FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

CONVERTING UNF RADIOISOTOPES INTO ENERGY (CURIE)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002691
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	March 15, 2022
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, April 4, 2022
Submission Deadline for Concept Papers:	9:30 AM ET, April 14, 2022
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	9:30 AM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	October 2022
Total Amount to Be Awarded	Approximately $48 million, subject to the availability of appropriated funds to be shared between FOAs DE-FOA-0002691 and DE-FOA-0002692.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B 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.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 of the FOA.

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

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REQUIRED DOCUMENTS CHECKLIST

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 Concept Papers, Full Applications, and Replies to Reviewer Comments, see Sections IV.C, IV.D, and IV.E of the FOA.

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables, and must include the following: ○ Concept Summary ○ Innovation and Impact ○ Proposed Work ○ Team Organization and Capabilities • Reprocessing Cost Estimator Workbook (.xlsx) using template available on ARPA-E eXCHANGE	Mandatory	IV.C	9:30 AM ET, April 14
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

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

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that—
(i) reduce imports of energy from foreign sources;
(ii) reduce energy-related emissions, including greenhouse gases;
(iii) improve the energy efficiency of all economic sectors;
(iv) provide transformative solutions to improve the management, clean-up, and disposal of radioactive waste and spent nuclear fuel; and
(v) improve the resilience, reliability, and security of infrastructure to produce, deliver, and store energy; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

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

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

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive 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 or the applied technology offices within DOE. By contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly 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 clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

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

B. PROGRAM OVERVIEW

The program goal of CURIE is to enable commercially viable reprocessing of used nuclear fuel (UNF)[3] from the current light water reactor (LWR) fleet by resolving key gaps/barriers in

[1] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.
[2] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.
[3] UNF is also referred to as "spent nuclear fuel" (SNF). https://www.energy.gov/ne/articles/5-fast-facts-about-spent-nuclear-fuel.

reprocessing ***technologies***, ***process monitoring***, and ***facility design***. The actinides in LWR UNF would ideally be reprocessed into feedstock that would be used to fuel advanced nuclear reactors (ARs), while other commercially valuable materials would be harvested for industrial and medical uses. Projects funded under CURIE will develop innovative separations technologies, process monitoring techniques for special nuclear material (SNM[4]), and/or equipment designs that will significantly improve the *economics* and *process monitoring* of reprocessing technologies while dramatically reducing the volume of high-level waste (HLW)[5] from LWR UNF requiring disposal (see Section I.C, "Program Objectives"). Specifically, CURIE is interested in separations technologies, process monitoring to enable predictive material accountancy, innovative equipment designs, and systems analyses that satisfy one or more of the ***global program metrics*** without negatively impacting other program metrics:

(1) significantly (i.e., at least an order of magnitude) reduce the volume of LWR HLW requiring permanent disposal,
(2) maintain disposal costs in the range of 0.1¢/kilowatt-hour (kWh)[6],
(3) provide a 1¢/kWh[7] fuel cost for a 200 metric tons heavy metal (MTHM)/yr n^{th}-of-a-kind (NOAK) facility,
(4) enable *in situ* SNM process monitoring approaches that predict, within 1% uncertainty and under representative conditions, the post-process material accountancy, and
(5) enable UNF separations that do not produce pure plutonium streams.

In aggregate, these metrics are envisioned to support a commercially viable reprocessing technology that would provide valuable AR fuel feedstock and the ability to recover fission products of interest (e.g., precious metals and medical radioisotopes) while minimizing the Nation's HLW waste impact. CURIE is part of a comprehensive, nearly $90 million ARPA-E strategy to manage and reduce the Nation's HLW waste inventory and is designed to complement the ARPA-E ONWARDS[8] program. While both the ONWARDS and CURIE programs seek to enable innovations that will minimize HLW quantities, CURIE focuses on the development of technologies that will enable UNF from the current LWR fleet to be utilized as feedstock for future nuclear fuel.

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[4] Special nuclear material is defined as plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235. https://www.nrc.gov/reading-rm/basic-ref/glossary/special-nuclear-material.html.
[5] High Level Waste Definition: https://www.nrc.gov/reading-rm/basic-ref/glossary/high-level-radioactive-waste-hlw.html.
[6] This is consistent with the fee of 1.0 mill per kilowatt-hour ($0.001/kWh, equal to $1.00/MWh) set by the *Nuclear Waste Policy Act of 1982*, as amended, to fund the Nuclear Waste Fund.
[7] The evaluation of fuel costs from a reprocessing facility using proposed technologies will be completed using the Reprocessing Cost Estimator Workbook provided on ARPA-E eXCHANGE.
[8] https://arpa-e.energy.gov/technologies/programs/onwards.

