul style="list-style-type: none"> <li>Updated FOA to include “Replies to Reviewer Comments”.</li> </ul>   |
| 05              | 8/7/2019    | <ul style="list-style-type: none"> <li>Inserted new Targeted Topic. Topic G: <a href="#">Supporting Entrepreneurial Energy Discoveries</a>. See Table 1. Targeted Topics, Appendix G and Total Amount to be awarded on Cover Page.</li> </ul>  |
| 06              | 9/17/2019   | <ul style="list-style-type: none"> <li>Inserted new Targeted Topic. Topic H: <a href="#">Establishing validation sites for field-level emissions quantification of agricultural bioenergy feedstock production</a>. See Table 1. Targeted Topics, Appendix H and Total Amount to be awarded on Cover Page.</li> <li>Extended FOA Close Date, see cover page of the FOA.</li> </ul> |
| 07              | 10/23/2019  | <ul style="list-style-type: none"> <li>Revised Submission Deadline for Replies to Reviewer Comments and Expected date for Notifications for Topic H. See Table 1. Targeted Topics and Appendix H.</li> </ul>   |
| 08              | 2/20/2020   | <ul style="list-style-type: none"> <li>Updated Section II.A Award Overview</li> <li>Inserted new Targeted Topic. Topic J: Biotechnologies to Ensure a Robust Supply of Critical Materials for Clean Energy. See Table 1. Targeted Topics, Appendix J and Total Amount to be awarded on Cover Page.</li> </ul>  |
| 09              | 4/2/2020    | <ul style="list-style-type: none"> <li>Inserted new Targeted Topic. Topic K Recycle Underutilized Solids to Energy (REUSE). See Table 1. Targeted Topics, Appendix I and Total Amount to be awarded on Cover Page.</li> <li>Inserted an additional Program Policy Factor in Section V.B.1</li> </ul>   |

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**TABLE 1. TARGETED TOPICS**

| Appendix | Targeted Topic Title  | Issue Date | Deadline for Questions to ARPA-E CO | Full Application Submission Deadline | Submission Deadline for Replies to Reviewer Comments | Total Amount to be Awarded (subject to the availability of funds) | Anticipated Awards | Max Period of Performance | Expected date for Notifications |
|----------|---|------------|-------------------------------------|--------------------------------------|--|---|--------------------|---------------------------|---------------------------------|
| A        | <a href="#">EXTREMELY DURABLE CONCRETES AND CEMENTITIOUS MATERIALS</a>  | 12/20/2018 | 5 PM ET, 2/8/2019                   | 9:30 AM ET, 2/26/2019                | N/A  | Approximately \$8M total  | 5-8 awards         | 24 months                 | May 2019                        |
| B        | <a href="#">LEVERAGING INNOVATIONS SUPPORTING NUCLEAR ENERGY</a>  | 12/20/2018 | 5 PM ET, 2/8/2019                   | 9:30 AM ET, 2/26/2019                | N/A  | Approximately \$8M total  | 3-5 awards         | 24 months                 | May 2019                        |
| C        | <a href="#">DOWNHOLE TOOLS TO ENABLE ENHANCED GEOTHERMAL SYSTEMS</a>  | 12/20/2018 | 5 PM ET, 2/8/2019                   | 9:30 AM ET, 2/26/2019                | N/A  | Approximately \$2M total  | 2-4 awards         | 24 months                 | May 2019                        |
| D        | <a href="#">&lt;RESERVED&gt;</a>  |            |                                     |                                      |  |   |                    |                           |                                 |
| E        | <a href="#">&lt;RESERVED&gt;</a>  |            |                                     |                                      |  |   |                    |                           |                                 |
| F        | <a href="#">HIGH VALUE METHANE PYROLYSIS</a>  | 5/21/2019  | 5 PM ET, 7/16/2019                  | 9:30 AM ET, 7/26/2019                | 5 PM ET, 9/4/2019                                    | Approximately \$5.5M total  | 3-5 awards         | 24 months                 | October 2019                    |
| G        | <a href="#">SUPPORTING ENTREPRENEURIAL ENERGY DISCOVERIES</a>   | 8/7/2019   | 5 PM ET, 9/27/2019                  | 9:30 AM ET, 10/8/2019                | None   | Approximately \$10M total   | 20-30 awards       | 24 months                 | December 2019                   |
| H        | <a href="#">Establishing validation sites for field-level emissions quantification of agricultural bioenergy feedstock production</a> | 9/19/2019  | 5 PM ET, 11/7/2019                  | 9:30 AM ET, 11/18/2019               | 5 PM ET, 12/11/2019                                  | Approximately \$10.0M total                                       | 3 awards           | 36 months                 | January 2020                    |
| I        | <a href="#">&lt;RESERVED&gt;</a>  |            |                                     |                                      |  |   |                    |                           |                                 |
| J        | <a href="#">Biotechnologies to Ensure a Robust Supply of Critical Materials for Clean Energy</a>                                      | 3/4/2020   | 5 PM ET, 4/27/2020                  | 9:30 AM ET, 5/7/2020                 | 5 PM ET, 6/22/2020                                   | Approximately \$5.0M total  | 5-10 awards        | 24 Months                 | August 2020                     |
| K        | <a href="#">Recycle Underutilized Solids to Energy</a>  | 4/2/2020   | 5 PM ET, 5/21/2020                  | 9:30 AM ET, 6/1/2020                 | 5 PM ET, 7/13/2020                                   | Approximately \$4.0M total  | 4-8 award          | 18 Months                 | August 2020                     |

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## REQUIRED DOCUMENTS CHECKLIST

Unless an exception or exceptions are described under a particular Targeted Topic, the following are applicable to all Targeted 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/<br>MANDATORY | FOA<br>SECTION |
|---------------------|--|------------------------|----------------|
| Full<br>Application | <ul style="list-style-type: none"> <li>• Each Applicant must submit a Technical Volume in Adobe PDF format by the stated deadline. Applicants may use the Technical Volume template available on ARPA-E eXCHANGE (<a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a>). The Technical Volume must include the following: <ul style="list-style-type: none"> <li>○ Executive Summary (1 page max.)</li> <li>○ Sections 1-5 (14 pages max.) <ul style="list-style-type: none"> <li>• 1. Innovation and Impact</li> <li>• 2. Proposed Work</li> <li>• 3. Technology to Market</li> <li>• 4. Team Organization and Capabilities</li> <li>• 5. Budget</li> </ul> </li> <li>○ Bibliographic References (no page limit)</li> <li>○ Personal Qualification Summaries (each PQS limited to 3 pages in length, no cumulative page limit)</li> </ul> </li> <li>• The Technical Volume must be accompanied by: <ul style="list-style-type: none"> <li>○ SF-424 (no page limit, Adobe PDF format);</li> <li>○ Budget Justification Workbook/SF424A (no page limit, Microsoft Excel format);</li> <li>○ Summary for Public Release (250 words max., Adobe PDF format);</li> <li>○ Summary Slide (1 page limit, Microsoft PowerPoint format) – Applicants may use the Summary Slide template available on ARPA-E eXCHANGE (<a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a>);</li> <li>○ SBA Company Registration Certificate generated in the SBA Company Registry (<a href="http://sbir.gov/registration">http://sbir.gov/registration</a>) (Adobe PDF format); If applicable, Certification for Applicants Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, or Private Equity Firms Applicants may use the SBIR VCOC Certification template available on ARPA-E eXCHANGE, (<a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a>) (Adobe PDF format);</li> <li>○ Completed and signed Business Assurances &amp; Disclosures Form (no page limit, Adobe PDF format)</li> <li>○ U.S. Manufacturing Plan (1 page limit, Adobe PDF format)</li> </ul> </li> </ul> | Mandatory              | IV.C           |

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|                            |   |          |      |
|----------------------------|---|----------|------|
| Reply to Reviewer Comments | <ul style="list-style-type: none"><li>• As set forth in Table 1, each Applicant may submit a Reply to Reviewer Comments in Adobe PDF format. This submission is optional. Applicants may use the Reply to Reviewer Comments template available on ARPA-E eXCHANGE (<a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a>). The Reply may include:<ul style="list-style-type: none"><li>○ Up to 2 pages of text; and</li><li>○ Up to 1 page of images.</li></ul></li></ul> | 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) to:

- “(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in—
  - (i) reductions of imports of energy from foreign sources;
  - (ii) reductions of energy-related emissions, including greenhouse gases; and
  - (iii) improvement in the energy efficiency of all economic sectors; 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 the programmatic authorizing statute codified at 42 U.S.C. § 16538. The FOA and any awards made under this FOA are subject to 2 C.F.R. Part 200 as amended by 2 C.F.R. Part 910.

ARPA-E funds research on and the development of high-potential, high-impact energy technologies that are too early for private-sector investment. 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 down 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 and it can be spurred by early-stage R&D supported by the applied energy offices in DOE. By contrast, ARPA-E supports high-risk, potentially transformative research that has the potential to create fundamentally new learning curves. ARPA-E R&D projects typically start with cost/performance estimates for the proposed technology that are well above the level of the competitive 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 lower 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 the 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.”<sup>1</sup> Applicants interested in receiving financial assistance for basic research 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 (<http://fossil.energy.gov/>), the Office of Nuclear Energy (<http://www.energy.gov/ne/office-nuclear-energy>), and the Office of Electricity Delivery and Energy Reliability (<http://energy.gov/oe/office-electricity-delivery-and-energy-reliability>).

## **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 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

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<sup>1</sup> OMB Circular A-11 ([https://www.whitehouse.gov/wp-content/uploads/2018/06/a11\\_web\\_toc.pdf](https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf)), Section 84, pg. 3.

between Small Business Concerns and partnering Research Institutions through Federally funded R&D activities.<sup>2</sup>

ARPA-E administers a joint SBIR/STTR program in accordance with the Small Business Act and the SBIR and STTR Program Policy Directive issued by the U.S. Small Business Administration (SBA).<sup>3</sup> 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. TARGETED TOPICS OVERVIEW**

This FOA will only accept applications in prespecified Targeted 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 Targeted Topics are posted.

Each technology specific Targeted Topic announcement will be visible on ARPA-E eXCHANGE as a supporting FOA document. Targeted 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

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<sup>2</sup> 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.

<sup>3</sup> See 84 Fed. Reg. 12794 (Apr. 2, 2019).

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 Targeted Topic(s) open at the time the application is submitted.

## **II. AWARD INFORMATION**

### **A. AWARD OVERVIEW**

See Targeted Topic Table and Topic Appendices for total amounts and anticipated number of awards for each 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. 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 \$3,677,642. Funding amounts will be consistent with the Phase I and Phase II limits posted on the SBA's website.<sup>4</sup>

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 \$256,580 and the maximum amount for a Phase I/II award is \$1,967,111.

### **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 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.

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<sup>4</sup> 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.

## **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. ARPA-E expects to award Grants for research funded under this FOA up to \$300,000.

## **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.”<sup>5</sup> Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement.

Cooperative Agreements involve the provision of financial or other support to accomplish a public purpose of support or stimulation authorized by Federal statute. Under Cooperative Agreements, the Government and Prime Recipients share responsibility for the direction of projects.

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.

ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement, which is available at <https://arpa-e.energy.gov/?q=site-page/funding-agreements>.

### **D. FEDERAL STEWARDSHIP**

ARPA-E will exercise Federal stewardship in overseeing the project activities performed under this Award. 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.

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<sup>5</sup> U.S. Congress, Conference Report to accompany the 21<sup>st</sup> Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).

### 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 SBA's "Guide to SBIR/ STTR Program Eligibility" available at [http://sbir.gov/sites/default/files/elig\\_size\\_compliance\\_guide.pdf](http://sbir.gov/sites/default/files/elig_size_compliance_guide.pdf).

A Small Business Concern<sup>6</sup> may apply as a Standalone Applicant<sup>7</sup> or as the lead organization for a Project Team.<sup>8</sup> 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.<sup>9</sup>

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 to SBA's "Guide to SBIR/ STTR Program Eligibility" available at [http://sbir.gov/sites/default/files/elig\\_size\\_compliance\\_guide.pdf](http://sbir.gov/sites/default/files/elig_size_compliance_guide.pdf).

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.

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<sup>6</sup> 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.

<sup>7</sup> A "Standalone Applicant" is an Applicant that applies for funding on its own, not as part of a Project Team.

<sup>8</sup> The term "Project Team" is used to mean any entity with multiple players working collaboratively and could encompass anything from an existing organization to an ad hoc teaming arrangement. A Project Team consists of the Prime Recipient, Subrecipients, and others performing any of the research and development work under an ARPA-E funding agreement, whether or not costs of performing the research and development work are being reimbursed under any agreement.

<sup>9</sup> 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.



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>).

### **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<sup>10</sup> 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<sup>11</sup>
- Government-Owned, Government Operated laboratories (GOGOs)

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<sup>10</sup> 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.

<sup>11</sup>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.

- State, local, and tribal government entities
- Foreign entities<sup>12</sup>

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.

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<sup>12</sup> All work by foreign entities must be performed by subsidiaries or affiliates incorporated in the United States (see Section IV.E.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.

**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<sup>13</sup> 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.**

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<sup>13</sup> 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 Policy Directive" at [https://www.sbir.gov/sites/default/files/SBIR-STTR\\_Policy\\_Directive\\_2019.pdf](https://www.sbir.gov/sites/default/files/SBIR-STTR_Policy_Directive_2019.pdf).

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 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<sup>14</sup>**

**Cost sharing will not be required for any project with Federal Project Funding of \$300,000 or less.** Otherwise, Applicants are bound by the cost share proposed in their Full Applications.

##### **1. PHASE I**

Prime Recipients/Project Teams are not required to contribute cost share during Phase I of an SBIR/STTR award.

##### **2. PHASE II AND IIS COST SHARE REQUIREMENT**

For Phase II and Phase IIS, Prime Recipients must contribute cost share as follows:

- Small businesses – or consortia of small businesses - will provide 0% cost share from the outset of the Phase II project through the first 12 months of Phase II (referred to as the “Cost Share Grace Period”). If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost<sup>15</sup> (including the costs incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.
- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are entitled to the same cost

<sup>14</sup> Please refer to Section VI.B.3-4 of the FOA for guidance on cost share payments and reporting.

<sup>15</sup> 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 and FFRDCs.

share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.

- Project teams that do not meet any of the above criteria are subject to a minimum cost share requirement of 20%.

### **3. LEGAL RESPONSIBILITY**

Although the cost share requirement applies to the Project Team as a whole, the funding agreement makes the Prime Recipient legally responsible for paying, or ensuring payment of the entire cost share. The Prime Recipient's cost share obligation is expressed in the funding agreement as a static amount in U.S. dollars (cost share amount) and as a percentage of the Total Project Cost (cost share percentage). If the funding agreement is terminated prior to the end of the period of performance, the Prime Recipient is required to contribute, or ensure contribution of, at least the cost share percentage of total expenditures incurred through the date of termination.

The Prime Recipient is solely responsible for managing cost share contributions by the Project Team and enforcing cost share obligations assumed by Project Team members in subawards or related agreements.

### **4. COST SHARE ALLOCATION**

Each Project Team is free to determine how much each Project Team member will contribute towards the cost share requirement. The amount contributed by individual Project Team members may vary, as long as the cost share requirement for the project as a whole is met.

### **5. COST SHARE TYPES AND ALLOWABILITY**

Every cost share contribution must be allowable under the applicable Federal cost principles, as described in Section IV.E.1 of the FOA.

Project Teams may provide cost share in the form of cash or in-kind contributions. Cash contributions may be provided by the Prime Recipient or Subrecipients. Allowable in-kind contributions include but are not limited to personnel costs, indirect costs, facilities and administrative costs, rental value of buildings or equipment, and the value of a service, other resource, or third party in-kind contribution. Project Teams may use funding or property received from state or local governments to meet the cost share requirement, so long as the funding or property was not provided to the state or local government by the Federal Government.

The Prime Recipient may not use the following sources to meet its cost share obligations:

- Revenues or royalties from the prospective operation of an activity beyond the period of performance;
- Proceeds from the prospective sale of an asset of an activity;
- Federal funding or property (e.g., Federal grants, equipment owned by the Federal Government); or
- Expenditures that were reimbursed under a separate Federal program.

In addition, Project Teams may not use independent research and development (IR&D) funds<sup>16</sup> to meet their cost share obligations under Cooperative Agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under “other transaction” agreements.

Project Teams may not use the same cash or in-kind contributions to meet cost share requirements for more than one project or program.

Cost share contributions must be specified in the project budget, verifiable from the Prime Recipient’s records, and necessary and reasonable for proper and efficient accomplishment of the project. Every cost share contribution must be reviewed and approved in advance by the Contracting Officer and incorporated into the project budget before the expenditures are incurred.

Applicants may wish to refer to 2 C.F.R. Parts 200 and 910, and 10 C.F.R Part 603 for additional guidance on cost sharing, specifically 2 C.F.R. §§ 200.306 and 910.130, and 10 C.F.R. §§ 603.525-555.

## **6. COST SHARE CONTRIBUTIONS BY FFRDCs AND GOGOS**

Because FFRDCs are funded by the Federal Government, costs incurred by FFRDCs generally may not be used to meet the cost share requirement. FFRDCs may contribute cost share only if the contributions are paid directly from the contractor’s Management Fee or a non-Federal source.

Because GOGOs/Federal Agencies are funded by the Federal Government, GOGOs/Federal Agencies may not provide cost share for the proposed project. However, the GOGO/Agency costs would be included in Total Project Costs for purposes of calculating the cost-sharing requirements of the applicant.

## **7. COST SHARE VERIFICATION**

Upon selection for award negotiations, Applicants are required to provide information and documentation regarding their cost share contributions. Please refer to Section VI.B.3 of the FOA for guidance on the requisite cost share information and documentation.

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<sup>16</sup> As defined in Federal Acquisition Regulation Subsection 31.205-18.

## **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 Targeted 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.

### **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 Targeted Topic Appendix
- Submissions that have been submitted in response to other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to other 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.

Each Targeted Topic may also include a section entitled “Submissions Specifically not of Interest.” Submissions that propose items contained within this section in each Targeted 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 Targeted Topic attached to this FOA, provided that each application is scientifically distinct.