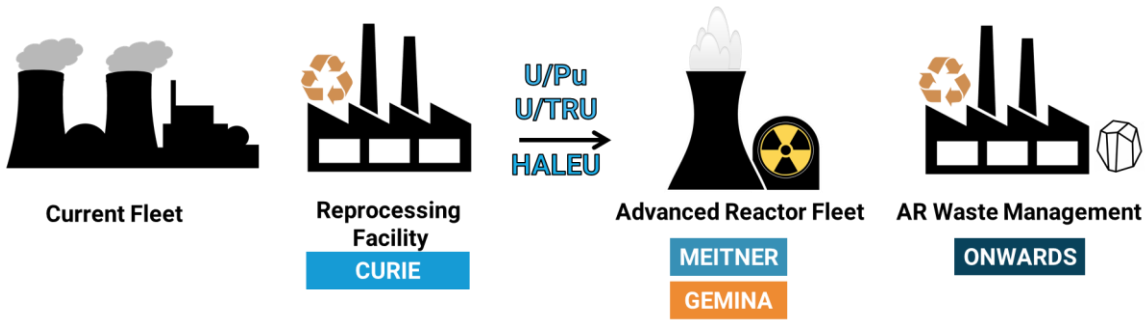

Figure 1. ARPA-E research and development in the advanced reactor technology space.

Background

Currently, the U.S. uses a once-through nuclear fuel cycle in which UNF is ultimately dispositioned as HLW even though more than 90% of the energy remains. However, a *closed* nuclear fuel cycle, which includes reprocessing UNF to recover reusable actinides and *recycling* them into new fuel, has the potential to improve fuel utilization – especially when coupled with advanced fast reactors – and drastically reduce the volume of HLW requiring disposal. Historically, commercial reprocessing facilities[9] (e.g., La Hague in France) have used the solvent extraction-based Plutonium Uranium Reduction-Extraction process (PUREX), which was developed in the 1950s to recover uranium and plutonium products as uranium trioxide and plutonium dioxide, respectively. The plutonium dioxide product serves a feedstock that is blended with uranium oxide to fabricate mixed oxide (MOX) fuel, which is used by LWRs. Reprocessing facilities generally have large footprints[10] and high throughputs (>1000 MTHM/yr), require numerous unit operations (see Figure 2 below), and generate several waste streams and large volumes of waste.[11] As indicated in the figure below, several material accountancy[12] operations are necessary, including before and after dissolution and for the final uranium and plutonium products. Though a reprocessing facility in the U.S. could enhance fuel utilization and reduce the volume of HLW requiring permanent disposal, current estimates for a similar large-scale PUREX-based reprocessing facility constructed in the U.S. are approximately $20 billion.[13] Given the advances in separations technologies, material accountancy and online monitoring technologies, and equipment design, opportunities exist to dramatically improve reprocessing facility economics by reducing the facility footprint, modularizing unit operations

[9] https://www.iaea.org/publications/8143/spent-fuel-reprocessing-options.

[10] For example, the original PUREX Plant was a concrete rectangle 1,005 feet long, 104 feet high (with approximately 40 feet below grade), and 61.5 feet wide. https://www.osti.gov/servlets/purl/10115226 Modern facilities are approximately half the size, though still generally large, multibillion-dollar facilities.

[11] Foare, G., Meze, F., Bader, S., McGee, D., Murray, P. and Prud'homme, P., 2013. Waste Estimates for a Future Recycling Plant in the US Based Upon AREVA Operating Experience–13206. Waste Management.

[12] https://www.nrc.gov/materials/fuel-cycle-fac/nuclear-mat-ctrl-acctng.html.

[13] Idaho National Laboratory, Report No. NTRD-FCO-2017-000265, "Advanced Fuel Cycle Cost Basis – 2017 Edition," Module F1: Spent Nuclear Fuel Aqueous Reprocessing Facility, published September 29, 2017.

and construction, reducing waste streams, facilitating regulatory compliance, and enabling timely and accurate nuclear material accounting for unit operations.

In addition, AR fuel feedstocks derived from reprocessing LWR UNF can help stabilize domestic AR fuel supply chains by providing AR vendors an alternative domestic fuel feedstock source. CURIE seeks to develop multiple reprocessing technologies, including aqueous, pyroprocessing, and fluoride volatility, all of which can provide feedstocks compatible with the fuel needs of AR designs nearing deployment (e.g., gas-cooled, molten salt, liquid metal-cooled). Any other separations technologies that meet program metrics are also within scope.

Generic PUREX Reprocessing Facility Flowsheet

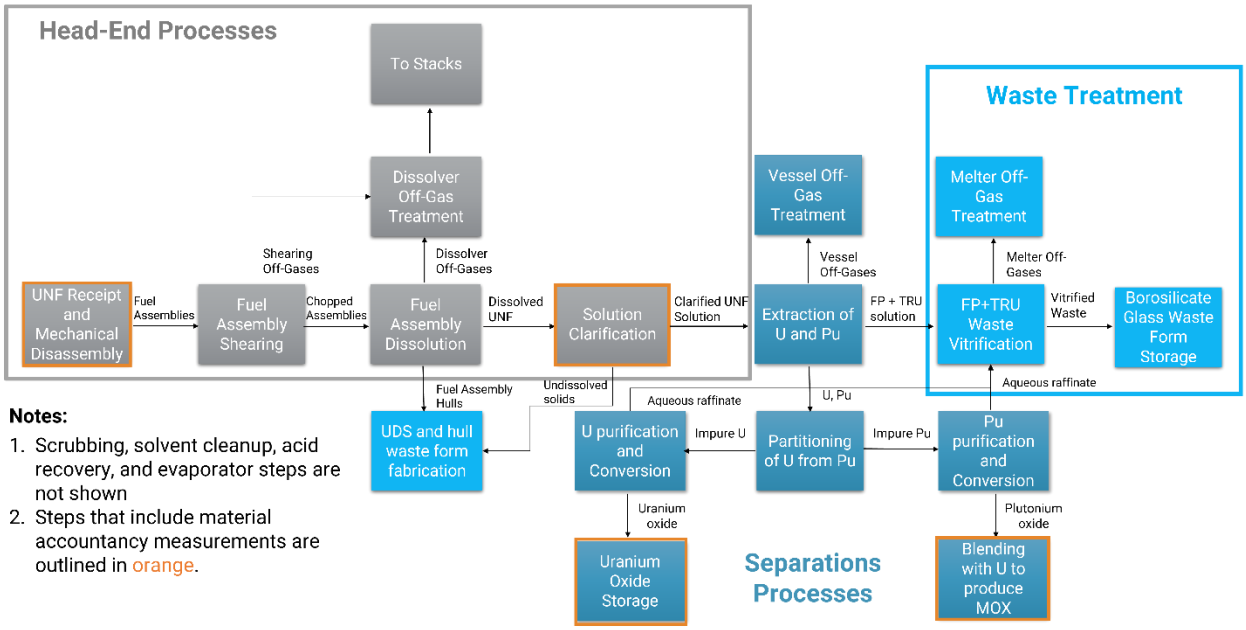

Figure 2. Unit operations associated with the PUREX process, the baseline commercial reprocessing technology.

Program Baselines

To enable applicants to assess the viability of various proposed technologies, including their ability to reach program goals, a general framework that defines process inputs, baseline flowsheets, process outputs, and cost assumptions is provided below. Note that teams can deviate from baseline parameters outlined herein when evaluating their proposed technologies if appropriate justification can be made.

The baseline LWR UNF assumed for technology development is zirconium alloy-clad uranium oxide UNF, which has an average cooling time of 10 years and a burnup of 44 GWd/MTU.[14] The envisioned feedstock products arising from a reprocessing facility in support of this program are provided in Table 1. These products could ultimately be sold to a fuel fabricator to produce AR fuel. In addition, fission products of interest (e.g., noble precious metals and medical radioisotopes) could be recovered for industrial or medical uses.

Table 1. Baseline elemental products arising from potential reprocessing facilities.

Reprocessing Facility Product	Composition (by weight %)
Uranium	100% uranium
U/Pu	70% uranium/30% plutonium
U/TRU	70% uranium/25.5% plutonium/4.5% minor actinides[15]

The presentation of known or baseline technological information is not meant to indicate ARPA-E's preference towards these technologies. ***ARPA-E is interested in significant technological disruptions, brought about by either known or outside-the-box technologies, that would enable achieving the global metrics, and relevant technical sub-metrics, identified in this program.***

Metric Justification, Importance, and Interconnections

1. **Significantly reduce the volume of LWR HLW requiring permanent disposal**: A significant domestic resource of 86,000 metric tons of UNF currently exists.[16] ARPA-E estimates that, if deployed broadly, recycling actinides recovered from LWR UNF could significantly (i.e., by an order of magnitude or more) reduce the quantity of HLW requiring permanent disposal. Reductions in volume can be achieved multiple ways, including by reconstituting UNF cladding and fission products into commercial products, accounting for reductions in future production of HLW due to the use of recycled material, or other means applicant can justify. Such a strategy would be transformational by enabling the expansion of nuclear power while limiting the waste disposal burden.

2. **Maintenance of 0.1¢/kWh disposal costs**: The Nuclear Waste Fund was established to fund the development and operation of a permanent disposal for commercial HLW. This fund

[14] "US Commercial Spent Nuclear Fuel Assembly Characteristics: 1968-2013", U.S. NRC, NUREG/CR-7227. Appendix A, Table A.14 contains UNF compositions in grams per metric tons of uranium.
[15] Minor actinides (MA) are defined as neptunium, americium and non-U or Pu actinides present in UNF. The approximate transuranic composition of UNF is 1% Pu and 0.1% minor actinides. The minor actinide composition proposed for U/TRU fuel maintains the 10:1 Pu:MA ratio present in UNF.
[16] Government Accountability Office, Report No. GAO-21-603, "Commercial Spent Nuclear Fuel: Congressional Action Needed to Break Impasse and Develop a Permanent Disposal Solution," published September 2021, available online at https://www.gao.gov/products/gao-21-603. Accessed November 12, 2021.

collected resources at the rate of 0.1¢/kWh to support the permanent disposal of UNF. Proposed UNF disposal solutions need to fit within the resources of the collective funds. [17] Reprocessing the existing (and future) LWR UNF could significantly reduce the quantities of HLW requiring permanent disposal and could significantly simplify waste management strategies and cost. Reprocessing UNF to facilitate complete consumption of long-lived actinides could also potentially obviate the need for a repository.