However, small businesses that qualify as a “Small Business Concern” may apply to only one of the two ARPA-E “Solicitation on topics informing new program areas” FOAs: ARPA-E FOA DE-FOA-0001954 (SBIR/STTR), Solicitation on topics informing new program areas (SBIR/STTR), or ARPA-E FOA DE-FOA-0001953, Solicitation on topics informing new program areas. 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-0001954, please review the eligibility requirements in Sections III.A – III.D above.



## 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 that are sole proprietors and do not have an Employer Identification Number may use social security numbers for purposes of registering in the SBA Company Registry. Applicants that do not possess a Dun and Bradstreet Data Universal Numbering System (DUNS) number may also use their social security number in the SBA Company Registry.

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 first 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.F.1 of the FOA and the "ARPA-E eXCHANGE Applicant Guide" (<https://arpa-e-foa.energy.gov/Manuals.aspx>).

#### 3. FULL APPLICATIONS

Applicants must submit a Full Application by the Targeted 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 Targeted 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.E 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.C.1 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 and program policy factors in Sections V.A.1 and V.B.1 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 content requirements described below.

| Component  | Required Format | Description and Information  |
|--|-----------------|--|
| <b>Technical Volume</b>  | PDF             | The centerpiece of the Full Application. Provides a detailed description of the proposed R&D project and Project Team. A Technical Volume template is available on ARPA-E eXCHANGE ( <a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a> ).  |
| <b>SF-424</b>  | PDF             | Application for Federal Assistance ( <a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a> ). 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. |
| <b>Budget Justification Workbook/SF-424A</b>   | XLS             | Budget Information – Non-Construction Programs ( <a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a> )   |
| <b>Summary for Public Release</b>  | PDF             | Short summary of the proposed R&D project. Intended for public release. A Summary for Public Release template is available on ARPA-E eXCHANGE ( <a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a> ).   |
| <b>SBA Company Registration Certificate</b>  | PDF             | Registration Certificate generated upon completion of registration in the SBA Company Registry ( <a href="http://sbir.gov/registration">http://sbir.gov/registration</a> ).  |
| <b>Certification for Applicants Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, or Private Equity Firms (if applicable)</b> | PDF             | Requires SBIR Applicants that are majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms to self-identify and verify registration as such in the SBA Company Registry ( <a href="http://sbir.gov/registration">http://sbir.gov/registration</a> ).                             |

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

|   |     |   |
|---|-----|---|
| <b>Summary Slide</b>                              | PPT | A four-panel project slide summarizing different aspects of the proposed R&D project. A Summary Slide template is available on ARPA-E eXCHANGE ( <a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a> ).   |
| <b>Business Assurances &amp; Disclosures Form</b> | PDF | Requires the Applicant to acknowledge eligibility with SBIR/STTR program requirements, make responsibility disclosures, and disclose potential 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 the Applicant is a FFRDC/DOE Lab, requires the Applicant to provide written authorization from the cognizant Federal agency and, if a DOE/NNSA FFRDC/DOE Lab, a Field Work Proposal. Allows the Applicant to request a waiver or modification of the Performance of Work in the United States requirement This form is available on ARPA-E eXCHANGE at <a href="https://arpa-e-foa.energy.gov">https://arpa-e-foa.energy.gov</a> . A sample response to the Business Assurances & Disclosures Form is also available on ARPA-E eXCHANGE. Business Assurances & Disclosures Form is also available on ARPA-E eXCHANGE. |
| <b>U.S. Manufacturing Plan</b>                    | PDF | As part of the application, Applicants are required to submit a U.S. Manufacturing Plan. The U.S. Manufacturing Plan represents the Applicant's measurable commitment to support U.S. manufacturing as a result of its award. See detailed U.S. Manufacturing Plan instructions and examples in the Seventh Component description below.  |

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>.

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

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

## **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>. 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 will review only the authorized number of pages and disregard any additional pages.

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, ARPA-E and reviewers are under no obligation to review cited sources (e.g., Internet websites).

## **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 are required to complete all required fields in accordance with the instructions.

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).
- 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.

|                  |                                   |  |
|------------------|-----------------------------------|--|
| <b>250 Words</b> | <b>SUMMARY FOR PUBLIC RELEASE</b> | <p>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.</p> <p><b>INSTRUCTIONS:</b></p> <p>(1) The Summary for Public Release <u>shall not exceed 250 words and one paragraph.</u></p> <p>(2) The Summary for Public Release <u>shall consist only of text</u>—no graphics, figures, or tables.</p> <p>(3) For applications selected for award negotiations, the Summary may be used as the basis for a public announcement by ARPA-E; therefore, <b><u>this Cover Page and Summary should not contain confidential or proprietary information.</u></b> See Section VIII.I of the FOA for additional information on marking confidential information.</p> |
|------------------|-----------------------------------|--|

## 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:

- Targeted 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.

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).



## **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**

Only those Applicants that are majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms are required to complete the Certification for Applicants Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, and Private Equity Funds. 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 Certification for Applicants Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, and Private Equity Funds, the Applicant is required to self-identify as an entity that falls into one of those categories, 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 not majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms are not required to complete this 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.

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 potential conflicts of interest within the Project Team



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.”<sup>17</sup> 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

Each entity on a Project Team must also report the entity’s DUNS number, confirmation of active registration in SAM, or the dates when the entity began or will begin the process of obtaining a DUNS number and/or register in SAM.

## 9. NINTH COMPONENT: U.S. MANUFACTURING PLAN

As part of the application, Applicants are required to submit a U.S. Manufacturing Plan that should not exceed one page in length. The U.S. Manufacturing Plan represents the Applicant’s measurable commitment to support U.S. manufacturing as a result of its award. U.S. Manufacturing Plans are a Program Policy Factor during the review and selection process. See Section V.B.1 of the FOA.

A U.S. Manufacturing Plan should contain the following or similar preamble: “If selected for funding, the Applicant agrees to the following commitments as a condition of that funding:” and, after the preamble, the plan should include one or more specific and measurable commitments. For example, an Applicant may commit particular types of products to be manufactured in the U.S. **These plans should not include requirements regarding the source of inputs<sup>18</sup> used during the manufacturing process.** In addition to or instead of making a commitment tied to a particular product, the Applicant may make other types of commitments still beneficial to U.S. manufacturing. An Applicant may commit to a particular investment in a new or existing U.S. manufacturing facility, keep certain activities based in the U.S. (i.e., final assembly) or support a certain number of jobs in the U.S. related to the technology and manufacturing. For an Applicant which is likely to license the technology to others, especially universities for which licensing may be the exclusive means of commercialization the

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<sup>17</sup> America COMPETES Act, Pub. L. No. 110-69, § 5012 (2007), as amended (codified at 42 U.S.C. § 16538).

<sup>18</sup> For purposes of this FOA, an input refers to something which is used during the manufacturing process which (1) was in existence prior to or first produced outside of an ARPA-E award; (2) does not embody a subject invention, or technology which is developed or improved under an ARPA-E award; and (3) was not produced through the use of a subject invention, or technology which is developed or improved under an ARPA-E award.

technology, the U.S. manufacturing plan may indicate the Applicant's plan and commitment to use a licensing strategy **for both exclusive and nonexclusive** licensing that would likely support U.S. manufacturing.

When an Applicant that is a domestic small business, domestic educational institution, or nonprofit organization is selected for an award, the U.S. Manufacturing Plan submitted by the Applicant may become part of the terms and conditions of the award **in addition to the requirements attaching to subject inventions described in VI.B.8 below**. See Section VI.B.8 of the FOA for U.S. Manufacturing Requirements applicable to large businesses. The Applicant/Awardee may request a waiver or modification of the U.S. Manufacturing Plan from DOE upon a showing that the original U.S. Manufacturing Plan is no longer economically feasible.

Class patent waivers usually apply to domestic large businesses as set forth in Section VIII of the 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 that any products embodying or produced through the use of an invention conceived or first actually reduced to practice under the award will be substantially manufactured in the United States, unless DOE agrees that the commitments proposed in the U.S. Manufacturing Plan are sufficient. The U.S. Manufacturing Plan submitted by the Applicant may become part of the terms and conditions of the award **in addition to the requirements attaching to subject inventions**.

#### **D. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS**

If Applicable to the Targeted 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>).

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.C.1 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 will review only the first three pages and disregard any additional pages.

| SECTION | PAGE LIMIT      | DESCRIPTION  |
|---------|-----------------|--|
| Text    | 2 pages maximum | <ul style="list-style-type: none"><li>Applicants may respond to one or more reviewer comments or supplement their Full Application.</li></ul>                              |
| Images  | 1 page maximum  | <ul style="list-style-type: none"><li>Applicants may provide graphs, charts, or other data to respond to reviewer comments or supplement their Full Application.</li></ul> |

#### **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 <http://arpa-e.energy.gov/?q=site-page/post-award-guidance-sbir-sttr>.

##### **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. ARPA-E generally does not accept budgets as submitted with the Full Application. Budgets 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.

Please refer to the “SBIR/STTR Applicants’ Guide to ARPA-E Award Negotiations” (<http://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance-sbir-sttr>) for additional guidance on pre-award costs.

### **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 which is subject to approval by the ARPA-E Program Director and Contracting Officer.

### **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.

### **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 – i.e., Prime Recipients must expend 100% of the Total Project Cost 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. The ARPA-E Contracting Officer will provide consent to purchase or reject within 30 calendar days of receipt of the Recipient's notification.

## **8. 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" (<http://www.whitehouse.gov/sites/default/files/omb/grants/sflllin.pdf>) 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.

## **9. 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.

## **10. 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.

### **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 Targeted 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 Targeted 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).

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 US dependence on foreign energy sources;
  - b. Stimulation of domestic manufacturing/U.S. Manufacturing Plan;
  - 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. **Effective April 2, 2020: 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/Pages/Opportunity-Zones.aspx>.

## 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](mailto: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 on a rolling basis approximately 90 days after submission of a Full Application.

## 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.E.2 of the FOA for guidance on pre-award costs. Please also refer to the “SBIR/STTR Applicants’ Guide to ARPA-E Award Negotiations” (<http://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance-sbir-sttr>) for guidance on the award negotiation process.

### ***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.E.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.

### **1. DUNS NUMBER AND SAM, FSRS, AND FEDCONNECT REGISTRATIONS**

Prime Recipients and Subrecipients are required to obtain a Dun and Bradstreet Data Universal Numbering System (DUNS) number at <http://fedgov.dnb.com/webform> and to register with the System for Award Management (SAM) at <https://www.sam.gov/portal/public/SAM/>.

Prime Recipients and Subrecipients should commence this process as soon as possible in order to expedite the execution of a funding agreement. Obtaining a DUNS number and registering with SAM 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/>.<sup>19</sup> 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.

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

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<sup>19</sup> The Federal Funding Accountability and Transparency Act, P.L. 109-282, 31 U.S.C. 6101 note.

may not execute subawards with Subrecipients until they obtain a DUNS number and complete their SAM registration. Prime Recipients and Subrecipients are required to keep their SAM and FSRs data current throughout the duration of the project.

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. Please refer to ARPA-E's Model Cooperative Agreement for SBIR/STTR awards (<http://arpa-e.energy.gov/?q=arpa-e-site-page/award-guidance-sbir-sttr>) for guidance on the National Policy Assurances.

## **3. PROOF OF COST SHARE COMMITMENT AND ALLOWABILITY**

Upon selection for award negotiations, the Prime Recipient must confirm in writing that the proposed cost share contribution is allowable in accordance with applicable Federal cost principles.

The Prime Recipient is also required to provide cost share commitment letters from Subrecipients or third parties that are providing cost share, whether cash or in-kind. Each Subrecipient or third party that is contributing cost share must provide a letter on appropriate letterhead that is signed by an authorized corporate representative.

Please refer to the "SBIR/STTR Applicants' Guide to ARPA-E Award Negotiations" (<http://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance-sbir-sttr>) for guidance on the contents of cost share commitment letters. The ARPA-E Contracting Officer will determine if cost share is allowable under applicable Federal cost principles. For additional information on cost share types and allowability see Section III.E.5 of the FOA.

## **4. COST SHARE PAYMENTS<sup>20</sup>**

All proposed cost share contributions for Phase II and Phase IIS of Combined Phase I/II/IIS awards must be reviewed in advance by the Contracting Officer and incorporated into the project budget before the expenditures are incurred.

ARPA-E requires Prime Recipients to contribute the cost share amount incrementally during the performance of work in Phase II and/or Phase IIS.<sup>21</sup> Specifically, every Prime Recipient is

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<sup>20</sup> Please refer to Section III.E of the FOA for guidance on cost share requirements.

<sup>21</sup> Prime Recipients may elect to pay the entire cost share amount at the start of the project.

required to contribute, at a minimum, the cost share percentage of total expenditures incurred during every billing period in Phase II and/or Phase IIS (subject to any applicable Cost Share Grace Period). For example, a Prime Recipient is required to contribute at least 10% of the total expenditures incurred during every billing period in Phase II if the funding agreement states that the cost share percentage in Phase II is 10%.

Prime Recipients must submit written documentation with every reimbursement request demonstrating that it (or Project Team, as appropriate) has provided the requisite cost share during the relevant billing period.

If Prime Recipients anticipate difficulty providing the requisite cost share every billing period, they may request authorization from the Contracting Officer upon selection for award negotiations to deviate from ARPA-E's standard cost share payment schedule.

Please refer to the "SBIR/STTR Applicants' Guide to ARPA-E Award Negotiations" (<http://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance-sbir-sttr>) for additional guidance on cost share payment requirements.

ARPA-E may deny reimbursement requests, in whole or in part, or modify or terminate funding agreements where Prime Recipients (or Project Teams) fail to comply with ARPA-E's cost share payment requirements.

## **5. 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).

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 <http://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance-sbir-sttr>. The Environmental Impact Questionnaire is due within 21 calendar days of the selection announcement.

## **6. 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. During the project period, 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.

## **7. 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 (<http://arpa-e.energy.gov/?q=arpa-e-site-page/award-guidance-sbir-sttr>) 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. The DMP must meet the minimum requirements set forth in ARPA-E's "Applicant Guide to Award Negotiations" available at the following website: <https://arpa-e.energy.gov/?q=arpa-e-site-page/pre-award-guidance>."

## **8. U.S. MANUFACTURING REQUIREMENT**

As part of its Full Application, each applicant is required to submit a U.S. Manufacturing Plan that includes the following U.S. Manufacturing Requirements. For more information on the required U.S Manufacturing Plan, see Section IV.C.7 above.



***a. SMALL BUSINESSES (INCLUDING SMALL BUSINESS CONCERNS)***

Small businesses (and in rare cases where a non-profit might manufacture) that are Prime Recipients or Subrecipients under ARPA-E funding agreements must agree that any products embodying any subject invention or produced through the use of any subject invention will be manufactured substantially in the United States for any use or sale anywhere in the world.

Small business must also agree that, for their exclusive and nonexclusive licensees, any products that embody any subject invention or that will be produced through the use of any subject invention will be manufactured substantially in the United States for any use or sale anywhere in the world.

Small businesses must require their assignees and entities acquiring a controlling interest in the small business to apply the same U.S. Manufacturing requirements to their licensees.

***b. LARGE BUSINESSES***

Large businesses that are Prime Recipients or Subrecipients (and in rare cases, foreign entities that are subrecipients) under ARPA-E funding agreements are required to substantially manufacture the following products in the United States: (1) products embodying subject inventions, and (2) products produced through the use of subject inventions. This requirement applies to products that are manufactured for use or sale in the United States and outside the United States.

Large businesses (and in rare cases, foreign entities that are subrecipients) must apply the same U.S. Manufacturing requirements to their assignees, licensees, and entities acquiring a controlling interest in the large business or foreign entity. Large businesses must require their assignees and entities acquiring a controlling interest in the large business to apply the same U.S. Manufacturing requirements to their licensees.

***c. EDUCATIONAL INSTITUTIONS AND NONPROFITS***

Domestic educational institutions and nonprofits that are Prime Recipients or Subrecipients under ARPA-E funding agreements must require their exclusive and nonexclusive licensees to substantially manufacture the following products in the United States for any use or sale anywhere in the world: (1) articles embodying subject inventions, and (2) articles produced through the use of subject inventions. Educational institutions and nonprofits must require their assignees to apply the same U.S. Manufacturing requirements to their licensees.

***d. FFRDCs/DOE LABS AND STATE AND LOCAL GOVERNMENT ENTITIES***

FFRDCs/DOE Labs that are GOCOs and state and local government entities that are Prime Recipients or Subrecipients under ARPA-E funding agreements must require their exclusive licensees to substantially manufacture the following products in the United States for any use

or sale in the United States: (1) products embodying subject inventions, and (2) products produced through the use of subject inventions. This requirement does not apply to products that are manufactured for use or sale overseas. They must also require their assignees to apply the same U.S. Manufacturing requirements to their exclusive licensees. GOGOs are subject to the requirements in 37 CFR § 404.5(a)(2).

#### ***e. CRITERIA FOR WAIVING U.S. MANUFACTURING REQUIREMENTS***

ARPA-E seeks to “enhance the economic and energy security of the United States ...” and “ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.” The preferred benefit to the U.S. economy is the creation and maintenance of manufacturing capabilities and jobs within the United States. However, an applicant or awardee may request a modification or waiver of the standard U.S. Manufacturing Requirement, or its submitted U.S. Manufacturing Plan, if the applicant/awardee can demonstrate to the satisfaction of DOE/ARPA-E that it is not commercially feasible to comply with U.S. manufacturing requirements. In addition, such requests must include a description of specific economic or other benefits to the U.S. economy which are related to the commercial use by requestor of the technology being funded by ARPA-E and which are commensurate with the Government’s contribution to the proposed work. These types of benefits are more easily measured and evaluated after technical advance has been made under an award, such as by the making of a subject invention.