3. **A 1¢/kWh fuel cost for a 200 MTHM/yr facility:** This cost metric is defined in the context of a hypothetical advanced reactor with a 200 MWe capacity and 100,000 MWd_t burnup. ARPA-E estimates that, for this hypothetical reactor, the HALEU fuel cost would be approximately 1.2¢/kWh. Developing a cost competitive reprocessing technology would minimize the production of further HLW by developing a commercial market for reprocessed materials, while stabilizing AR fueling with a domestic material source. The 1¢/kWh cost metric is also comparable to LWR fuel costs, which are estimated at 0.65¢/kWh. Therefore, reprocessed fuel at 1¢/kWh could enable backwards compatibility with the existing LWR fleet.

   The scale metric of 200 MTHM/yr supports the modular deployment of reprocessing technologies. Modular deployment would be enabling for reprocessing in many ways, including potential supply chain development, NOAK deployment benefits (including enhanced learning effects), increased access to capital resources, and flexibility to match reprocessing product outputs with advanced reactor needs by monitoring AR deployment plans.[18] A 200 MTHM/yr facility throughput is also anticipated to provide a sufficient U/Pu or U/TRU feedstock to meet AR fuel needs in the 2030 timeframe. [19]

   Viable costing scenarios for the capital and operational expenditures of a reprocessing facility are shown in Table 2. These solutions are provided as an example, as a 1¢/kWh target fuel cost could be achieved by multiple capital expenditure [20] (CapEx) and operational

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[17] As of 2020, the current balance in the Nuclear Waste Fund is approximately $43 billion. More information is available at https://www.energy.gov/sites/prod/files/2020/12/f81/FY20%20-%20NWF%20Annual%20Financial%20Report%20Summary.pdf, accessed November 12, 2021.

[18] Pyroprocessing can be used to produce a metallic product that is suitable for metallic fuel fabrication for sodium fast reactors. Aqueous reprocessing is anticipated to be most compatible with thermal-spectrum reactors due to the decontamination requirements of thermal-spectrum technologies. Fluoride volatility yields actinide fluoride products that can be used to fabricate fluoride or metallic fuels or could be re-enriched.

[19] A July 23, 2020, letter from the Nuclear Energy Institute (NEI) President and CEO Maria Korsnick to U.S. Secretary of Energy Dan Brouillette, NEI estimates that, by 2032, approximately 220 MT HALEU per year would be needed to supply AR needs. Letter accessed online on November 14, 2021. U/TRU or U/Pu fuel would provide the feedstock equivalent to the same amount of HALEU, and reprocessed material could serve as a HALEU feedstock.

[20] Capital Expenditures - money spent by a business or organization on acquiring or maintaining fixed assets, such as land, buildings, and equipment.

expenditure[21] (OpEx) combinations. The values were calculated using the Reprocessing Cost Estimator[22] associated with this FOA. Preliminary findings from such analysis suggest that two-fold and >10-fold reductions are required in aqueous facility OpEx and CapEx costs, respectively. Pyroprocessing solutions would require less significant decreases in facility OpEx and CapEx relative to an aqueous facility, though advances are still required to reach the 1¢/kWh fuel cost goal. The cost target of a $500-$600 million CapEx would also be less than the up to $800 million in legal fees the U.S. government is currently paying annually due to lack of progress associated with UNF disposal.[23]

Table 2. Demonstration of fuel costs derived from State-of-the-Art (SOTA) aqueous and pyroprocessing technologies, as well as potential CapEx and OpEx solutions that would be consistent with program goals.

	Aqueous SOTA	Aqueous Potential Solution	Pyroprocessing SOTA[a]	Pyroprocessing Potential Solution
Capital Expenditure	$20,000,000,000	$600,000,000	$600,000,000	$500,000,000
Operational Expenditure (as % of CapEx)	5%	4%	10%	5%
Throughput (MTHM)	800	200	200	200
Fuel Cost (¢/kWh)	6.3	1.0	1.4	1.0

[a]Derived from the LANDMARK study: Pilot_Scale_Pyroprocessing_Facility.pdf(anl.gov)

Regardless of reprocessing facility type, construction costs (e.g., concrete & rebar) constitute a significant fraction[24,25] (>50%) of the overall facility CapEx. Therefore, minimizing foundations, structures, waste and associated tankage, and facility footprint through process and hardware design can have a significant impact on overall cost. Other ways of minimizing cost could include, but are not limited to, innovative designs, construction technology, and management or changes to the separations process that decrease the overall footprint. Cost breakdowns can be assessed using the Reprocessing

[21] Operational Expenditures - money spent on the ongoing costs of running a business or organization, such as wages and rent on premises.
[22] The Reprocessing Cost Estimator Tool provided by ARPA-E in eXCHANGE will be used by teams to assess the cost impact of their technologies. This will be discussed in more detail below.
[23] https://www.nei.org/advocacy/make-regulations-smarter/used-nuclear-fuel.
[24] LANDMARK Foundation & Argonne National Laboratory, 2018 "Summary Report Conceptual Design of a Pilot-Scale Pyroprocessing Facility", April 2018.
[25] Washington Savannah River Company, 2007, "Engineering Alternative Studies for Separations Summary Report," EAS-G-ESR-G-00049, June 2007. (This document has a restricted distribution, may be proprietary, or both, and is not publicly releasable.)

Cost Estimator. In general, HLW, off-gas, and low-level waste (LLW)[26] waste management can be a significant cost driver for both reprocessing CapEx and OpEx, so approaches that minimize these wastes are expected to reduce these costs by minimizing both the amount of facility footprint (e.g., concrete and rebar) dedicated to these operations and the staffing needed to support waste management.