Such benefits may include one or more of the following:

- Direct or indirect investment in U.S.-based plant and equipment.
- Creation of new and/or higher-quality U.S.-based jobs.
- Enhancement of the domestic skills base.
- Further domestic development of the technology.
- Significant reinvestment of profits in the domestic economy.
- Positive impact on the U.S. balance of payments in terms of product and service exports as well as foreign licensing royalties and receipts.
- Appropriate recognition of U.S. taxpayer support for the technology; e.g., a quid-pro-quo commensurate with the economic benefit that would be domestically derived by the U.S. taxpayer from U.S.-based manufacture.
- Cross-licensing, sublicensing, and reassignment provisions in licenses which seek to maximize the benefits to the U.S. taxpayer.
- Any foreign manufacturing/use will occur in a country that protects U.S. patents/intellectual property.

### **9. CORPORATE FELONY CONVICTIONS AND FEDERAL TAX LIABILITY**

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

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

- 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.

## **10. 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 §200.205(c), subparagraphs (1) through (4). ARPA-E may require special award terms and conditions depending upon results of the risk analysis.

## **11. RECIPIENT INTEGRITY AND PERFORMANCE MATTERS**

Prior to making a Federal award with a total amount of Federal share greater than the simplified acquisition threshold (presently \$250,000), 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. 200.205).

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. §200.205.

## **12. 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 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.

### **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 for SBIR/STTR Awards (<http://arpa-e.energy.gov/?q=arpa-e-site-page/award-guidance-sbir-sttr>).

## VII. AGENCY CONTACTS

### A. COMMUNICATIONS WITH ARPA-E

Upon the issuance of a Targeted 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](mailto: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](mailto: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 periodic 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 Targeted Topic 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](mailto: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](mailto: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.

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

## VIII. OTHER INFORMATION

### A. TITLE TO SUBJECT INVENTIONS

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

- 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. If Prime Recipients/Subrecipients elect to retain title, they must file a patent application in a timely fashion, generally one year from election of title, though: a) extensions can be granted, and b) earlier filing is required for certain situations (“statutory bars,” governed by 35 U.S.C. § 102) involving publication, sale, or public use of the subject invention.
- All other parties: The Federal Non-Nuclear Energy Research and Development Act of 1974, 42 U.S.C. 5908, provides that the Government obtains title to new inventions unless a waiver is granted (*see below*).
- Class Waiver: Under 42 U.S.C. § 5908, title to subject inventions vests in the U.S. Government and large businesses and foreign entities do not have the automatic right to elect to retain title to subject inventions. However, ARPA-E typically issues “class patent waivers” under which large businesses and foreign entities that meet certain stated requirements, such as cost sharing of at least 20%, may elect to retain title to their subject inventions. If a large business or foreign entity elects to retain title to its subject invention, it must file a patent application in a timely fashion. If the class waiver does not apply, a party may request a waiver in accordance with 10 C.F.R. §784.
- GOGOs are subject to the requirements of 37 C.F.R. Part 501.
- Determination of Exceptional Circumstances (DEC): DOE has determined that exceptional circumstances exist that warrant the modification of the standard patent rights clause for small businesses and non-profit awardees under Bayh-Dole to maximize the manufacture of technologies supported by ARPA-E awards in the United States. The DEC, including a right of appeal, is dated September 9, 2013 and is available at the following link: <http://energy.gov/gc/downloads/determination-exceptional-circumstances-under-bayh-dole-act-energy-efficiency-renewable>. Please see Section IV.C.7 and VI.B.8 for more information on U.S. Manufacturing Requirements.

### 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 Targeted Topic announcements, are also posted to these websites. 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 Targeted Topics are posted. 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, Reply to Reviewer Comments, or other submission containing confidential, proprietary, or privileged information must 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>.
- ARPA-E will not pay a fee or profit on Cooperative Agreements resulting from this FOA to recipients or subrecipients.
- Actual or suspected fraud, waste, or abuse may be reported to the DOE Office of Inspector General (OIG) at 1-800-541-1625.

#### **K. 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.

## 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 Full Application, and Reply to Reviewer Comments..

**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 in accordance with 2 C.F.R. § 200.29.

**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.

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

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

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

**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 any of the research and development work under an ARPA-E funding agreement, whether or not costs of performing the research and development work are being reimbursed under any agreement.

**SBA:** U.S. Small Business Administration.

**SBIR:** Small Business Innovation Research Program.

**Small Business Concern:** 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.

**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.

**Targeted 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 targeted 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 Targeted 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.

## I. APPENDIX A: EXTREMELY DURABLE CONCRETES AND CEMENTITIOUS MATERIALS

**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“Extremely Durable Concretes and Cementitious Materials”**

|  |                                  |
|--|----------------------------------|
| Topic Issue Date   | December 20, 2018                |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, February 8, 2019        |
| Submission Deadline for Full Applications  | 9:30 AM ET, February 26, 2019    |
| Expected Date for Selection Notifications  | May 2019                         |
| Total Amount to be Awarded   | Approximately \$8M total funding |
| Anticipated Awards   | 5-8 awards                       |
| Maximum Period of Performance  | 24 Months                        |

## 1. Introduction

This announcement describes a research thrust titled “Extremely Durable Concretes and Cementitious Materials.” 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 advancement of concretes, precursors (*e.g.* cementitious & pozzolanic materials, aggregates, admixtures) and concrete structures, (2) encourage dialogue amongst those interested in this area, and (3) provide a timetable for the submission of Full Applications.

## 2. Topic Description

ARPA-E is interested in receiving Full Applications in support of advancing extremely durable concretes and cementitious materials. This topic seeks research towards concrete that outlasts conventional concrete, reduces lifetime O&M expenses and their associated energy requirements, and therefore greatly reduces cement/concrete. Work under this program will consist of early stage research.

### A. Topic Overview

Concrete is second only to water as the most widely used substance in the world,<sup>22</sup> largely due to the material’s low cost, abundance, and relative stability in myriad environments (*e.g.* marine; high temperature, pressure, salinity, radiation). The ubiquity of concrete comes with a significant energy and emissions footprint,<sup>23</sup> which threatens to grow as domestic

<sup>22</sup> Scrivener, Karen L., Vanderley M. John, and Ellis M. Gartner. "Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry." (2016).

<sup>23</sup> EIA. The cement industry is the most energy intensive of all manufacturing industries. July 1, 2013. EIA: Today in Energy. <https://www.eia.gov/todayinenergy/detail.php?id=11911>

infrastructure degrades with age.<sup>24</sup> Concrete is also a critical material for U.S. energy production, one that can have a significant impact on the cost, productivity, and resilience of key resources such as nuclear, fossil, wind, and hydroelectric power.

Over the last century, alterations to concrete mixtures – namely, the increase in cement fineness and C3S content and concomitant C2S decrease<sup>25</sup> – have emphasized early strength gain to accommodate an increase in the rate of construction. Several surveys have uncovered an increasing rate of deterioration for these early-strength mixtures when compared to older, higher C2S concrete blends.<sup>26</sup> More specifically, modern (e.g. 1950 and beyond) concrete mixes have been found to crack more easily, primarily due to lower creep, higher shrinkage and a higher elastic modulus.<sup>26</sup> Cracks present a critical vulnerability to any concrete structure, allowing harmful ions and gases to penetrate the structure's interior; in many cases, these harmful substances come in contact with the reinforcing steel used in most concrete structures. Corrosion of the steel rebar via the permeation of either water, air, and/or chlorine (such as from the marine environment or common de-icing salts), can result in a 12-27% reduction in usable life expectancy for the concrete structure.<sup>27</sup>

Rising demand for concrete – which, in the U.S., is largely driven by an aging infrastructure – could more than double the energy and emissions associated with its domestic production. Furthermore, the use of modern concrete mixtures in repair and replacement of infrastructure composed of older, more-durable concrete threatens to further drive energy use as the push for strength and speed comes at the cost of long-term durability. Without intervention, modern mixtures require more frequent repair and replacement, which translates to higher energy and emissions for both concrete production and the labor, equipment, *etc.*, associated with operation and maintenance. At the same time, the low cost and operational simplicity of modern concrete represents a major hurdle to innovation as infrastructure projects face strong pressure towards low cost bids and complicated incentives between suppliers, builders, owners and operators. Attempts to introduce superior performance at a higher cost (e.g. materials, labor, curing time) – or without a clear value proposition – are unlikely to succeed on an impactful scale. In light of these market criteria, reverting to mixtures that improve durability at the cost of construction efficiency is not a viable option.

While previous efforts have seen some success in reducing the energy intensity of cement and concrete *production*, ARPA-E sees an opportunity to lower the energy devoted to concrete

<sup>24</sup> ASCE. 2017 Infrastructure Report Card. American Society of Civil Engineers (2017).

<sup>25</sup> C<sub>3</sub>S is tricalcium silicate, also known as Alite; it is a component of cement which is largely responsible for the fast-setting and initial strength development of cement. Alite is also formed at the highest cement kiln temperatures (1300+ °C) and is a contributor to the high CO<sub>2</sub> emissions and energy requirements from cement production. C<sub>2</sub>S is dicalcium silicate, also known as Belite; it is less reactive at early stages, contributing to strength development at later stages, and can be produced at lower kiln temperatures (up to 100 °C lower than Alite).

<sup>26</sup> Mehta, P. Kumar, and Richard W. Burrows. "Building durable structures in the 21st century." *Indian Concrete Journal* 75.7 (2001): 437-443.

<sup>27</sup> Jones, Scott, *et al.* "Simulation studies of methods to delay corrosion and increase service life for cracked concrete exposed to chlorides." *Cement and Concrete Composites* 58 (2015): 59-69.



materials and infrastructure by extending the *service life/use* stage of the material's lifecycle. **Therefore, the overarching objective of this research opportunity is to develop material and process improvements that would (1) significantly (*e.g.* 2X or more) improve the durability of concrete and cementitious materials, while (2) maintaining or lowering the energy and emissions related to production and deployment of the material, and (3) remaining cost competitive with traditional materials when accounting for the intended service life and maintenance cycle.**

More durable concrete can lower the overall energy input for concrete structures by significantly delaying the need for repair and replacement; for major concrete projects, and particularly for nuclear facilities, such developments could have tremendous economic potential. Finally, there may be also opportunities to lower infrastructure investment costs through advanced mixtures and manufacturing practices that improve durability while reducing material and/or time requirements for construction. If successful, these developments would produce high value, differentiated products and processes that would better position the U.S. concrete and construction industry to lead in a growing international market.

ARPA-E seeks input from researchers, manufacturers, suppliers and end-users of such technologies (*e.g.* the construction, manufacturers, specifiers, civil, and nuclear engineering communities). Consistent with the agency's mission, ARPA-E is seeking clearly disruptive, novel technologies, early in their R&D cycle. Incremental improvements and integration strategies for existing technologies are not of interest.

## **B. Technical Areas of Interest & Performance Targets**

ARPA-E is specifically interested in technologies within one or more of the categories below that would:

- (1) significantly (*e.g.* 2X or more) improve the durability of concrete and cementitious materials, while
- (2) maintain or lower the energy and emissions related to production and deployment of the material, and
- (3) remaining cost competitive with traditional materials when accounting for the intended service life and maintenance cycle.

### **CATEGORY 1 – Materials & Mixtures:**

- Molecular design of more durable cementitious materials and concrete mixtures
  - Significantly reduce (*i.e.*  $\leq 100\mu\text{m}$ ), or eliminate, micro-cracking
  - Improve ductility (Target 0.75% - 2%)
  - Self-healing (*e.g.* w/wo chemical additives, fibers, active aggregate, pozzolans)
  - Extremely low permeability
  - Similar or reduced set-time while improving toughness and durability
- Materials and mixtures capable of enabling additive manufacturing techniques while preserving or enhancing durability

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

**CATEGORY 2 – Advanced Processing:**

- Advanced mixing and/or pre-blending systems to enable scale up of tailored mixtures
- Novel pathways toward low-temperature processing of highly-durable materials
- Novel methods of achieving and/or verifying uniformity of mixture designs and final structures
- Novel manufacturing and/or construction approaches that would result in reduced set-time while improving concrete toughness and durability
- Technologies to enable additive manufacturing for large-scale ( $> 125 \text{ m}^3$ ) construction (e.g. system controls, precise material delivery, in-field blending or compounding)

**CATEGORY 3 – Modeling, Testing, Sensing, & Maintenance:**

- Structure-process-property predictive models to define degradation pathways, enable more precise mixture evaluation, and identify optimal repair timing and materials
- Accelerated durability testing for concretes and cementitious materials
- Advanced non-destructive survey and sensing techniques for monitoring concrete structures
- Novel repair methods capable of significantly extending the lifetime of existing concrete structures

**In addition to the requirements stated in the FOA, please include this table in the Technical Volume. Note that this table will count towards the 14 page limit of the Technical Volume.**

Please provide estimates of the durability improvement, embodied energy savings, and cost of the proposed technology:

| Description  | Response/Comments<br>(include references where possible) |
|--|--|
| <u>Estimated durability improvement</u> : Provide the anticipated application, lifetime for SOA materials and expected improvement (e.g. %, years) for both maintenance frequency and replacement frequency. |  |
| <u>Estimated embodied energy savings</u> : Provide the estimated energy intensity of the proposed solution, the anticipated demand and associated energy savings throughout the service life cycle.          |  |
| <u>Estimated cost</u> : Provide the target cost and associated assumptions for your proposed technology. Should the target cost exceed that of traditional materials or                                      |  |

|   |  |
|---|--|
| approaches, please justify the cost in the context of service life, maintenance schedule, user impact, etc. |  |
|---|--|

### 3. Submissions Specifically Not of Interest

Submissions that propose the following may be deemed nonresponsive and may not merit review or be considered:

- Approaches seeking incremental improvements to current cement and concrete materials, including OPC, geopolymers, and additives.
- Approaches seeking incremental improvements to concrete construction techniques, including marginal advances in pour-in-place and pre-casting techniques.
- Approaches seeking incremental improvements to additive manufacturing techniques, equipment and materials, including technologies specifically targeted to small-scale (<125 m<sup>3</sup>) 'printed' structures.
- Demonstration projects that do not include a significant degree of technical risk.
- Approaches for which the capital, material, labor, and repair costs (life-cycle cost) exceed *current* life-cycle costs in the proposed application space.
- Technologies that are not suitable for use throughout the entire United States, including technologies that rely on a single, site-specific geologic material (*e.g.* limited, specific mineral only located in a particular region) are specifically not of interest.
- Primary application areas other than nuclear or infrastructure (*e.g.* commercial and residential buildings)

## II. APPENDIX B: LEVERAGING INNOVATIONS SUPPORTING NUCLEAR ENERGY

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“Leveraging Innovations Supporting Nuclear Energy”**

|  |                               |
|--|-------------------------------|
| Topic Issue Date   | December 20, 2018             |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, February 8, 2019     |
| Submission Deadline for Full Applications  | 9:30 AM ET, February 26, 2019 |
| Expected Date for Selection Notifications  | May 2019                      |
| Total Amount to be Awarded   | Approximately \$8M total      |
| Anticipated Awards   | 3-5 awards                    |
| Maximum Period of Performance  | 24 Months                     |

## 1. Introduction

This announcement describes a research thrust titled “Leveraging Innovations Supporting Nuclear Energy.” 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 development of enabling technologies which will reduce the cost of nuclear energy (2) provide a timetable for the submission of Full Applications.

## 2. Topic Description

For nuclear energy to support U.S. national interests in the coming decades, the next generation of nuclear reactor plants need to simultaneously achieve extremely low construction capital costs, short construction and commissioning times, and “walkaway” safe and secure operation. To attain these goals, innovative, enabling technologies for existing advanced reactor designs<sup>28</sup> are needed. There are many different advanced nuclear reactor designs being developed in the U.S.<sup>29</sup> The collection of these reactor designs has the potential to meet many different market needs of the future: flexible, dispatchable electricity generation; a variety of generation sizes; high-temperature heat; autonomous operations; etc. For these technologies to be successful, however, they need to avoid the challenges faced by the current fleet of nuclear reactors as well as domestic new build projects. Existing nuclear power plants are facing the significant challenge of having comparatively high operational and maintenance (O&M) costs that come from the high staffing level required for operation, maintenance, safety, and security.<sup>30</sup> Many of the Generation III+ reactors under construction have been plagued by

<sup>28</sup> Existing advanced reactor designs include classes of non-light water reactors that are being planned or have been used in the past. This includes designs that use as heat transfer media: gas, lead (or lead-bismuth alloy), molten salt, sodium, supercritical water, organics; and as nuclear fuel types: ceramic oxides, nitride, metal, triso clad, silicon carbide clad, metal clad, liquid eutectic.

<sup>29</sup> <https://www.thirdway.org/graphic/keeping-up-with-the-advanced-nuclear-industry>

<sup>30</sup> Nuclear Energy Institute. *Nuclear Costs in Context*. April 2016.

escalating capital costs and unpredictable construction schedules. Today, only two such Gen III+ Light Water Reactors (LWRs) are scheduled to come online in the U.S. by 2021, significantly behind schedule and over budget.<sup>31</sup>

It is clear that a substantial reduction of construction cost, O&M cost, and construction time, in combination with targeting reactor plant operation for commercial viability, is required to fundamentally enhance the competitiveness and attractiveness of nuclear energy. The ARPA-E MEITNER Program (DE-FOA-0001798)<sup>32</sup> is already investigating several innovative technologies that forward this goal. The purpose of this Targeted Topic is to address key technology gaps in the portfolio.

## A. Technical Areas of Interest

- Approaches employing sensors, data analytics, robotics, and advanced controls (including autonomy and integration of machine learning) that limit or eliminate the need for humans to conduct regular monitoring and maintenance and enable early corrective action for abnormal conditions.
- High-performance moderators for gas-cooled reactors to enable increased power density.
- Advanced power conversion systems for ultra-high temperature (>1500 °C) reactors.
- Flexible power production via technologies that enable physically changing plant power output via sophisticated controls systems or management of reactor feedback behavior, or systems that enable variable output like storing heat for later use.
- Advanced construction techniques for faster, lower-cost construction.

## B. Technical Performance Targets

Table 1 lists the design target areas for this research thrust and provides the current state-of-the-art. Note that these are the same targets as in the ARPA-E MEITNER (DE-FOA-0001798) Program. Applicants are required to address at *least one* area, providing their own targets if the entry is blank. Applicants must detail either (1) how their technology enables the performance specified, or, (2) in the case that this performance is not yet obtainable, a realistic pathway such that the performance may be obtained in a relevant timeframe. Technoeconomic analysis to support claims of impact is required.