4. **Accurate and predictive UNF process monitoring:** ARPA-E is seeking technologies that enable the accurate, in-process monitoring[27] of SNM during UNF reprocessing. A program target is the development of approaches that would enable accurate prediction (within 1% uncertainty) of the post-process accountancy value assessed using offline approaches. Such technologies would be transformative in their ability to mitigate in-process diversion of UNF, enable off-site monitoring, provide substantially improved process control, and benefit future safeguards/monitoring. Process monitoring could also show early detection of potential process upsets, increase overall facility safety, and improve predictive maintenance of reprocessing facilities. For these reasons, ARPA-E anticipates joint-use technologies[28] could provide an overall cost benefit to the facility and would thus naturally incentivize participation in safeguards efforts.

5. **Development of UNF separations that do not produce pure plutonium streams:** The currently used commercial UNF separations process, PUREX, produces a pure plutonium stream. Separations that develop a co-recovered actinide product, either U/Pu or U/TRU, would represent a lower proliferation risk and are consistent with CURIE program goals of increasing the overall proliferation resistance of reprocessing technologies and products.

Collectively, these metrics provide a path forward for commercially viable, safe, and secure reprocessing technologies.

General Information

This FOA is focused on supporting the development of viable technologies to achieve the global program metrics. Technical categories of interest are identified in Section I.D of the FOA. Performance targets for the technical categories of interest are provided in Section I.E of the FOA. Section I.F of the FOA provides information on research resources and teaming partnerships that may support Applicants in successfully completing the research and development (R&D) activities necessary to demonstrate the viability of the proposed

[26] See the NRC's definition of low-level waste and the waste classification tables promulgated in 10 CFR 61.55 for more information.
[27] Generally, in-process monitoring would complete measurement and analysis within two minutes. Longer times are not considered non-responsive to this FOA, but applicants would need to justify how the proposed technology can provide satisfactory predictive, in-process monitoring results.
[28] For the purpose of this FOA, joint-use safeguards technology is defined as technology used both for safeguards monitoring and facility operations.

technology. ARPA-E strongly encourages formation of multidisciplinary teams from various sectors to address multiple program metrics, such as having a team composed of individuals or organizations representing the chemical industry, major construction, and sensor development.

It is recognized that R&D to support the development and testing of separations and online monitoring technologies to achieve CURIE's goals may necessitate access to research resources (e.g., materials, facilities, software, computing resources, subject matter experts). These types of facilities include items such as, but not limited to, actinide isotopes and other radioactive materials; licenses and processes to support material handling, storage, and disposal; hot-cells and gloveboxes; and high-performance or field-specific computing codes and facilities. Applicants without existing access to such research resources are encouraged to establish teaming relationships with commercial entities, national laboratories, universities, etc., that do possess such research resources to successfully complete their proposed R&D activities. Applicants without access to such research resources or teaming relationships **will not be disqualified,** nor will they be deemed nonresponsive at the Concept Paper stage for that reason alone. However, applicants at the later Full Application stage will need to be able to demonstrate that they have access to the research resources needed to successfully complete R&D activities proposed in their Full Applications. The resources and teaming relationships for separations and monitoring testing with actual UNF will be evaluated during the performance period of the CURIE program and are not a significant evaluation criterion during the Concept Paper and Full Application stages. Additional information regarding research resources and teaming relationships can be found in Section I.F of the FOA.

C. PROGRAM OBJECTIVES

The program goal of CURIE is to enable commercially viable reprocessing of UNF from the current LWR fleet by resolving key gaps/barriers in reprocessing ***technologies***, ***process monitoring***, and ***facility design***. Specifically, CURIE seeks to support development of technologies that enable

- a significant reduction of the volume of LWR HLW requiring permanent disposal;
- global system disposal costs in the range of 0.1¢/ kWh;
- separations technologies supporting a 1¢/kWh fuel cost for a 200 MTHM/yr NOAK facility;
- *in situ* SNM process monitoring approaches that predict, within 1% uncertainty under representative conditions, the post-process material accountancy; and
- development of UNF separations that do not produce pure plutonium streams.

D. TECHNICAL CATEGORIES OF INTEREST

Four technological categories have been identified as offering the most likely avenues to achieving substantial improvements in affordability and process monitoring to support predictive materials accountancy. While technologies discussed below are of interest, new

technologies not considered for reprocessing are encouraged, as well as significant disruptions to more established technologies.

i) Category 1 – Reprocessing Technologies: This technology area includes process improvements that minimize waste volumes, compress unit operations (e.g., combine dissolution with solvent extraction), improve intrinsic proliferation resistance of actinide separations (including the prevention of creating pure plutonium streams), increase resource utilization efficiency, simplify off-gas management, enable repurposing and recovery of valuable fission products (e.g., noble metals, medical radioisotopes), optimize equipment design, and bolster commercialization supporting the 1¢/kWh fuel cost target.