**In addition to the requirements stated in the FOA, please include this Table, along with supporting information and analysis in the Potential Impact Section of the Technical Volume. Note that this table will count towards the 14 page limit of the Technical Volume.**

<sup>31</sup> <http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx>,  
<https://www.scana.com/investors/nuclear/questions-answers>

<sup>32</sup> <https://arpa-e.energy.gov/?q=arpa-e-programs/MEITNER>

**Table 1.** Enabling technologies sought by ARPA-E must improve reactor performance in *one or more* target areas.

| ID | Metric  | Units               | State-of-the-Art        | Performance with new technology |
|----|---|---------------------|-------------------------|---------------------------------|
| 1  | Overnight construction cost                         | \$/W <sub>e</sub>   | 2-7 <sup>33</sup>       | < 2                             |
| 2  | On-site construction time                           | Months              | > 60 <sup>34</sup>      |                                 |
| 3  | Total staffing level (on-site & off-site)           | FTE/GW <sub>e</sub> | 450-750 <sup>35</sup>   | < 50                            |
| 4  | Emergency planning zone (EPZ)*                      | Miles               | 10 and 50 <sup>36</sup> |                                 |
| 5  | Time before human response required for an accident | Days                | 3 <sup>37</sup>         |                                 |
| 6  | Onsite backup power                                 | kW <sub>e</sub>     | > 0 kW <sup>38</sup>    |                                 |
| 7a | Ramp rate without steam bypass                      | power capacity/min  | 5% <sup>39</sup>        |                                 |
| 7b | Process heat temperature                            | °C                  | N/A                     |                                 |

\* As measured from the center of the nuclear reactor core to the boundary: location where, during an accident, radiation levels are 0.25 millisieverts/month or less above the background level.

As indicated in the Technical Volume Template heading, specify a technical category: Autonomous Operation, Gas Reactor Moderators, Advanced Power Conversion, Load Following, Advanced Construction. In addition, specify a technical subcategory based on heat transfer medium: Multiple Types / General, Gas, Heat Pipe, Lead, Molten Salt, Sodium, Other.

### 3. Submissions Specifically Not of Interest

- Technologies specifically for LWRs, including Generation III or III+ LWR designs.
- Technology development that is not distinct in approach or objective from activities currently supported by or actively under consideration for funding by any office within the Department of Energy.
- Exploratory work in new nuclear reactor core concepts.

<sup>33</sup> <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx>, <http://www.world-nuclear-news.org/NN-Flamanville-EPR-timetable-and-costs-revised-0309154.html>

<sup>34</sup> <http://www.world-nuclear-news.org/NN-Key-commissioning-test-completed-at-Korean-unit-1711165.html>, <http://www.world-nuclear-news.org/NN-Flamanville-EPR-timetable-and-costs-revised-0309154.html>

<sup>35</sup> <https://www.eucg.org/pub/3ff048c1-f842-57dd-f625-bc35440aa9c4>

<sup>36</sup> <https://www.nrc.gov/about-nrc/emerg-preparedness/about-emerg-preparedness/planning-zones.html>

<sup>37</sup> [http://www.nuscalepower.com/images/our\\_technology/nuscale-safety-nucl-tech-may12-pre.pdf](http://www.nuscalepower.com/images/our_technology/nuscale-safety-nucl-tech-may12-pre.pdf), [https://www.iaea.org/NuclearPower/Downloads/Technology/meetings/2011-Jul-4-8-ANRT-WS/2\\_USA\\_UK\\_AP1000\\_Westinghouse\\_Pfister.pdf](https://www.iaea.org/NuclearPower/Downloads/Technology/meetings/2011-Jul-4-8-ANRT-WS/2_USA_UK_AP1000_Westinghouse_Pfister.pdf)

<sup>38</sup> <https://www.nrc.gov/docs/ML1122/ML11229A062.pdf>

<sup>39</sup> <http://nuclear-economics.com/12-nuclear-flexibility/>

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).



- Technologies for reactors that require fuel enriched to >20%  $^{235}\text{U}$  (if using uranium for fuel) or fuels that are not expected to be available for large-scale commercial deployment in the foreseeable future.
- Regulatory approaches.
- Heat exchangers.



### III. APPENDIX C: DOWNHOLE TOOLS TO ENABLE ENHANCED GEOTHERMAL SYSTEMS

**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“Downhole Tools to Enable Enhanced Geothermal Systems”**

|  |                               |
|--|-------------------------------|
| Notice Issue Date  | December 20, 2018             |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, February 8, 2019     |
| Submission Deadline for Full Applications  | 9:30 AM ET, February 26, 2019 |
| Expected Date for Selection Notifications  | May 2019                      |
| Total Amount to be Awarded   | Approximately \$2M total      |
| Anticipated Awards   | 2-4 awards                    |
| Maximum Period of Performance  | 24 Months                     |

## 1. Introduction

This announcement describes a research thrust titled “Downhole Tools to Enable Enhanced Geothermal Systems”. 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 development of novel, ultra-high pressure and temperature sensors, (2) encourage dialogue amongst those interested in this area, and (3) provide a timetable for the submission of full applications.

## 2. Topic Description

The United States possesses a massive strategic asset in its supply of geothermal energy: deep, extremely hot (3-10 km, 150-350+ °C) enhanced geothermal systems (EGS) represent a potential zero-carbon resource capable of delivering hundreds of gigawatts of baseload electricity with a small land footprint per unit power.<sup>40,41</sup> Moreover, utilizing this resource leverages many of the domestic oil & gas (O&G) industry’s sophisticated subsurface techniques and sources of human capital. However, US geothermal production has been stagnant at 2-3 GW for decades, owing to difficult technical requirements, high risk profiles, long payback times, and geographic limitations for shallow (< 3 km), more easily accessible hydrothermal sites.

EGS has the potential to improve the economics and lessen the geographic restrictions on geothermal energy, but unlocking this resource will require step-changes in reservoir engineering capabilities. In particular, there is a strong need to measure rock stress state,

<sup>40</sup> Tester, J.W., Anderson, B.J., Batchelor, A.S., Blackwell, D.D., DiPippo, R., Drake, E., Garnish, J., Livesay, B., Moore, M.C., Nichols, K. and Petty, S., 2006. The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century. Massachusetts Institute of Technology, 209.

<sup>41</sup> Goldstein, B., Hiriart, G., Bertani, R., Bromley, C., Gutiérrez-Negrín, L., Huenges, E., Muraoka, H., Ragnarsson, A., Tester, J., Zui, V., 2011: Geothermal Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C. (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

temperature, and permeability during reservoir development, as well as geofluid flow rates, temperatures, and steam fractions during operation.<sup>42</sup>

A wide variety of downhole sensing tools have been developed for O&G applications. Many of these tools are rated to 150–175 °C and thus suitable for low-temperature geothermal systems, but there is a substantial technological gap in tools suitable to the high-temperature environments relevant to deep EGS.<sup>43</sup> Further complicating matters, when compared to traditional O&G, EGS rock formations are harder and less homogeneous, fluid compositions can be more corrosive, and operators work within tighter economic constraints.<sup>44</sup> Thus, while tools developed for O&G may provide sources of inspiration, they are far from uniformly transferable to EGS.

ARPA-E seeks novel low-cost sensor technologies capable of mitigating risks and lowering costs in EGS development by better characterizing rock formations and fluid enthalpy at depth. Technologies of interest include but are not limited to fiber-optic sensors and enthalpy measurement devices, as well as companion electronics and communications equipment. Successful projects will facilitate reservoir creation and maintenance, reduce unexpected reservoir behavior, and ultimately lower costs associated with EGS. Successful technologies developed for this purpose may also offer side benefits in applications including O&G, subsurface energy/CO<sub>2</sub> storage, aerospace and automotive engineering, nuclear energy, and space exploration.

## A. Technical Areas of Interest

High-temperature downhole sensing tools for reservoir engineering, including but not limited to the following two categories:

- A. Fiber-optic based sensors, such as distributed acoustic sensing (DAS), distributed temperature sensing (DTS), and distributed strain sensing (DSS).
- B. Sensors that measure geofluid enthalpy; in particular, devices that measure real-time flowrate, temperature, steam fraction and pressure.

Integrated sensors that can serve more than one function over the course of operations (e.g. strain and flow measurements) are encouraged.

<sup>42</sup> Reinsch, T., Dobson, P., Asanuma, H., Huenges, E., Poletto, F. and Sanjuan, B., 2017. Utilizing supercritical geothermal systems: a review of past ventures and ongoing research activities. *Geothermal Energy*, 5(1), p.16.

<sup>43</sup> DeBruijn, G., Skeates, C., Greenaway, R., Harrison, D., Parris, M., James, S., Mueller, F., Ray, S., Riding, M., Temple, L., Wutherich, K., 2008. High Pressure, High Temperature Technologies. *Oilfield Review* p.46.

<sup>44</sup> Gehringer, M., Loksha, V., 2012. *Geothermal Handbook: Planning and Financing Power Generation*. ESMAP Technical Report 002/12. World Bank, Washington, DC.

## B. Technical Performance Targets

Across both categories:

- Continuous (>100 hour) operation at >280 °C/>100 bar/30,000 ppm total dissolved solids (TDS); ideally above >373 °C/>221 bar/300,000 ppm TDS.
- Maximum diameter of 5”.
- > 99% measurement accuracy over instrument lifetime.
- Compatibility with standard signal processing equipment.
- Measurement resolution and sensitivity matching or exceeding the state-of-the-art in analogous sensors made for oil & gas applications.
- Costs, once scaled up, that are no higher than those of analogous sensors made for oil & gas applications.

Specific to Category A:

- Spatial resolution of < 1 m in 10 km.
- Scalability to > 10 km fiber length.

Specific to Category B:

- Measurement location should be precisely known or easily derived.
- Quantification of both low flowrates characteristic of small fractures (Darcy regime) and high flowrates characteristic of wellbores (> 80 kg/s).
- Flow direction measurement capabilities.

## 3. Submissions Specifically Not of Interest

Submissions that propose the following may be deemed nonresponsive and may not merit review or be considered:

- Tools that have a maximum operating temperature of  $\leq 280$  °C.
- Solutions applicable to only shallow (< 3km) depths.
- Incremental advances to existing tools.
- High-temperature electronics/optics without a downhole sensor.
- Models without developing a new technology.
- Development of new wells.
- Improvements to practice without developing a new technology.

#### IV. APPENDIX D: RESERVED

## V. APPENDIX E: RESERVED

## VI. APPENDIX F: HIGH VALUE METHANE PYROLYSIS



**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“High Value Methane Pyrolysis”**

|  |   |
|--|---|
| Topic Issue Date   | May 21 2019   |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, July 16, 2019  |
| Submission Deadline for Full Applications  | 9:30 AM ET, July 26, 2019   |
| Submission Deadline for Replies to Reviewer Comments:                                    | 5 PM ET, Wednesday, September 4, 2019   |
| Expected Date for Selection Notifications  | October 2019  |
| Total Amount to be Awarded   | Approximately \$5.5 million, subject to the availability of appropriated funds.                                   |
| Anticipated Awards   | ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between \$500,000 and \$2.0 million. |
| Maximum Period of Performance  | 24 Months   |

## 1. Introduction

This announcement describes a research thrust entitled “High Value Methane Pyrolysis”. The purpose of this announcement is to (1) focus the attention of the scientific and technical community on specific areas of interest related to methane pyrolysis, (2) encourage dialogue amongst those interested in this area, and (3) provide a timetable for the submission of full applications.

## 2. Topic Description

The United States currently produces about 10 million tons of hydrogen per year, primarily for use at petroleum refineries and for the production of ammonia and methanol. Today, nearly all of hydrogen produced in the US is derived from natural gas via steam methane reforming, a process which converts natural gas and water into hydrogen and carbon dioxide. Steam methane reforming, which is done almost exclusively in centralized facilities, offers the lowest factory gate cost of hydrogen (~\$1.0-\$1.2/kg), but also produces large quantities of carbon dioxide (9-14 kgCO<sub>2</sub>/kgH<sub>2</sub>).<sup>45</sup> While the market demand for hydrogen from steam methane reforming has remained relative steady over the last few years, there is a significant growth potential for hydrogen with a small CO<sub>2</sub> footprint in electricity production, transportation, and novel chemical processes. Already, hydrogen use in the transportation sector has seen rapid growth with 500 megawatts of fuel cells shipped worldwide in 2016.<sup>46</sup> Current options for

<sup>45</sup> Department of Energy Office of Energy Efficiency and Renewable Energy. Fuel Cell Technologies Market Report 2016. [https://www.energy.gov/sites/prod/files/2017/10/f37/fcto\_2016\_market\_report.pdf]

<sup>46</sup> Department of Energy Office of Energy Efficiency and Renewable Energy. R&D Opportunities for Development of Natural Gas Conversion Technologies. [https://www.pnnl.gov/main/publications/external/technical\_reports/PNNL-26726.pdf]

producing hydrogen with little or no release of carbon dioxide include electrolysis of water to hydrogen and oxygen and steam methane reforming with CO<sub>2</sub> capture and sequestration.

A third option is to split methane directly into hydrogen and elemental carbon at high temperatures. *The hydrogen produced in this process, which is also known as methane pyrolysis or methane cracking, would contain roughly half the embodied energy of the natural gas feedstock, while the carbon could be used as a product.* Carbon products that have been produced via methane pyrolysis include metallurgical coke, carbon black, graphite, carbon nanotubes, and carbon fiber.<sup>45</sup>

The economics for methane pyrolysis is made more favorable when the carbon byproduct is valuable<sup>47</sup>, or when the process is made more efficient and/or economical by the use of novel catalyzed processes. Methane can be pyrolyzed with high yields at moderate temperatures on supported or molten metal catalysts (Ni, Co, Fe, Pt, Pd); however, catalysts are rapidly deactivated by solid carbon.<sup>48</sup> Another complication is that processes optimized for hydrogen production may not produce valuable carbon products; optimizing processes for both hydrogen and valuable carbon products concurrently is a daunting challenge. Furthermore, it is important to recognize that, in the context of hydrogen production on an energy-relevant scale, the volumes of co-produced carbon would be very large. For perspective, to produce the amount of hydrogen required to produce 1 quadrillion (10<sup>15</sup>) BTU (1 quad) of energy, over 22 million tons of carbon would be generated. Therefore, potential applications for the resulting carbon products at scale have to be on a correspondingly large scale, e.g., on the scale of the construction sector or large-scale manufacturing industries. These applications will require the carbon materials to have useful macroscopic properties with regard to thermal, electrical, and/or mechanical performance.

*While ARPA-E has already selected for award negotiations a small number of methane pyrolysis projects as part of the OPEN 2018 funding opportunity, ARPA-E has identified an ongoing need to better understand the formation and control the production of specific carbon structures in a process environment that is simultaneously suitable for the economical production of hydrogen at scale (> 10,000 tons/yr.) with a low CO<sub>2</sub> footprint.*

The functional performance of the carbon materials derived by methane pyrolysis will be determined by the molecular structure of the carbon, as well as by the arrangement and alignment of substructures at the nano-or meso-scale. Processes capable of selectively controlling the molecular structure, e.g. via rearrangement of carbon-carbon bonds, and/or the solid phases (i.e. crystal structure or molecular ordering) may have the potential to shift from a lower value carbon to a higher value carbon product. In addition, there is a critical need for high-quality experimental data to better understand, and ultimately control, the elemental steps of forming carbon-carbon bonds and carbon structure development under methane

<sup>47</sup> Keipi, T., Hankalin, V., Nummelin, J., and Raiko, R., Techno-economic analysis of four concepts for thermal decomposition of methane: Reduction of CO<sub>2</sub> emissions in natural gas combustion. Energy Conversion and Management, 2016. 110: p 1-12.

<sup>48</sup> Amin, A. M., Croiset, E., Epling, W. Review of methane catalytic cracking for hydrogen production, International Journal of Hydrogen Energy, 2011, 36, 2904.

pyrolysis conditions. Probing for chemical and/or structural information using non-intrusive in-situ methods at a time scale applicable for realistic process control at scale is a challenge, as are intrusive sampling and ex-situ measurement techniques. Therefore, *ARPA-E is also interested in combining novel integrated catalytic processes to pyrolyze methane with in-situ advanced monitoring and analytical techniques* to enable material development and process optimization to produce low cost hydrogen coupled with higher value carbon products at scale.

## A. Technical Area of Interest

ARPA-E is specifically interested in *integrated and scalable catalytic approaches that can economically convert natural gas to both fuel cell-grade hydrogen and higher value carbon materials* such as carbon fiber or other structural materials with a low CO<sub>2</sub> footprint. (Table 1)

While scalable hydrogen production is the ultimate goal, the emphasis is to advance the identification, understanding, and control of new reaction conditions and processes necessary to direct carbon formation towards desirable product targets. Critical consideration should also be given to both (i) the separation techniques required to economically recover the targeted grades of carbon, and (ii) advanced monitoring tools (in-situ and ex-situ) to enable fundamental understanding of carbon-carbon bond formation, rearrangement, and intermolecular aggregation into valuable carbon products under current methane pyrolysis conditions (20 bar; 800–1100 °C), *in ways that are applicable for real-time process monitoring and control* (i.e. low latency).

## B. Technical Performance Targets

**Table 1:** Catalytic processes to pyrolyze methane to hydrogen and carbon: Performance Targets

| Performance Metric  | Target |
|---|--------|
| Net H <sub>2</sub> Yield% (of theoretical) <sup>(a)</sup>           | > 25   |
| Hydrogen Cost (\$/kg) <sup>(b)</sup>                                | < 1.5  |
| (CAPEX+OPEX) Increase Factor vs SMR+CCS <sup>(b)</sup>              | < 2.5  |
| Carbon Product Price (\$/kg)  | < 5    |
| CO <sub>2</sub> Emissions (kg CO <sub>2</sub> / kg H <sub>2</sub> ) | < 3    |

<sup>(a)</sup> Net H<sub>2</sub> Yield = (mol H<sub>2</sub> produced-mol H<sub>2</sub> used in process)/(2 mol CH<sub>4</sub>).