ii) Category 2 – Integrated Monitoring & Materials Accountancy: This technology area includes pathways to support online monitoring of fissile materials during LWR UNF reprocessing. This could include improved sensor fusion, instrumentation to support automated collection of process monitoring training sets, or novel sensors. ARPA-E seeks technologies that allow the ability to use online monitoring under relevant process conditions (i.e., potentially high radiation fields including up to ~1000 R/hr gamma or neutron emission rates of 10^4-10^5 neutron/sec, complicated mixtures of actinides and fission products) to predict post-process materials accountancy within 1% uncertainty. The post-process materials accountancy itself must be validated using established methodologies (e.g., mass spectroscopy, alpha counting, etc.).

iii) Category 3 – System Design & Assessment: A reprocessing facility is a complex chemical and radiological facility with many opportunities for design optimization that could reduce a reprocessing facility's footprint, optimize throughput, facilitate efficiencies in construction and deployment that reduce CapEx and/or OpEx, and ensure adequate safeguards are maintained in a cost-effective manner. This category is intended for proposals that focus on lowering construction costs for reprocessing facilities via approaches such as (but not limited to) modularization of unit operations, automation, development of digital twins, and the use of advanced manufacturing and construction techniques. Moreover, systems analysis proposals that enable optimization of the facility footprint and throughput of reprocessing facilities, evaluate risks associated with a reprocessing facility, and otherwise explore ways of dramatically improving the economics of reprocessing facilities are encouraged in this category. Though this category focuses on identifying optimization opportunities in design and construction of a reprocessing facility, it should be significantly integrated with Category 1 & 2 efforts.

iv) Category 4 – Other: This category is provided for submissions that do not cleanly fall into the above three categories but can potentially meet overall programmatic objectives (detailed in Section I.C). Submissions must provide a compelling case for inclusion based on delivering a significant improvement to reprocessing affordability or safeguards.

Each applicant is required to indicate their primary technological category(s) of focus, as well as any secondary area(s), if appropriate.

ARPA-E **strongly** encourages proposals spanning two or more technical categories. For example, online monitoring associated with materials accountancy may provide significant benefit in the development of new separations technologies. Proposals that consider the economic impacts on diverse areas (i.e., head-end operations, off-gas treatment, separations, waste management, safeguards) are also encouraged.

Coordination between teams with complementary technologies or proposals is also possible. For example, a proposal focusing on a head-end dissolution technology may benefit from generally coordinating this effort with a separate proposal focusing on the subsequent actinide/fission product separations. If a proposal is coordinating with another proposal, this should be indicated in the Concept Paper concept summary and Full Application Technical Volume executive summary.

As a reminder, applicants without access to such research resources or teaming relationships **will not be disqualified,** nor will they be deemed nonresponsive at the Concept Paper stage for that reason alone. However, applicants at the Full Application stage will need to be able to demonstrate that they have access to the research resources needed to successfully complete R&D activities proposed in their Full Applications.

For a proposed technology in Category I or II, the submission must clearly articulate the following:

- How the proposed technology leads to cost savings for the impacted unit operation.
- The technology's impacts on the capital and operating costs of other parts of the reprocessing facility. For example, a separation may minimize process waste and, consequentially, decrease the downstream cost of waste treatment at the facility.
- Which technological adjustments to the broader facility and fuel cycle are required to support the proposed technology. For example, a proposed separation technology may require a more selective headend process, which is upstream of separations.
- The number and volume of waste streams generated relative to the SOTA.

When evaluating impacts to CapEx, OpEx, and anticipated ¢/kWh fuel cost, all applicants should use the Reprocessing Cost Estimator Workbook associated with this FOA, and provide the information contained in the following table. The reprocessing cost estimator should enable applicants to understand the upstream, direct, and downstream impacts of their technology to reprocessing costs regarding capital, operational and, ultimately, fuel costs.

Category	Upstream Impact	Direct Impact	Downstream Impact
Capital Expenditure (% savings)			
Operational Expenditure (%savings)			
Anticipated total ¢/kWh fuel cost			

Scaled UNF Separation and Monitoring Testing

ARPA-E is interested in testing potential technologies with actual UNF, although lack of access to UNF or facilities appropriate for UNF handling is not a prerequisite for a successful application. During the CURIE program, ARPA-E will evaluate whether technologies are viable for UNF testing and, subject to ARPA-E's discretion, the availability of appropriated funds and the existence of appropriate CURIE program technologies, additional funds may be provided for additional studies (see Section II.B. Renewal Awards). Preliminary goals of such testing could include achieving the following sub-metrics:

- Complete actinide co-recovery (>99% by weight),
- Product within 1% of proposed product composition (selected from Table 1),
- Sufficient fission product decontamination from product (<0.1% by weight),
- Assessment of separation reproducibility (e.g., execution of multiple extraction/stripping cycles).
- Throughput of 2 kg/hour for eight hours and three testing runs (Rate is ~10% scale of 200 MTHM/year facility, assuming 100% capacity factor),
- *in situ* SNM process monitoring approaches that predict, within 1% uncertainty and under representative conditions, the post-process material accountancy,
- Off-gas capture efficacy (>99% by weight).

The actual goals of UNF testing with developed separations and monitoring technology, as well as the physical and program resources, will be assessed during the program. The product produced during such an evaluation should be one of the products identified in Table 1 unless sufficient justification for an alternative product can be provided. If applicants are interested in scaled UNF testing, high-level descriptions (no more than 1 page) of the test, scale, facilities available, resources needed, and how the UNF testing effort would interface with the base three-year program should be included in the Full Application proposal.