<sup>(b)</sup> Input parameters, product specifications and methodology as defined in H2A DOE model, 380 t H<sub>2</sub> / day centralized H<sub>2</sub> generation.<sup>(49,49)</sup>

Note that these targets are intentionally flexible. For example, a higher cost process that also produced higher value carbon may be more attractive than a lower cost process that can't be controlled well enough to produce a high value carbon product. Applicants are expected to utilize the methodology described in the H2A DOE model (centralized hydrogen production

models)<sup>(49,50)</sup> to project the performance metrics listed in Table 1 for their proposed process, and specify the size of the intended market and expected properties (i.e. electrical, mechanical) for the carbon co-product. Applicants must also include a description of the separating techniques and any advanced monitoring tools, as described in Section 2.A. above, that would be necessary for successful completion of the proposed approach.

### 3. Areas Specifically Not of Interest

Submissions that propose the following may be deemed nonresponsive and may not merit review or be considered:

- Approaches that produce carbon materials primarily intended as filler in composites where the performance properties of the composite are defined primarily by the binder and not the carbon material.
- Approaches that produce carbon materials from non-gaseous feedstocks, e.g. pitch or polyacrylonitrile (PAN)
- Approaches that are unscalable.
- Approaches based on solar-thermal methane pyrolysis.
- Standard IR, Raman, UV-Vis, microscopy techniques for ex-situ analysis of polyaromatic hydrocarbons

<sup>49</sup> <https://www.nrel.gov/hydrogen/h2a-production-models.html>, centralized hydrogen production model, v3 2018.

<sup>50</sup> <https://www.nrel.gov/hydrogen/h2a-production-case-studies.html>, case study: central natural gas, future central hydrogen production from natural gas with CO2 sequestration version 3.2018

## VII. APPENDIX G: Supporting Entrepreneurial Energy Discoveries

**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“Supporting Entrepreneurial Energy Discoveries (SEED)”**

|  |   |
|--|---|
| Notice Issue Date  | August 7, 2019  |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, September 27, 2019   |
| Submission Deadline for Full Applications  | 9:30 AM ET, October 8, 2019   |
| Expected Date for Selection Notifications  | December 2019   |
| Total Amount to be Awarded   | Approximately \$10 million, subject to the availability of appropriated funds.  |
| Anticipated Awards   | ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between \$200,000 and \$500,000. Awards up to and including \$250,000 will be issued as Phase I grants; Awards that are over \$250,000 will be issued as Phase I/II grants, with a go/no-go milestone at the end of Phase I. |
| Maximum Period of Performance  | 24 Months   |

## 1. Introduction

This announcement describes a research thrust entitled “Supporting Entrepreneurial Energy Discoveries (SEED)”. The purpose of this announcement is to (1) focus the attention of the scientific and technical community to disruptive concepts in energy-related technologies, (2) encourage dialogue amongst those interested in this area, and (3) provide a timetable for the submission of full applications.

## 2. Topic description

The broad objective of SEED is to identify and support disruptive concepts in energy-related technologies within small businesses, including collaborations with universities and national labs. Projects funded through SEED 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 reductions in U.S. energy consumption (measured in quads), energy-related imports (measured in quads), or energy-related emissions (measured in megatons/gigatons of CO<sub>2</sub> or CH<sub>4</sub>, etc.). Awards under this program will support research projects that establish potential new areas for technology development and provide ARPA-E with information that could lead to new ARPA-E 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 for new energy technologies.



## A. Technical Areas of Interest

Applications are sought that address one or more of ARPA-E's Mission Areas (see Section I.A.). Each Applicant must explain how the proposed concept represents a transformative approach. Applicants may propose technology development efforts with the potential for high impact in ARPA-E Mission Areas, but there is special interest in the following topics:

- Advanced bioreactors for production of complex, value-added materials to significantly reduce greenhouse gas emissions
- Approaches and tools to create enhanced geothermal systems above 300 °C without hydraulic stimulation
- Non-evaporative dehydration and drying technologies
- Approaches to significantly enhance the rate and/or potential scale of carbon mineralization, either *in situ* or *ex situ*
- Separation of CO<sub>2</sub> from ambient air (direct air capture)
- High-rate separation of dissolved inorganic carbon from the ocean to produce a CO<sub>2</sub> stream
- Advanced trees and other engineered biological systems for carbon sequestration
- Innovative deep ocean collector designs for mining polymetallic nodules
- Environmental sensors capable of operation in deep ocean environments for mining polymetallic nodules
- Non-carbothermic smelting technologies

## 3. ARPA-E Funding Agreement

ARPA-E anticipates awarding fixed-amount grants resulting from this Targeted 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. Equal payments will be made, one each upon submission and acceptance by ARPA-E of the quarterly report demonstrating sufficient technical progress. 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 submit a final technical report to ARPA-E and 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 Targeted Topic is \$500,000. Notwithstanding the requirement set forth at FOA Section III.E, cost share is not required for awards resulting from this Targeted Topic.



#### 4. Content and Form of Full Applications

Notwithstanding the instructions at FOA Section IV.C, the content of Full Applications for this Topic are limited to the following:

| Component  | Required Format | Description and Information  |
|--|-----------------|--|
| <b>Technical Volume (Fixed-Amount Grant)</b>   | 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 ( <a href="https://arpa-e-foa.energy.gov/">https://arpa-e-foa.energy.gov/</a> ).<br><br><b>Note – Section and page maximums for this Topic’s Technical Volume differ from the standard Technical Volume Template under this FOA.</b>  |
| <b>SF-424</b>  | PDF             | Application for Federal Assistance ( <a href="https://arpa-e-foa.energy.gov/">https://arpa-e-foa.energy.gov/</a> ). Applicants are responsible for ensuring that the proposed amounts listed in eXCHANGE match those listed on forms SF-424 and SF-424A. Inconsistent submissions may impact ARPA-E’s final award determination.   |
| <b>SF-424A (Fixed-Amount Grant)</b>  | XLS             | Budget Information – Non-Construction Programs ( <a href="https://arpa-e-foa.energy.gov/">https://arpa-e-foa.energy.gov/</a> )   |
| <b>SBA Company Registration Certificate</b>  | PDF             | Registration Certificate generated upon completion of registration in the SBA Company Registry ( <a href="http://sbir.gov/registration">http://sbir.gov/registration</a> ).  |
| <b>Certification for Applicants Majority-Owned by Multiple Venture Capital Operating Companies, Hedge Funds, or Private Equity Firms (if applicable)</b> | PDF             | Requires SBIR Applicants that are majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms to self-identify and verify registration as such in the SBA Company Registry ( <a href="http://sbir.gov/registration">http://sbir.gov/registration</a> ).   |
| <b>Business Assurances &amp; Disclosures Form</b>  | PDF             | Requires the Applicant to make responsibility disclosures and disclose potential conflicts of interest within the Applicant Team. Requires the Applicant to 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 the Applicant is a FFRDC/DOE Lab, requires the Applicant to provide written authorization from the cognizant Federal agency and, if a DOE/NNSA FFRDC/DOE Lab, a Field Work Proposal. Allows the Applicant to request a waiver or modification of the Performance of Work in the |

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

| Component                      | Required Format | Description and Information  |
|--------------------------------|-----------------|--|
|                                |                 | United States requirement. This form is available on ARPA-E eXCHANGE at <a href="https://arpa-e-foa.energy.gov/">https://arpa-e-foa.energy.gov/</a> . A sample response to the Business Assurances & Disclosures Form is also available on ARPA-E eXCHANGE.  |
| <b>U.S. Manufacturing Plan</b> | PDF             | As part of the application, Applicants are required to submit a U.S. Manufacturing Plan. The U.S. Manufacturing Plan represents the Applicant's measurable commitment to support U.S. manufacturing as a result of its award. See detailed U.S. Manufacturing Plan instructions and examples in the Seventh Component description below. |

Detailed guidance on the content of the Technical Volume, SF-424, Business Assurances & Disclosures Form, and U.S. Manufacturing Plan can be found in FOA Section IV.C at paragraphs One, Two, Eight and Nine respectively. Guidance on the content of the SF-424A can be found on its p.2.

Templates for preparing Full Applications under this Targeted Topic may be found on ARPA-E Exchange at [ARPA-E-CO@hq.doe.gov](mailto:ARPA-E-CO@hq.doe.gov).

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## **VIII. APPENDIX H: Establishing validation sites for field-level emissions quantification of agricultural bioenergy feedstock production**

**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“Establishing validation sites for field-level emissions quantification of agricultural bioenergy feedstock production”**

|  |   |
|--|---|
| Topic Issue Date   | September 17, 2019  |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, November 7, 2019   |
| Submission Deadline for Full Applications  | 9:30 AM ET, November 18, 2019   |
| Submission Deadline for Replies to Reviewer Comments:                                    | 5 PM ET, <b>Wednesday December 11, 2019</b>   |
| Expected Date for Selection Notifications  | <b>January 2020</b>   |
| Total Amount to be Awarded   | Approximately \$10.0 million, subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0001953 and DE-FOA-0001954 for this Targeted Topic. |
| Anticipated Awards   | ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between \$100,000 and \$3.61 million.  |
| Maximum Period of Performance  | 36 Months   |

## 1. Introduction

This announcement describes a research thrust titled “Establishing validation sites for field-level emissions quantification of agricultural bioenergy feedstock production.” The purpose of this announcement is to (1) focus attention of technical and research communities on the challenges and benefits of establishing “ground truth” sites in feedstock production environments as a means to validate emerging sensors and sensor systems capable of quantifying field-level emissions, (2) encourage dialogue amongst technology developers, feedstock producers and relevant agricultural stakeholders about leveraging these field sites, and (3) provide a timetable for the submission of Full Applications.

## 2. Topic Description

The United States produces ~16 billion gallons of ethanol annually, meeting ~1% of our nation’s

energy needs.<sup>51</sup> The primary feedstock for ethanol production is starch from corn and sorghum, making the ethanol industry one of the largest consumers of domestic grain (38% in 2018).<sup>52</sup> Ethanol and other bio-based fuels have the potential to provide an emissions-free source of energy on a net basis<sup>53</sup>, but not without a shift in feedstock production practices. Current feedstock production practices are driven by yield, and low profit margins leave feedstock growers with limited options for increasing productivity; often, this comes in the form of over-fertilization, which produces unnecessary emissions,<sup>54</sup> impacts water quality,<sup>55</sup> and has uncertain returns (e.g. an estimated \$267–702 million dollars of fertilizer value is lost each year<sup>56</sup>). While these impacts become clear when aggregated to the regional or national scale, field-level contributions remain unknown. This lack of visibility, combined with the absence of economic incentives beyond yield, leaves feedstock producers to estimate and assume the risk of new management practices to their primary revenue stream (i.e. yield). By establishing sites and protocols for measuring the impact of management practices on both yield and emissions (CO<sub>2</sub> equivalent), this funding opportunity aims to bridge the technology gap between feedstock producers and existing market incentives that can de-risk sustainable management practices and defray the cost of monitoring their impact.

Analysis by Argonne labs using the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model provides a complete lifecycle analysis (LCA) of transportation fuels including gasoline and ethanol derived from multiple different feedstocks.<sup>57</sup> On average, grain production accounts for 36% of the fuel production life cycle; however, there is a broad range of yields and efficiencies across different regions and significant room for improvement to both. New developments in digital agriculture, analytics, sensor engineering, and identity preservation developed for medical and security purposes are primed for adaption to agricultural production systems to create new monitoring and decision support systems.<sup>58</sup> These datasets have the potential to drive new value streams through ecosystem service markets focused on reducing emissions and improving soil quality. While downstream stages of ethanol production are already realizing significant value through existing markets (e.g. California's Low-Carbon Fuel Standard), grain producers do not have access to those markets because they lack reliable, and cost-effective, methods of quantifying ecosystem impacts.

<sup>51</sup> EIA Monthly Energy Review, Table 10.3 from the U.S. Energy Information Administration

<sup>52</sup> United States Department of Agriculture Economic Research Service Feed Grain Yearbook. Total Production category and Feed and Residual Use category collected from Table 4, Produced for Other Uses category and Used for Ethanol category collected from Table 31. Last Accessed 1/10/2019

<sup>53</sup> Includes assumptions about soil organic carbon storage potential – see the ARPA-E ROOTS FOA (DE-FOA-0001565) for more details.

<sup>54</sup> EPA. 2019. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017 (Chapter 5: Agriculture).

<sup>55</sup> USGS. Nitrogen and Water. [https://www.usgs.gov/special-topic/water-science-school/science/nitrogen-and-water?qt-science\\_center\\_objects=0#qt-science\\_center\\_objects](https://www.usgs.gov/special-topic/water-science-school/science/nitrogen-and-water?qt-science_center_objects=0#qt-science_center_objects)

<sup>56</sup> Basso, Bruno, et al. "Yield stability analysis reveals sources of large-scale nitrogen loss from the US Midwest." *Scientific reports* 9.1 (2019): 5774.

<sup>57</sup> <https://greet.es.anl.gov/>

<sup>58</sup> ARPA-E 2018 Workshop: The Energy-Smart Farm: Distributed Intelligence Networks for Highly Variable and Resource Constrained Crop Production Environments. <https://arpa-e.energy.gov/?q=workshop/energy-smart-farm-distributed-intelligence-networks-highly-variable-and-resource>

Accurate quantification of field-level inputs, emissions, and yield would allow producers to participate in these existing markets, complementing existing yield-based revenues with economic incentives for input efficiency and restorative practices. While initially applying to existing markets, which could extend to biomass crop feedstocks, these tools could also be applied to production agriculture more broadly to improve its energy balance.

Precision agriculture, including variable prescriptions for seed and chemical inputs, is critical to improving production efficiency. Economic forces have hindered adoption of technology for grain production, and decision support and agronomic advice based on sensor data is lacking as innovators from other communities have only recently become interested in working in agriculture. Furthermore, the R&D community lacks methods for validating the performance of new technologies, particularly in large-scale feedstock production environments. Establishing methods for validating commercial solutions for field-level emissions quantification is essential to building stakeholder trust in these technologies and the markets they feed into.

ARPA-E will provide financial support to teams that include production farms that could market directly to ethanol and other biofuel producers to develop datasets of current production inputs (e.g. fertilizer, chemicals, fuel) and outcomes (e.g. yield, emissions, water quality) in a commercial production environment. In doing so, this funding opportunity aims to fund the creation of “gold-standard” datasets to (i) pilot data capture and transfer methods for supply-chain-wide LCA, (ii) validate new, low-cost technology approaches to measuring and improving feedstock production efficiency, and (iii) provide new high-resolution data to the R&D community for technology development (e.g. remote sensing to reduce physical footprint of high-resolution monitoring; new modeling, prediction and extrapolation techniques).

## **A. Technical Areas of Interest & Performance Targets**

ARPA-E seeks to fund the development of “ground truth” solutions that establish measurements and protocols for emissions monitoring at the field level and provide agronomic insight. The primary goal of this targeted topic is to fund project teams to establish publicly available open-source, high-resolution datasets to support testing and validation of emerging biofuel production monitoring technologies. A submission to this Targeted Topic must include an applicable commercial field site (described in more detail below) and describe the Applicant’s ability to:

- Establish a data protocol (e.g. modality, spatial resolution, and frequency) for quantifying field-level emissions, including soil carbon storage.
- Develop clear methods for assessing commercial solutions for emissions quantification at the field level.
- Garner stakeholder input and collaboration across the supply chain.
- Secure and share field-level datasets (i.e. open access data) both during and after the period of performance.



- Engage community members across the energy-water-food nexus to share best practices, collaborate on technology challenges, and encourage data standardization and transparency.

**Data requirements:** The data requirements listed below are intended to serve as a framework and should be considered a minimum requirement for quantifying (i) fertilizer-induced emissions, (ii) biomass-induced emissions, (iii) biomass nitrogen content, and (iv) soil organic carbon (SOC) sequestered at high accuracy and precision.

Applicants must define how they will ensure data quality and data security. Applicants must also describe how and for how long they will make the data sets publically available. ARPA-E is agnostic to the measurement approach used to monitor yields, crop status, and agronomic inputs.

**Sampling requirements for soil and plant data verification:**

| Sample                               | Requirement   |
|--------------------------------------|---|
| Soil (health/nutrient monitoring)    | 3-5 stratified samples per acre (0-30, 30-60, and 60-100 cm) every year |
| Plant (nutrient monitoring)          | Minimum of 5 tissue samples per acre per year                           |
| Plant composition (fiber, ash, etc.) | Minimum of 3 plant sample per acre post harvest per year                |

**Additional measurement requirements\*:**

| Data  | Unit  | Minimum resolution | Minimum Frequency   |
|---|---|--------------------|---|
| Yield   | kg/acre (dry)   | Acre               | Seasonal  |
| Soil pH   | pH  | Subacre            | Seasonal  |
| Soil carbon (1 m depth; measurements at 0-30, 30-60, and 60-100 cm)                   | %   | Acre               | Annual  |
| Soil temperature  | C/F   | Subacre            | Daily   |
| Soil moisture   | %   | Subacre            | Daily   |
| Gas exchange** - CO <sub>2</sub> , N <sub>2</sub> O, CH <sub>4</sub>                  | ppb (N <sub>2</sub> O);<br>ppm (CO <sub>2</sub> , CH <sub>4</sub> ) | Field              | Continuous (i.e. >90% data capture on a second-by-second basis) |
| Wind speed & direction  | m/s   | Field              | Continuous  |
| Solar radiation   | w/m <sup>2</sup>  | Field              | Continuous  |
| Water quality - Sediment, NO <sub>3</sub> <sup>-</sup> , NH <sub>4</sub> <sup>+</sup> | ppm   | Field              | Per flow event  |

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).



\*This table is intended to provide a minimum set of data requirements for the validation sites; it is not a comprehensive list.

\*\*Gas exchange should be monitored according to the state of the art methods described in: Nemitz, Eiko, et al. "Standardisation of eddy-covariance flux measurements of methane and nitrous oxide." International agrophysics 32.4 (2018): 517-549.

**Site requirements:** Project funds should be used to support measurements and protocols for emissions monitoring at the field level, which can include farm auditing by life cycle experts to verify the data quality and estimate production efficiency. Teams must be willing to provide access to their sites for the purpose of deploying sensing technologies on a seasonal basis for the duration of the project.

ARPA-E is specifically interested in field sites for biofuel feedstock production that are:

- (1) Directly marketing to biofuel producers
- (2) Geographically representative (e.g. different climates, soils)
- (3) Capable of meeting the site and equipment requirements listed below:

| "Ground Truth"<br>Component | Requirement(s)   |
|-----------------------------|--|
| Site Selection              | <ul style="list-style-type: none"> <li>• Commercial feedstock production setting</li> <li>• 3-4 representative sites per crop/team</li> <li>• Minimum 85 acres per site</li> <li>• Minimum of 1 letter of support for land lease</li> </ul>          |
| Equipment                   | <ul style="list-style-type: none"> <li>• Eddy covariance for GHG flux measurement</li> <li>• Weather station for real-time data</li> <li>• Yield, management and input mapping*</li> <li>• High speed data coverage across the test sites</li> </ul> |

\* Additional information such as planting, fertilization, and harvest timing; input type (e.g. manure, ammonium nitrate) and application method; soil management practices (e.g. tillage, cover crops and residues, etc.); and pesticide/herbicide/fungicide type and application rates and timing, must be captured.

### 3. Areas Specifically Not of Interest

Submissions that propose the following may be deemed nonresponsive and may not be merit reviewed or considered:

- R&D, pilot, or any other non-commercial field sites
- Monitoring approaches that solely, or heavily, rely on novel and unproven sensing techniques
- Approaches that solely, or heavily, rely on simulation-based monitoring
- Incomplete teams (e.g. sensor developers without production and/or analytics partners) or measurement frameworks (e.g. soil monitoring without aboveground emissions monitoring)

#### 4. Cost Sharing

Notwithstanding the requirement set forth at FOA Section III.E, cost share is not required for awards resulting from this Targeted Topic.

## IX. APPENDIX I: RESERVED

**X. APPENDIX J: Biotechnologies to Ensure a Robust Supply of Critical Materials for Clean Energy**

**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“Biotechnologies to Ensure a Robust Supply of Critical Materials for Clean Energy”**

|  |   |
|--|---|
| Topic Issue Date   | March 4, 2020   |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, Monday, April 27, 2020   |
| Submission Deadline for Full Applications  | 9:30 AM ET, Thursday May 7, 2020  |
| Submission Deadline for Replies to Reviewer Comments:                                    | 5 PM ET, Monday June 22, 2020   |
| Expected Date for Selection Notifications  | August 2020   |
| Total Amount to be Awarded   | Approximately \$5,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0001953 and DE-FOA-0001954 for this Targeted Topic. |
| Anticipated Awards   | ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between \$500,000 and \$1,500,000.   |
| Maximum Period of Performance  | 24 Months   |

## 1. Introduction

This announcement describes an exploratory research thrust titled “Biotechnologies to Ensure a Robust Mineral Supply Chain for Clean Energy.” The purpose of this announcement is to (1) solicit Full Applications from the technical and research communities to address mining supply challenges on the exploration/sensing, extraction, separation, recovery and purification of critical materials (CMs) using a variety of feed-mineral sources, (2) encourage partnerships with existing mining stakeholders, and (3) provide a timetable for the submission of Full Applications.

## 2. Topic Description

The U.S. Department of Energy’s Advanced Research Projects Agency – Energy (ARPA-E) is interested in receiving Full Applications in support of addressing mining industry challenges. The broad objective of this topic is to identify research that supports a robust supply of certain metals and elements in the U.S. via biological-based/bio-augmented processes across the entire mining supply chain including exploration and sensing, mining (extraction), separation, recovery, refining, and recycling.

## A. Topic Overview

With global competition for minerals in emerging tech, defense, and energy applications, any shortage of critical resources “constitutes a strategic vulnerability for the security and prosperity of the United States.”<sup>59</sup> The U.S. Department of the Interior (DOI) has recently issued a list of such materials, which include<sup>60</sup>: 1) Rare Earth Elements (REEs) consisting of the Lanthanide series (La-Lu) as well as yttrium and scandium; 2) The Platinum Group Metals (PGMs); and 3) Select members of the CM list as follows: cobalt, fluorspar (CaF<sub>2</sub>), manganese, niobium and tin.

In addition to the CMs identified by DOI, other base transition metals of interest for this ARPA-E program are Nickel (Ni) and Copper (Cu). In 2018, the global Ni demand for Li-ion batteries was 85,000 tons and this is expected to increase by 30-40% per year<sup>61</sup>. The U.S. nickel production represents less than 1% (19,000 tons) of the total global production.

While the U.S. is the third largest global copper producer - with 1.2 million tons produced in 2018 - just behind Chile and Peru<sup>62</sup>, the unique thermal and electrical properties of this metal make it a crucial element for energy efficiency applications. The issues around this material are production costs due to declining domestic ore grades and the associated energy along with environmental concerns around Cu extraction and processing.

Bio-based mining technologies offer potential advantages of lower energy requirements and production of less amounts of hazardous by-products, making them a potentially promising option for domestic CM, Ni, and Cu production. However, these techniques remain largely unproven, especially at scale.

## B. Technical Areas of Interest

ARPA-E seeks novel and transformative technical approaches in microbiology, synthetic biology, and process engineering to harness nature’s tools<sup>63</sup> to produce a robust, clean, non-toxic, and low-cost supply of CMs identified above, Ni, and Cu. **For all categories in this FOA**, applicants

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<sup>59</sup> “Interior Seeks Public Comment on Draft List of 35 Minerals Deemed Critical to U.S. National Security and the Economy”, U.S. DOI press release, February 16, 2018. [<https://www.doi.gov/pressreleases/interior-seeks-public-comment-draft-list-35-minerals-deemed-critical-us-national>]

<sup>60</sup> “Final List of Critical Minerals 2018”. U.S. DOI, Office of the Secretary, Federal Register/ Vol. 83, No 97 p. 23295 May 18, 2018 [<https://www.govinfo.gov/content/pkg/FR-2018-05-18/pdf/2018-10667.pdf>]

<sup>61</sup> Written Testimony of Simon Moores, Managing Director, Benchmark Mineral Intelligence, before US Senate Committee on Energy and Natural Resources, February 5, 2019. [[https://www.energy.senate.gov/public/index.cfm/files/serve?File\\_id=9BAC3577-C7A4-4D6D-A5AA-33ACDB97C233](https://www.energy.senate.gov/public/index.cfm/files/serve?File_id=9BAC3577-C7A4-4D6D-A5AA-33ACDB97C233)]

<sup>62</sup> *Ibid*

<sup>63</sup> It is estimated that about half of all proteins in nature have a metal co-factor.

are encouraged to discuss in their Technical Volume how their proposed concept will impact any one or more of the following:

- The advancement of the fundamental understanding of the complex functionality of multispecies consortia in biomining;
- The understanding of fundamental reaction mechanism and thermodynamic constants;
- The development of new or advancement of existing analytical techniques;
- the potential for concurrent extraction and recovery of “non-critical” elements like manganese, gold, iron<sup>64</sup>, and phosphorous, or compounds like limestone and silicates, or radioactive materials, like uranium and thorium, that may become associated co-products in the proposed extraction of the CMs, and
- The potential development of a bioinformatic database on biomining.

### **CATEGORY 1 – Mineral Pre-processing**

Mineral pre-processing may include exploration approaches to better understand the ores and beneficiation steps that would ultimately improve the economic outlook of the entire mining operation.

- Novel ideas for the use of microbes to pretreat potential mining sites. For example, injecting microbes into mining sites to increase mining yields once the production cycle starts.
- Novel bio-comminution techniques. Mineral-feed weakening and breakage (i.e., crushing, grinding and pulverizing) is usually the most energy intensive and costly step in the mining process accounting for 65 to 80% of the total energy consumption. E.g., geomicrobiology.<sup>65</sup>
- Novel bio-beneficiation techniques to pre-concentrate materials and minimize the size of downstream treatment. For example, the use of biopanning (phage display)<sup>66</sup> to produce biosurfactants to selectively float mineral particles; REE-presorption using macroorganisms such as macroalgae and duckweed; among others.
- Novel low cost, portable, minimal interference spectrometers for sensing of CMs. For example, bio-inspired luminescence-based sensors that can rapidly and selectively screen between REE-rich and REE-poor sources.

### **CATEGORY 2 – Biomining**

Biomining, also known as bioleaching (dissolution of the target-metal) or biooxidation (dissolution of the target-metal surrounding matrix), is a process where an electron interplay takes place between metal-containing materials (like ores) and microorganisms (like bacteria or

<sup>64</sup> For example, the utilization of Ferredox-type processes (e.g., combination of elemental sulfur oxidation with ferric iron reduction to obtain nickel from goethite or limonite ores) that would yield recovered iron.

<sup>65</sup> Gadd G.M. “Metals, minerals and microbes: geomicrobiology and bioremediation”, *Microbiology* (2010) 156 p. 628 [https://doi.org/10.1099/mic.0.037143-0].

<sup>66</sup> Phage display refers to the use of virus to infect bacteria (bacteriophages) to produce selective peptides.



fungi) with the objective to facilitate the solubilization and recovery of metals. These biotechnological processes could significantly facilitate the extraction of critical metals. The extraction may occur by secretion of organic acids, cell metal intake, or via metabolic use of metal in aerobic or anaerobic respiration.

a) Natural cell approach

- Discovery and identification of relevant biomining microbes and consortia candidates living in habitats like mine waters or degraded gas & oil pipelines that demonstrate high biocatalytic activity towards CM extraction/oxidation (e.g., microbial-mediated metal leaching), high electron exchange capacity with CMs, high resistance to extreme conditions like metallic ions, metabolic dependences (e.g. REE-dependent bacteria like *M. extorquens*).
- Understanding the functionality of naturally occurring microbial communities in biomining, as opposed to single-species systems. The whole-community genetic capacity could be studied by metagenomics and metatranscriptomics sequencing analysis to better understand the performance of multispecies assemblages. For example, the understanding of biopassivation effects whereby one strain solubilizes a CMs while another irreversibly sequesters it to inhibit the formation of a toxic environment.
- Methods to increase resistance and adaptation of natural cells. For example, adaptive evolution, acclimation, natural mutagenesis followed by selection of media containing metals.
- Novel mineral-concentration methods that can be employed in combination with biomining to minimize the amount of materials being processed downstream. For example, microorganisms that demonstrate high mineral bioaccumulation rates (hyperaccumulation) inside the cell (as pure metal, metal compounds, nanoparticles) or outside the cell (selective CM-biosorption).

b) Engineered cell approach

- Synthetic biology to target the design of specific metal-binding proteins, enzymes, chelators, siderophore-like molecules (e.g., lanthanophores), or sequestration systems. For example, the metabolic engineering of microbes to over produce REE-binding proteins, similar to lanmodulin.
- Engineered microbes that overproduce acid biolixiviants solutions of organic acids (e.g., citric, oxalic, tartaric, gluconic) and acid combination suites.
- Identification and regulation of genes/gene clusters associated with stress-responses - to the presence of acid, metal, osmotic stress and temperature – and genetic modifications to prevent/disrupt passivation effects. For example, genetic engineering of candidate genes into a microbial extremophile that already have a desired level of environmental tolerance to pH and/or temperature; engineered-cells for the production of passivation-inhibitors.
- Genetic modifications that allow for enhanced bioleaching, surface-mediated biomining, selective bioaccumulation, immobilization, and mineralization of CMs. For example, genetically-modified microalgae to enhance metal recovery.

### CATEGORY 3 – Mineral Post-processing

CMs post-processing may involve costly recovery, separation, and concentration steps. These steps may be integrated to the previous step (biomining), done separately or even eliminated. Under this category, we seek solutions involving:

- Novel microbial reduction and recovery techniques that transform critical elements into valuable, saleable products. For example, a process where a microorganism reduces  $\text{PdCl}_4^{2-}$  into its metallic nanoparticle form ( $\text{Pd}^0$ ) that can be used directly in the manufacturing of palladium-supported catalysts.
- The separation of individual rare earths elements remains a significant challenge. The refining of mixed metals into individual metals is of interest. For example, the use of selective natural or bioengineered proteins or cell surfaces<sup>67</sup> that can allow bioaffinity-based purification processes.
- Processes that minimize the energy intensity for the recovery of CMs from highly dilute streams. For example, phytomining<sup>68</sup>, biomining/bioassembly approaches, living filters, and other bioseparation matrices, such as membranes.

### CATEGORY 4 – Supplementary Abiotic Processing

ARPA-E recognizes that hybrid approaches that couple one (or more) abiotic steps in the CM sourcing pathway may provide a more concentrated, economical, and scalable solution. Examples of such supplementary processes may include but are not limited to the use of robots for surgical extraction of CM-containing components from electronic waste; electrochemical or electromagnetic treatment that transforms primary or secondary mineral sources into amenable bioleaching feed-material; acoustic dissolution to produce aqueous solutions rich in CMs; selective lixiviant extractions; carbon dioxide extractions (e.g., mineral carbonations to produce metal-carbonates, CM supercritical  $\text{CO}_2$  extractions); task-specific ionic liquids (TSILs); fabrication processes that make use of chemical states as presented by bio-extraction.

## C. Technical performance targets

**In addition to the requirements stated in this FOA, please include all items listed on Tables 1 and 2 in the Technical Volume. Note that these tables will count toward the 14-page limit of the Technical Volume. Also, if the proposed solution applies to more than one category (e.g., process intensification), clearly indicate so in the Technical Volume.**

Guidance on the cost (\$/kg) of some CMs is publicly available<sup>69</sup>. However, in this FOA, we

<sup>67</sup> Chang E. et al. "Surface complexation model of rare earth element adsorption onto bacterial surfaces with lanthanide binding tags" *Applied Geochemistry* 112 (2020) 104478 p.1 [https://doi.org/10.1016/j.apgeochem.2019.104478]

<sup>68</sup> Plants that accumulate high concentrations of metals.

<sup>69</sup> Leader A. et al. "The effect of critical material prices on the competitiveness of clean energy technologies" *Materials for Renewable and Sustainable Energy* (2019) 8:8 p.1-17 [https://doi.org/10.1007/s40243-019-0146-z]

assume that mining costs will closely follow both material and energy (M&E) balance performance and the metric space is built around these fundamental concepts. Use **1 tonne of product** as the basis for calculation.

**Table 1.** Performance targets

| Metric                        | Applicable to Category | State-of-the-art (SOA)                             | Performance target with proposed technology   |
|-------------------------------|------------------------|--|---|
| Material balance <sup>a</sup> | 1-4                    | To be derived in detail and submitted by applicant | * Zero toxic tailings left behind <sup>b</sup><br>* Concurrent liberation of $\geq 90\%$ beneficial coproducts (if any) |
| Energy balance <sup>a</sup>   | 1-4                    | To be derived in detail and submitted by applicant | $\geq 50\%$ energy savings over SOA <sup>c</sup>  |

<sup>a</sup> Applicants are expected to follow standard chemical engineering guidelines to produce the material & energy balances for both the SOA and proposed technology processes. Please review **Example 1** below and note that ARPA-E expects to review a complete pathway (e.g., ore-to-refined CM) not just a single unit operation. While M&E balances emphasis can be given to the proposed step(s), the respondent is responsible to provide a complete M&E balance for the pathway and is encouraged to use conventional/SOA processes to complete the processing steps in the pathway.

<sup>b</sup> The material balance has to be detailed enough to allow the reviewing team to quantify the amount of left over materials (e.g., tailings) (if any) for the proposed process.

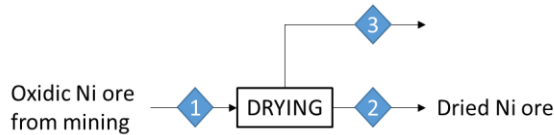
<sup>c</sup> The energy target may be flexible for tradeoffs where, for example, the CM extraction yield or CM level of concentration is substantially increased over the SOA while maintaining the same level of energy demand of SOA (i.e., no energy savings).

### Example 1. Material & Energy Balance in the Conventional Production of Nickel

The conventional pathway for producing metallic nickel from oxidic nickel minerals involves ore mining, drying or calcination, pyrometallurgical steps (roasting and smelting), followed by hydrometallurgical and refining steps. The following diagram details the drying step of a low grade oxidic nickel ore (please note that the FOA response should include a complete pathway). The drying step will remove most of the moisture in the ore. The M&E balance basis is 1 tonne of nickel product.

### Material Balance for ore drying

All units in kg:



\* Add as many materials as needed.

\*\* Add as many streams as needed

| Material*  | Stream 1       | Stream 2                  | Stream 3      | ** |
|--|----------------|---------------------------|---------------|----|
| Ni   | 1,000          | 1,000                     | -             |    |
| Si   | 70,540         | 70,540                    | -             |    |
| Mg   | 43,782         | 43,782                    | -             |    |
| Fe   | 33,472         | 33,472                    | -             |    |
| Ca   | 20,944         | 20,944                    | -             |    |
| S  | 4,891          | 4,891                     | -             |    |
| H <sub>2</sub> O (moisture and chemically bound) | 77,989         | 19,497 (chemically bound) | 58,492        |    |
| SO <sub>2</sub>                                  | -              | -                         | -             |    |
| O <sub>2</sub> (from air)                        | -              | -                         | -             |    |
| Other minerals                                   | 20,345         | 20,345                    | -             |    |
| <b>Total</b>                                     | <b>272,963</b> | <b>214,471</b>            | <b>58,492</b> |    |

### Energy Balance for ore drying

The theoretical amount of energy required ( $Q_{\text{drying}}$ ) to dry the nickel ore is:

$$Q_{\text{drying}} = m_{\text{ore}} \cdot c_p \text{ ore} \cdot \Delta T + m_{\text{moisture}} \cdot c_p \text{ water} \cdot \Delta T + m_{\text{moisture}} \cdot \Delta H_{\text{vap}}$$

Where  $m_{\text{ore}}$  is the dry mass of the ore (214,471 kg),  $c_p$  is the average heat capacity of the ore (0.4 kJ/kg · K),  $\Delta T$  is the temperature difference (373 K-293 K= 80 K),  $m_{\text{moisture}}$  is the mass of moisture (58,492 kg),  $c_p \text{ water}$  is the heat capacity of water (4.187 kJ/kg · K) and  $\Delta H_{\text{vap}}$  is the specific heat of vaporization of water (2.26 MJ/kg). Therefore,  $Q_{\text{drying}}$  is 161.7 GJ.