1. Category I – Reprocessing Technologies

Reprocessing technological solutions must address the affordability and complexity of facility head-end, off-gas, separations, and/or waste management operations. In all aspects of technical or facility development, the potential interfaces a given technology has with online monitoring, materials accountancy, or safeguards-by-design principles should be addressed.

Reprocessing technologies responsive to this technical category will aim to achieve the following sub-metrics:

- reduce by at least an order of magnitude the volume of LWR HLW requiring permanent disposal,
- provide appropriate nuclear fuel feedstock (see Table 1)
- have an actinide content in waste streams of <0.1% by weight,
- have a fission product content in product streams of <0.1% by weight,
- have compatibility or potential compatibility with online monitoring technologies
- support a 1¢/kWh fuel cost and throughput needs for a 200 MTHM facility, and
- be compatible with at least one existing demonstrated waste form or is co-developed with a compatible waste form suitable for final geological disposal.[29]

While online monitoring is relevant to enabling challenging separations and supporting separations development, for the purposes of this FOA, requirements for online monitoring proposals will be discussed in Category 2. Again, projects that span multiple categories are highly recommended in CURIE applications.

Separations Technologies

Separations of LWR UNF represents an opportunity to support AR fueling and minimize waste from U.S. nuclear energy production. The separation of long- and short-lived radionuclides can reduce the volume of radioactive waste that requires long-term storage[30]; however, the production of new high-volume waste streams (e.g., added solvents, equipment) must be minimal relative to a once-through fuel cycle. Further, an economically viable reprocessing facility must have market-appropriate capital and operating costs. To help performers evaluate the benefits their technology confers on capital and operational costs, ARPA-E has provided the Reprocessing Cost Estimator Excel Workbook that applicants should use for estimating technology cost benefits.

A variety of approaches currently exist that have been, or could be, used for the separations of UNF, including aqueous processing (e.g., solvent extraction), pyroprocessing, fluoride or chloride volatility, supercritical CO_2, and chromatography.[31] Of interest to this FOA are separations technologies that would significantly improve the economic viability of commercial

[29] If neither criterion is met, the case must be made that the technology could potentially provide a significant disruption to reprocessing cost and safeguards SOTA, such that separate investment in a novel waste form would be justified.
[30] Baptista, Annibal; Parker, Joshua; Park, Jung-Ho. "Advantages and disadvantages of nuclear fuel reprocessing". *Energia Nucleara*; v. 19(1-2); p. 32-35. https://inis.iaea.org/search/search.aspx?orig_q=RN:39071523.
[31] World Nuclear Association. "Processing of Used Nuclear Fuel" (Updated December 2020). https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel.aspx.

reprocessing and decrease the proliferation-risk of material produced from a reprocessing facility. This could include the design of new chemistries, engineering, or equipment designs. While such approaches are not the only way of achieving the cost targets, ARPA-E anticipates proposals in this area will incorporate advancements that reduce the number of process and secondary waste streams, significantly reducing the overall facility footprint and number of facility operations. Such improvements are expected to reduce the overall facility CapEx, OpEx, and ultimately, fuel cost.

Each of the abovementioned separations technologies will require head-end treatment to prepare the UNF for separations and off-gas capture systems to recover volatile fission products. Commercial PUREX-based reprocessing facilities (see Figure 2) employ off-gas treatment systems throughout the facility to capture volatile and semi-volatile radionuclides such as ^{3}H, ^{85}Kr, ^{14}C, ^{106}Ru, and ^{129}I. More selective head-end processing could limit the presence of challenging matrix elements (e.g., ^{3}H, Zr, and Ru) present during separations – minimizing the number and volume of waste streams and, ultimately, facility cost. Head-end operations (including off-gas capture) that significantly simplify downstream chemistry, improve valuable product recovery, and improve the overall cost attractiveness of a reprocessing facility are encouraged under this FOA.

Chemical and radiological HLW and LLW generated from reprocessing can add significant cost to the OpEx and CapEx of a facility. The HLW streams emerging from a reprocessing facility are those primarily containing fission products and minor actinides. The LLW streams would include process wastes, such as metal- (i.e., assembly hardware- and/or hull-) and off-gas- (^{85}Kr-, ^{14}C-, and ^{3}H-) containing wastes, and secondary wastes such as nitrate effluents, spent resins, and solvent residues. Notably, for the SOTA commercial PUREX process, more than 90% of the initial radioactivity is contained in the small volume of HLW generated, while approximately 96% of the total volume of waste generated is LLW.[32] Table 3 illustrates key process wastes, estimated volumes, and their waste classifications for wastes generated from a hypothetical large reprocessing facility licensed and constructed in the U.S. using existing NRC regulations. Proposed separations technologies that are associated with substantially less waste production or have effective strategies for post-separation waste management are viewed by ARPA-E as a promising approach to managing reprocessing facility costs.

[32] HLW volume and radioactivity estimate taken from Orano's reprocessing website describing radioactive waste generated from reprocessing. Last accessed 12/16/2021.