Additional guidance on M&E balances for complete mining processes can be found in the published literature.<sup>70</sup> In response to this FOA, provide an overall energy requirement in units of **GJ per one tonne of product**, see Table IX in reference<sup>71</sup> for examples.

<sup>70</sup> ANL/ESD-15/11 "Material and Energy Flows Associated with Select Metals in GREET2: Molybdenum, Platinum, Zinc, Nickel, Silicon" Sept 2015. [Material and Energy Flows Associated with Select Metals in GREET2: Molybdenum, Platinum, Zinc, Nickel, Silicon].

<sup>71</sup> Talens-Pieró L., Villalba-Méndez G. "Material and Energy Requirement for Rare Earth Production" JOM vol. 65, No 10, 2013. [doi: 10.1007/s11837-013-0719-8].

**Table 2.** Concept summary table

| Variable   | Response (include references where possible)  |
|--|---|
| End-product(s)   | List all relevant material(s) to be produced and % recovery (e.g., 56% Nd recovery)   |
| Source of the critical material(s)   | Specify the U.S. available source (primary/native or secondary/artificial) of CMs and comment on the source sustainability (abundance, concentration, and variability for economic viability). Examples: ores (ARPA-E is particularly interested in bastnäsite, ultramafic ores <sup>72</sup> and phosphate rock <sup>73</sup> ), mining wastes (mine tailings), coal waste streams <sup>74</sup> (coal ash, acid mine drainage <sup>75</sup> ), waste-to-energy combustion residues (fly and bottom ashes), sea nodules, post-consumer wastes (electronic waste, electric motors, batteries, permanent magnets), landfill and ashfill wastes, medical waste, spent catalysts, steel slags, drill cuttings, produced waters (oil & gas), wastewater, seawater, other. |
| Biology  | Provide description of the microorganism, consortia or biological solution approach. Describe relevant metabolism. Why was this biology selected? Vigorous? Well-adapted? Highly selective?   |
| Reactor/system type and operation mode (continuous, semi-continuous, batch, other) | Specify, sketch, and describe the reactor/system configuration and operation mode: (multiple) continuous stirred tank reactor(s), leach column, fluidized-bed reactor (e.g., gravity assisted), biofilms (e.g., bioleaching heap, membrane biofilm reactors), air lift reactor (Pachuca tank), living filter, electrochemical reactor, bioelectrochemical reactor, wetland, vat, lagoon, raceway pond, in-situ bioleaching, hierarchical reactor design (e.g., 3D printed structure, microfluidic systems), other.  |
| Current scale  | Provide current scale and proof-of-concept reaction/recovery yield(s).  |
| Proposed TRL – scale up factor   | Provide and justify new TRL, reactor scale and expected reaction/recovery yield(s). Also provide scale up factor as compared to current proof-of-concept scale (e.g., x 10).  |
| Carbon source, growth media, and carbon sequestration                              | What is the planned organic nutrition (e.g., spent brewer grain) that the microorganism will consume to grow and reproduce? Is nutrition locally available (e.g., decomposing plant matter in a wetland)? Is growth media expected to be a significant price tag in the economics of the process? Is there any associated CO <sub>2</sub> mineralization/storage potential?   |
| Energy source  | What is the source of energy for metabolism (e.g., sunlight, ferric iron)?  |
| Oxygen source and diffusion  | If O <sub>2</sub> is needed in the process, describe how the system will optimize gas transfer into the liquid and circumvent mass transfer diffusion limitations. If the proposed system is located in a constrained location (e.g., deep in-situ biomining), what are the anticipated challenges to oxygen supply?  |
| Residence time   | Provide estimate of residence times. How will the configuration/time proposed be optimized to minimize residence time while providing sufficient time to grow, reproduce and metabolize the materials undergoing bioleaching-extraction?  |

<sup>72</sup> Sun J-Z, et al. "Mechanism of Mg<sup>2+</sup> dissolution from olivine and serpentine: Implication for bioleaching of high-magnesium nickel sulfide ore at elevated temperature pH" *International Journal of Minerals, Metallurgy and Materials* 26, 9 (2019) p. 1069 [https://doi.org/10.1007/s12613-019-1823-8].

<sup>73</sup> Liang H. et al. "Rare-earth leaching from Florida phosphate rock in wet-process phosphoric acid production" *Minerals & Metallurgical Processing*, 2017, Vol. 34, No. 3, p. 146 [https://doi.org/10.19150/mmp.7615]

<sup>74</sup> DOE (2017) "High Concentrations of rare earth elements found in American coal basins" [www.energy.gov/articles/high-concentrations-rare-earth-elements-found-american-coal-basins]

<sup>75</sup> Vass, C.R., Noble, A. & Ziemkiewicz, P.F. "The Occurrence and Concentration of Rare Earth Elements in Acid Mine Drainage and Treatment By-products: Part 1—Initial Survey of the Northern Appalachian Coal Basin" *Mining, Metallurgy & Exploration* (2019) 36: 903. [https://doi-org.proxy.scejournals.org/10.1007/s42461-019-0097-z].

|   |   |
|---|---|
| Control of competitors and contaminants | Describe how the competition of mutated forms, unrelated organisms, the presence of toxins (e.g., salt, jarosite) will be controlled. In other words, how will the proposed system outgrow competitors, inhibit contamination, evade toxicity? How long is the system expected to run without interruption? |
| Environmental impact                    | Are the environmental impacts of the proposed biomining approach significantly better than those of conventional approaches (hydrometallurgy and pyrometallurgy)?   |
| Circular economy                        | Do you anticipate that the proposed process would be integrated into an existing facility, like a mine, landfill, waste-to-energy plant, wastewater treatment plant, other?   |

### 3. Program Structure

The maximum period of performance of this program is 24 months. It is expected that all programs will undergo a midpoint review (Go/No Go gate).

### 4. Submissions Specifically Not of Interest

Submissions that propose the following may be deemed nonresponsive and may not be merit reviewed or considered:

- Approaches seeking incremental improvements – rather than transformational solutions – to current mining applications.
- Scale-up projects for existing technologies that do not have significant technical risk.

### 5. Cost Sharing

Notwithstanding the requirement set forth at FOA Section III.E, cost share is not required for awards resulting from this Targeted Topic.



## **XI. APPENDIX K: Recycle Underutilized Solids to Energy**

**Special Program Announcement for**  
**Solicitation on Topics Informing New Program Areas (DE-FOA-0001954)**  
**“Recycle Underutilized Solids to Energy”**

|  |   |
|--|---|
| Topic Issue Date   | April 2, 2020   |
| Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a> | 5 PM ET, Thursday, May 21, 2020   |
| Submission Deadline for Full Applications  | 9:30 AM ET, Monday, June 1, 2020  |
| Submission Deadline for Replies to Reviewer Comments:                                    | 5 PM ET, Monday July 13, 2020   |
| Expected Date for Selection Notifications  | August 2020   |
| Total Amount to be Awarded   | Approximately \$4,000,000 subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0001953 and DE-FOA-0001954 for this Targeted Topic. |
| Anticipated Awards   | ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between \$100,000 to \$1,000,000   |
| Maximum Period of Performance  | 18 Months   |

## 1. Introduction

This announcement describes an exploratory research program, “Recycle Underutilized Solids to Energy” (REUSE). The purpose of this announcement is to (1) focus the attention of the scientific and technical community on specific areas of interest related to converting high-energy materials currently going into landfills into high-energy content liquid product capable of displacing energy imports used for fuel or chemical production, (2) encourage dialogue amongst those interested in this area, and (3) provide a timetable for submission of full applications.

ARPA-E seeks to screen a wide range of feeds, products, and processes. This exploratory program has a duration of 12-18 months.

## 2. Topic Description

ARPA-E is interested in receiving Full Applications in support of the exploratory REUSE program. Under the REUSE Topic, ARPA-E seeks to fund the development of technologies to convert high-energy materials currently going to landfills into a high-energy content liquid product. The high-energy materials include plastics (#1-7 polymers, rubber, and composites) and paper.



ARPA-E anticipates deployment of multiple low-cost, simple, flexible, small-scale (100-500 ton per day) regional facilities using modular plants (“REUSE facilities”). This scale is consistent with the sources for high-energy materials, which include ~300 Material Recovery Facilities and industrial waste sources.

ARPA-E-funded processes under this Topic will create a high-energy content liquid that can be easily shipped to and stored at points of aggregation. The liquid product could be used as a fuel blend stock or an intermediate for further conversion to fuels or chemicals. It does not need to be a highly-refined fuel such as gasoline or diesel. The ultimate end products could represent down-cycling or up-cycling the feeds.

The assumption is that REUSE facilities can be more economical than the paradigm of large-scale facilities making purity products, due to cost of transporting and aggregating waste and the high operating cost (OPEX) and high capital cost (CAPEX) for product purification. We assume it will be more economical to transport the liquid product to existing large-scale facilities, such as chemical plants, refineries, or fuel depots, than to transport waste to a central processing plants.

The critical issues for REUSE are demonstrating simple, flexible “liquefaction chemistry” and meeting economic targets for low-cost, small scale “liquefaction” plants. “Liquefaction chemistry” means converting solid high-energy materials to a high-energy content liquid product. It implies cracking carbon-carbon bonds, which requires some combination of heat, chemical reactants, and/or catalysts. REUSE processes will need to be robust -- tolerant to a wide range of feed composition and quality. The second critical issue is economic viability of small-scale facilities. We hypothesize costs will be lowered by “economies of numbers”, developing simple, repeatable, modular units, versus through “economies of scale” with large, field-erected, custom-engineered facilities designed to produce a limited number of high-purity products.

ARPA-E is interested in submissions which offer disruptive, vs incremental, advances compared to current technology. Applicants can propose novel chemical routes; novel hardware, process integration, and/or process simplification using known chemical routes; or a combination of novel chemistry and hardware/process design.

Projects funded under this Topic will have two primary tasks. In the first task, lab-scale tests will develop performance and design criteria for proposed processes. In the second task, the experimental results will be used to develop a preliminary process design and techno-economic analysis for a 250 ton per day (feed) facility.

## **A. Target Feeds**

ARPA-E seeks to divert high-energy materials from landfills. The target high-energy materials include plastics (#1-7 polymers, rubber, and composites) and paper. These feeds include:

- Plastic waste from manufacturing sites (pre-consumer waste), estimated at 1-2 MM

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](mailto: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](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

ton/yr

- Ag waste: From irrigation tubing, silage, greenhouses, and mulching, 0.4 MM ton plastic in 2018<sup>76</sup>
- Tires: The US Tire Manufacturing Association reported 0.6 MM ton tires were landfilled in 2017,<sup>77</sup> much lower than the Environmental Protection Agency estimate of 4.95 MM ton for 2017.<sup>78</sup>
- Auto shredder residue, 1.9 MM ton/yr plastics and 1.1 MM ton/yr rubber, and a growing amount of composite materials (glass fiber, natural fiber, and carbon fiber).<sup>79</sup>
- ~ 300 Material Recovery Facilities (MRF). More than 90% of the US population has access to curbside recycling, and/or drop-off centers,<sup>80</sup> which send recyclables to MRFs for separation and baling. Potential feeds include low-value MRF bales and MRF bales rejected to landfills.

Economics of REUSE facilities depend on feed costs. Materials sent to landfills are valued at the average US tipping fee, -\$55/ton.<sup>81</sup> Table 1, from the 2020 Curbside Recycling Report, shows prices for plastics and paper bales produced by MRFs.<sup>82</sup> As discussed below, some plastics and paper materials separated at MRFs are landfilled due to contamination, lack of market, or both. We assume all materials sent from MRFs to landfill are valued at -\$55/ton.

**Table 1 Material Price per Ton<sup>81</sup>**

| Material                              | Price per ton |
|---------------------------------------|---------------|
| #1 PET Bottles (includes thermoforms) | \$188         |
| #2 HDPE Natural Bottles and Jars      | \$1008        |
| #2 HDPE Colored Bottles and Jars      | \$262         |
| "#3-7" Other Plastic Packaging        | \$5           |
| Bulk Rigid Plastics                   | \$48          |
| Mixed Paper                           | -\$2          |

<sup>76</sup> Recovering Agricultural Plastics: Obstacles and Opportunities, Waste Advantage Magazine, Sept 1, 2018

<sup>77</sup> 2017 U.S. Scrap Tire Management Summary, U.S. Tire Manufacturers Association, July 18, 2018

<sup>78</sup> Rubber and Leather: Material-Specific Data, <https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/rubber-and-leather-material-specific-data>

<sup>79</sup> 2014 ENERGY AND ECONOMIC VALUE OF MUNICIPAL SOLID WASTE (MSW), INCLUDING NON-RECYCLED PLASTICS (NRP), CURRENTLY LANDFILLED IN THE FIFTY STATES, Nickolas J. Themelis and Charles Mussche, July 9, 2014 <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.645.7112&rep=rep1&type=pdf>

<sup>80</sup> Perceptions and realities of recycling vary widely from place to place, DrewDeSilver, Pew Research Center, <https://www.pewresearch.org/staff/drew-desilver/>

<sup>81</sup> EREF releases analysis on national landfill tipping fees, <https://www.wastetodaymagazine.com/article/eref-releases-analysis-national-msw-landfill-tipping-fees/>

<sup>82</sup> 2020 STATE OF CURBSIDE RECYCLING REPORT, THE RECYCLING PARTNERSHIP, <https://recyclingpartnership.org/stateofcurbside/>

In addition to the industrial sources cited above, REUSE target feeds include the following materials from MRFs:

- “#3-7” plastics (PVC, LDPE, PP, PS, and other, respectively).
- Films, which overlaps the #3-7 category because films include #2 HDPE, #4 LDPE, and #5 PP. The 2020 Curbside Recycling Report estimates 3.6 MM tons of film material is available. Most of the 0.4 MM ton/yr agricultural plastic use is film, and has a low recycle rate.
- Bulk rigid plastics, which are primarily injection molded HDPE and PP. Bales are likely to contain smaller amounts of other #3-7 polymers, depending on the MRF processing system.<sup>83</sup>
- Mixed paper, essentially paper that does not meet specifications for corrugated cardboard or newspaper. It includes phone books, magazines, junk mail, and office paper.
- MRF bales that are rejected to landfills due to low quality. China’s ban on recycled paper or plastics with more than 0.5% contamination has led to a collapse of prices for bales that do not meet this requirement. Recently the price of mixed plastic dropped to zero.<sup>84</sup> Yasar et al reported that the majority of newsprint and cardboard bales were outside ISRI specifications.
- Residual bales from MRF. Typically 15-30% of the MRF incoming material is rejected as residuals.<sup>85</sup> These bales contain enough plastic and paper to support “secondary” MRF processing. However, they also contain dirt, food, and other contaminants.
- Plastics that cannot be recycled with currently available technology, particularly due to presence of impurities.

Additional information about Target Feeds is available on the ARPA-E website in the REUSE Webinar and REUSE Background Information document found here: <https://arpa-e.energy.gov/?q=news-item/trash-treasure-reuse-creates-feedstock-plastic-waste>.

## B. Target Products

As discussed above, ARPA-E is interested in liquid products that can be easily shipped to and stored at points of aggregation. The value of potential products varies widely, impacting the economics of potential technologies developed under this Topic. The price for hydrocarbon

<sup>83</sup> National Mixed Rigid Plastic Bale Composition Study Executive Summary – Summer 2015, [https://plasticsrecycling.org/images/pdf/resources/reports/Executive\\_Summary\\_Bale\\_Sort\\_2015.pdf](https://plasticsrecycling.org/images/pdf/resources/reports/Executive_Summary_Bale_Sort_2015.pdf)

<sup>84</sup> Update on International & Domestic Recycling Markets, J Semrau, MRF Stakeholder meeting Oct 7, 2019

<sup>85</sup> Measuring Composition and Contamination at the MRF, John Culbertson, Northeast Recycling Conference, October 31 2018

products are shown in Table 2, based on January 2020 US Gulf Coast,<sup>86,87,88</sup> and shown graphically in Figure 1. The price increases with carbon number/boiling point from the light gases (methane, ethane, propane, butane) to vacuum gas oil and light cycle oil, and then drops again for heavy products, such as #6 fuel oil and petroleum coke.

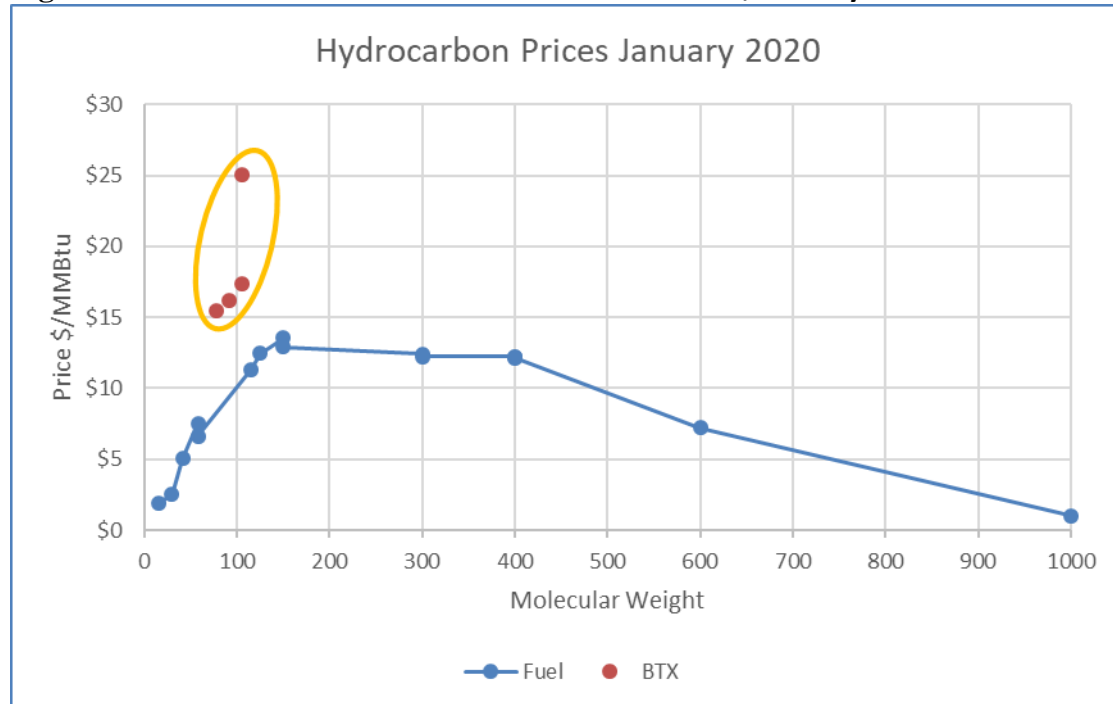
**Table 2 Gulf Coast Value for Fuels and Chemical Feeds, January 2020**

| Hydrocarbon Stream            | \$/MMBtu | Description/Use                          |
|-------------------------------|----------|--|
| West Texas Intermediate (WTI) | 11.85    | Crude                                    |
| Natural Gas                   | 1.92     | Fuel gas                                 |
| Ethane                        | 2.50     | Fuel gas                                 |
| Propane                       | 5.04     | Cracker feedstock                        |
| Isobutane                     | 7.54     | Fuel gas                                 |
| Normal Butane                 | 6.65     | Cracker feedstock<br>Gasoline blendstock |
| Naphtha                       | 11.29    | Gasoline                                 |
| CBOB                          | 12.45    | Cracker feedstock                        |
| Ultra low sulfur diesel       | 13.53    | Diesel,                                  |
| No. 2 Oil                     | 12.92    | Marine blendstock                        |
| Low sulfur Light Cycle Oil    | 12.41    | Gasoline feedstock                       |
| Light Cycle Oil               | 12.26    | Marine blendstock                        |
| Vacuum Gas Oil (Low Sulfur)   | 12.26    | Diesel feedstock                         |
| Vacuum Gas Oil (Med Sulfur)   | 12.22    | Marine blendstock                        |
| Vacuum Gas Oil (High Sulfur)  | 12.13    |  |
| No. 6 Oil 3% S, Gulf Coast    | 7.23     | Marine blendstock                        |
| Petroleum Coke                | 1.02     | Solid fuel                               |
| Benzene                       | 15.94    | Chemical feedstock                       |
| Toluene                       | 16.15    |  |
| m-Xylene                      | 17.85    |  |
| p-Xylene                      | 25.05    |  |

<sup>86</sup> OPIS International Feedstocks Intelligence Report, Jan 9, 2020

<sup>87</sup> BTX Market Report and Price Trend, Fiber2Fashion.com, <https://www.fibre2fashion.com/market-intelligence/textile-market-watch/benzene-price-trends-industry-reports/18/>

<sup>88</sup> EIA Table 4.12.A. Average Cost of Petroleum Coke Delivered for Electricity Generation by State, November 2019 and 2018, [https://www.eia.gov/electricity/monthly/epm\\_table\\_grapher.php?t=epmt\\_4\\_12\\_a](https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_4_12_a)

**Figure 1 Gulf Coast Value for Fuels and Chemical Feeds, January 2020**

Ethane, propane, and butanes can be used as feeds for crackers, which produce plastic precursors. Consequently these products represent a path to “close the loop” on plastics recycling. However, transporting the lighter ethane, propane, and butanes is relatively more expensive, and their value is lower than heavier hydrocarbons.

Naphtha and heavier hydrocarbons through Light Cycle Oil (LCO) and Vacuum Gas Oil (VGO) are significantly more valuable, easier to transport, and also can be used as or converted to cracker feeds. Liquids in these boiling point ranges could also be used as a refinery feedstock, essentially substituting for low-sulfur (sweet) crude.

Heavier hydrocarbon streams may be useful as low-sulfur bunker fuel. The International Marine Organization (IMO) mandates to lower fuel sulfur content to 0.5% by weight creates new demand for Marine Gas Oil (MGO), a mix of distillates; and Very Low Sulfur Fuel Oil, which can be made from blending LCO and/or VGO. IMO compliant fuels are priced \$10-20/bbl higher than WTI.<sup>89</sup>

In comparison with fuel products, chemical feedstocks such as benzene, toluene, and xylene (BTX) have significantly higher value. These chemicals are precursors to plastics, and can also be an option for “closing the loop” on plastics recycling.

<sup>89</sup> <https://shipandbunker.com/news/world/391062-imo-2020-no-large-speed-bump-thus-far>

ARPA-E is open to other liquid products not shown in Table 2. Oxygenated compounds, including ketones, aldehydes, alcohols, and/or acids are generally more valuable than their hydrocarbon counterparts. These can be used in chemical or biological processes. ARPA-E also encourages processes that depolymerize composites, producing recyclable matrix components capable of being shipped to a central location.

Table 2 shows the importance of minimizing light gases and very heavy liquids or char. Applicants with significant light gas and/or char production need to discuss the impact on their process economics.

ARPA-E discourages processes that produce high acid (acid number >0.5mg KOH/g) hydrocarbon liquids, and is not interested in high TAN (acid number >1.0mg KOH/g) liquids. REUSE discourages chemically unstable liquids (ie gum-forming liquids produced in some biomass pyrolysis processes), or processes that produce harmful co-products such as certain polycyclic aromatic hydrocarbons (PAH). Applicants with processes that produce these materials must discuss how these processes can be commercially viable.

### C. Target Technologies

Cracking carbon-carbon bonds is a common step for all processes converting plastics, paper, or plastic/paper mixtures into liquid products. Cracking carbon-carbon bonds requires some combination of heat, chemical reactants, and/or catalysts. The discussion below highlights some processes and critical issues. These processes are discussed in further detail on the ARPA-E website in the REUSE Webinar and REUSE Background Information document found here: <https://arpa-e.energy.gov/?q=news-item/trash-treasure-reuse-creates-feedstock-plastic-waste>.

Using intermediate refinery streams to slurry plastics and/or paper may facilitate incorporating the liquid products into downstream refinery and petrochemical processes. Slurrying the solid wastes may improve material handling and enhance reactivity. Several hydrocarbon refinery streams, including crude oil, vacuum gas oil (VGO), heavy cycle oil (HCO), light cycle oil (LCO), benzene/toluene/xylene (BTX), naphtha, and middle distillates, are potential slurrying agents.

ARPA-E encourages submissions that address innovations for developing repeatable, modular units, and/or designs that reduce CAPEX by reducing engineering and/or construction costs. In addition to modularization, it may be necessary to simplify unit operations (ie flash separations vs distillation, firing light ends in process heaters vs recovering and selling a full product slate, etc). Costs for feeds such as hydrogen and costs for managing wastes such as sulfur, nitrogen, and waste water will need careful consideration. It may be advantageous to build REUSE projects adjacent to other facilities, such as upstream MRFs or downstream refineries or chemical plants. However, for the REUSE program the process economics will be evaluated on a stand-alone basis.



There are several potential technical issues common to all these processes which Applicants must address:

- Ability to configure the process for continuous operation, or strategy to manage multiple batch operations.
- Tolerance of the process for likely contaminants.
- Degree of feed pre-treatment required to feed plastic/paper (ie size reduction), manage contaminants (ie washing), etc.
- Monetizing or disposing light gases – ie combustible co-products which cannot be incorporated into the liquid product
- Emissions (sulfur and/or nitrogen compounds, wastewater)
- Potential to form hazardous co-products (ie polycyclic aromatic hydrocarbons)
- Need to dispose by-products (ie insoluble materials separated from the liquid product, char, salts)

The discussion below highlights some particular concerns for each process option. Applicants must address these issues for the specific technology they propose.

### **Hydrotreating/hydrocracking/hydrogenolysis**

Hydrotreating has been demonstrated with plastics slurried in hydrocarbon liquids in tests dating back to the 1970's. There is considerable literature on hydrotreating biomass and biomass-derived liquids, but less work on hydrotreating paper.

There are several technical challenges with hydrotreating/hydrogenolysis. The first is the relatively high cost of hydrogen for small-scale facilities. The second is the relatively small size of the reactors. The third is the thermal balance associated with hydrogenation reactions, particularly for high oxygen content feeds such as PET and paper. The fourth is catalyst life. Applicants proposing hydrotreating/hydrocracking/hydrogenolysis processes must address these issues.

### **Thermal cracking**

Thermal cracking in this context covers processes that slurry the plastic and/or paper feed in a refinery intermediate stream and use an indirectly heated reactor operating under reducing conditions. From the 1970's through about 2000 there were numerous studies to convert plastics to fuel, often starting with a thermal cracking step. Starting in the 1970's researchers also investigated thermal cracking of cellulosic materials.

ARPA-E is less interested in processes that use slurring materials that must be recovered to be economical, such as donor solvent processes using decalin or tetralin. Submissions using expensive solvents must address expected solvent losses and solvent recovery process(es).

One of the technical challenges with thermal cracking is the potential to generate harmful co-products, such as polycyclic aromatic hydrocarbons (PAH), from waste materials under reducing



conditions.<sup>90</sup> A second issue is the potential to form coke or carbon deposits on fired heaters or heat exchangers. Applicants proposing Thermal Cracking processes must address these issues.

### **Torrefaction/Pyrolysis/Solvolysis/Hydrothermal liquefaction**

Torrefaction/Pyrolysis in this context covers processes that use an indirectly heated reactor operating under reducing conditions (i.e., allothermal reactor). Solvolysis refers to a process in which the solvent is the primary reactant with the substrate. Hydrothermal liquefaction refers to sub- or supercritical reactions with water. There is extensive literature on pyrolysis, solvolysis, and hydrothermal liquefaction of composites,<sup>91</sup> plastics, cellulosic materials, and mixtures of plastics and cellulosic materials. ARPA-E is not encouraging submissions for these processes, unless the Applicants can demonstrate a disruptive aspect of their technology, and/or a significant techno-economic breakthrough compared to current state of art.

### **Autothermal pyrolysis/gasification**

Autothermal pyrolysis/gasification in this context covers the continuum of processes that use substoichiometric quantities of air/oxygen to produce liquid-range products. The equivalence ration,  $\phi$  (moles oxidant fed/moles oxidant for complete combustion) ranges from about 0.05 for autothermal operations to about 0.4 for gasification. ARPA-E is interested in processes that directly produce liquids; consequently  $\phi$  will typically be less than 0.2. ARPA-E is not interested in processes that produce light gases or syngas that are subsequently converted to liquids using chemical or biological processes.

There are several challenges associated with autothermal pyrolysis/gasification. The first issue is managing thermal profiles/gas distribution in fixed- or moving-bed reactors. The second issue is attrition, agglomeration, and erosion in fluidized bed reactors. Applicants proposing autothermal pyrolysis/gasifier processes must address these issues.

### **Fluid catalytic cracking (FCC)**

There are many investigations using plastics or paper/cellulosic materials in FCC processes. Some processes co-feed waste materials with refinery streams; however, not all FCC processes require a slurry media.

There are several technical challenges with catalytic cracking plastics. The first issue is the need to achieve thermal balance in the reactor/regenerator. The second issue, for paper and plastics such as PET contain significant oxygen, is minimizing carbon losses/maximizing liquid fuel production. The third issue is economically maintaining catalyst life. The fourth is scaling down FCC reactor equipment to the scale anticipated in REUSE. Applicants proposing cracking processes must address these issues.

### **Oxidative processes**

<sup>90</sup> Polycyclic aromatic hydrocarbons (PAH) formation from the pyrolysis of different municipal solid waste fractions, Hui Zhou, et al, Waste Management, October 2014, 36

<sup>91</sup> Current status of recycling of fibre reinforced polymers: Review of technologies, reuse and resulting properties, G. Oliveux et al, Progress in Materials Science 72 (2015) 61–99

Oxidation using reactants other than oxygen can produce liquids from hydrocarbons to highly-oxygenated products including ketones, aldehydes, and acids. Examples include NO and NO<sub>2</sub>; nitric acid; Ca(OH)<sub>2</sub>; and solid sulfur.

There are several technical challenges with oxidative processes. The first is the cost of reactants. The second is the materials of construction. The third is the thermal balance and methods for maintaining reactor temperature. Applicants proposing oxidative processes must address these issues.

### **Other Processes**

ARPA-E is interested in other novel and disruptive processes that can convert plastics and paper to a stable, easily transportable liquid product, ideally with high energy yield and minimal production of light gases and/or char.

## **D. Task 1: Test Considerations**

As discussed above, the first task will be lab-scale tests to quantify performance and design criteria for the proposed processes. In the second task, the experimental results will be used to develop a preliminary process design and techno-economic evaluation for a 250 ton per day (feed) facility.

To ensure the testing program supports the second task, Applicants must provide a preliminary process flow diagram and a preliminary heat and material balance for their process. ARPA-E expects Applicants to justify estimated quantities for feeds, products, emissions, wastes, and any deleterious co-products based on experimental results, extrapolations from the literature, modeling, or reasoning from chemical principles.

Applicants must list the critical design issues for their technology, as presently understood. Applicants must discuss how their test program addresses their design issues, the common issues for all technologies, and technical issues specific for a given technology as discussed above. The scale and duration of testing needs to be appropriate to quantify performance and design criteria. For example, test units should be at the gram scale and larger. Applicants should note their experience with scaling up test results from their proposed units to commercial units. Applicants proposing to use milligram or smaller scale systems need to address potential limited ability to analyze products or assess thermal effects. Test duration should be sufficient to span the expected residence time distribution of the scaled-up process, and long enough to address catalyst deactivation, if appropriate. If catalyst deactivation dictates excessively long tests, ARPA-E is open to testing programs with appropriately pre-aged catalysts.

Applicants must specify the feeds they plan to test. ARPA-E strongly encourages processes and test programs with a wide range of feeds/co-feeds.

## E. Task 2: Preliminary Process Design and Techno-economic Evaluation

The second task is development of a preliminary process design and techno-economic analysis based on the experimental results for a 250 ton per day (feed) facility. Project Teams will develop a preliminary process design, and create a process model using Aspen or similar modelling tools. The process design will incorporate the critical design parameters, or ranges of parameters, as determined in the first task. The process model will include a detailed heat and material balance with a summary of inputs (feeds, utilities) and products/co-products and emissions from the process. It will also be used to develop an equipment list.

The heat and material balance and equipment list will be used to develop a preliminary estimate of the CAPEX and OPEX for the “inside battery limits” (ISBL) or core unit operations of the process. CAPEX and OPEX are expected to be in the range of +/-30% based using typical costing tools such as Aspen ICARUS or equivalent. An example of this type of analysis is available at <https://www.nrel.gov/docs/fy19osti/71949.pdf>. Applicants can request assistance from ARPA-E for access to process modeling and/or costing tools in their submission.

ARPA-E anticipates facilities that can compete economically using repeatable, simple, and modular designs. Applicants should identify potential concepts for process simplification, modularity, thermal integration, managing light gases, and minimizing costs for rejecting heteroatoms and char.

### 3. Progress Reporting

To aid in assessing the Recipient’s technical progress under any cooperative agreement resulting from this Targeted Topic, ARPA-E requires quarterly reporting throughout an agreement’s performance period. This includes reporting on the following subject matter:

- Test results, including
  - feed and product characterization,
  - test operating conditions
  - yields for gas, liquid, and solid products
  - material balance closure
- Process summary, including
  - Process flow diagram(s)
  - Heat and material balance for “best operating condition(s)”
  - Preliminary equipment sizing
- Summary of process economic model, including
  - CAPEX
  - OPEX
  - Revenue

- Assessment of commercial potential
- Discussion of common and specific technical issues for Awardee's technology
- Recommendations for next steps for Awardee's technology development

#### 4. Areas Specifically Not of Interest

Submissions that propose the following may be deemed nonresponsive and may not merit review or be considered:

- Submissions that do not include a process flow diagram and preliminary heat and material balance
- Submissions that do not include a list of target feeds.
- Processes that are exclusively mechanical recycling, i.e. milling, grinding, etc.
- Torrefaction/Pyrolysis/Solvolyis/Hydrothermal liquefaction, per note in Process Technology section
- Gasification processes in which light gases (H<sub>2</sub>, CO, methane, C<sub>2</sub> and C<sub>3</sub> hydrocarbons) account for more than 20% of the heating value of the products
- Combustion/incineration processes
- Anaerobic digestion or biological decomposition processes
- Incremental modifications to current deinking/paper recycling processes
- Processes that require multiple conversion steps to produce a liquid product, ie gasification + Fischer-Tropsch
- Processes that cannot be deployed widely throughout the United States, including technologies that rely on a single, site-specific resource.
- Submissions that focus solely on PET and/or HDPE bottles.

#### 5. Modifications to Technical Volume Template

The Technical Volume template for the REUSE Topic has multiple modifications. Cumulative page limits for Sections 1-5 is 14 pages, excluding the required process flow diagram and the heat and material balance, and optional cost model.

## 6. Content and Form of Full Applications

Notwithstanding the instructions at FOA Section IV.C, “Technical Volume: Topic K” is replacing the “Technical Volume Template” provided. All other Components remain the same and can be found in Section IV.C.

| Component   | Required Format | Description and Information  |
|---|-----------------|--|
| Technical Volume<br><br>Technical Volume: Topic K | PDF             | <p>The centerpiece of the Full Application. Provides a detailed description of the proposed R&amp;D project and Applicant Team. A Technical Volume template is available on ARPA-E eXCHANGE (<a href="https://arpa-e-foa.energy.gov/">https://arpa-e-foa.energy.gov/</a>).</p> <p><b>Note – Section and page maximums for this Topic’s Technical Volume differ from the standard Technical Volume Template under this FOA.</b></p> |

## 7. Cost Sharing

Notwithstanding the requirement set forth at FOA Section III.E, cost share is not required for awards resulting from this Targeted Topic.

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