Table 3. Estimated Forms, Volumes, and Waste Classification of Process Wastes Generated in an 800 MT/yr Reprocessing Facility*

Process Waste Form	Volume (per MTIHM)†	Waste Classification‡
Vitrified FPs	0.91 m^3	HLW
Compacted Metal Process Wastes	0.85 m^3	GTCC§
Iodine-129 Waste (as Synthetic Rock)	6.25 x 10^{-4} m^3	GTCC
Kr-85 (in 50 L Cylinders)	0.005 m^3	A
C-14 Waste (in Cement)	0.075 m^3	A
Tritiated Wastes (in Cement)	5 m^3	B
Salt-Bearing Wastes (in Cement)	1.4 m^3	A

*Excerpted from G. Foare et al., "Waste Estimates for a Future Recycling Plant in the US Based Upon AREVA Operating Experience," paper #13206, WM 2013 Conference, February 24-28, 2013, Phoenix, AZ, USA.

†MTIHM = Metric Tons of Initial Heavy Metal. Volumes listed assume 5-year cooled UNF and do not include secondary waste stream (e.g., spent resins) volumes. For 50-year-old UNF, Kr-85 capture is unnecessary, and the volume of tritiated waste is expected to be lower because of its decay.

‡ Waste classifications were made based on existing NRC regulations. See the NRC waste classification tables promulgated in 10 CFR 61.55 for more information.

§GTCC=Greater Than Class C; GTCC waste is currently deemed unsuitable for near-surface disposal.

While Category 2 specifically discusses the development of sensors, monitoring, and other enabling technologies relevant to monitoring and safeguarding a UNF reprocessing *facility*, the role of safeguards and security-by-design must also be considered in separations technologies development, and any technology solution proposed shall not make safeguarding more challenging. Technologies that improve proliferation-resistance and/or intrinsically limit, at the chemical level, production of pure plutonium streams are of specific interest. ARPA-E is interested in process and production designs that would improve economics and security and provide enhanced opportunities for safeguarding. Online monitoring technologies that can be integrated with process controls is considered an important design principle.

Predominant examples of separations technologies include aqueous processing (e.g., solvent extraction), pyroprocessing, and fluoride volatility. These technologies will be discussed in more detail below and the technical viability of these processes in various subcategories are presented in illustrative radar charts in Figure 3 that represent ARPA-E's general assessment of technology risks and competencies. Further discussion of the radar charts in Figure 3 are provided in the sub-section below. While not explicitly discussed below, ***novel technologies beyond aqueous, pyroprocessing, and fluoride volatility that enable other processing approaches are also of interest and encouraged.***

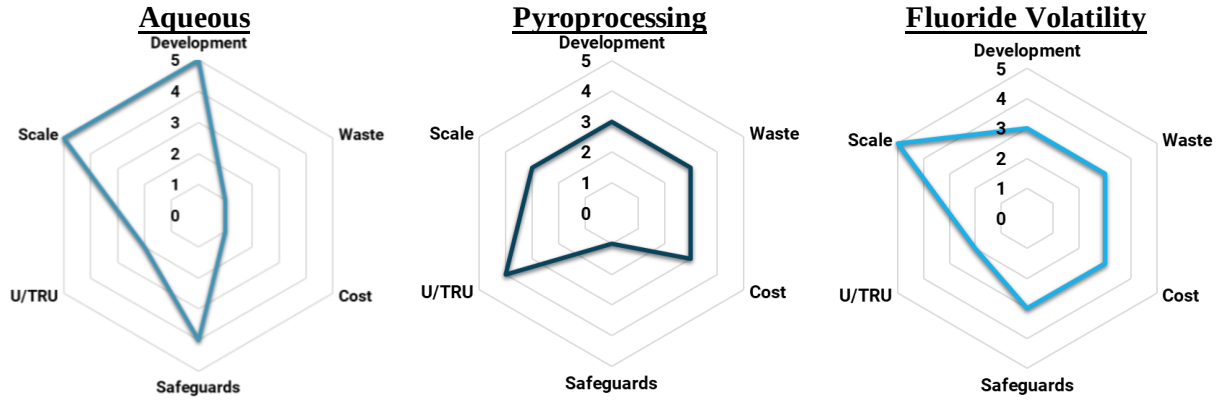

Figure 3. ARPA-E's general assessment of various demonstrated technologies for reprocessing UNF. A *5* is considered a technology strength, whereas a *0* is considered a technology weakness.

Aqueous (Solvent Extraction)

The standard method for separation of UNF, and the only method presently practiced on a commercial, industrial scale, is the PUREX process.[33] Derivative processes include CoDCon[34] (co-decontamination) or COEX (co-extraction of actinides).[35] These technologies are generally recognized to scale well and have a high level of development. However, there is no demonstrated pathway for a U/TRU fuel from a solvent extraction technology, and safeguards are largely established but are associated with significant cost. As discussed above, HLW and LLW management with aqueous separations is a significant challenge for this technology.

In general, many opportunities exist for the development of alternative solvent extraction technologies that would disrupt the processing landscape. Technologies that would enable the co-recovery of the AR fuel cycle-relevant actinides (i.e., uranium through americium) in a single separation step could improve both the economics and potentially proliferation resistance. Other technologies that could improve the group separations of the actinides or minimize third phase formation, thus allowing a higher solvent loading and minimizing LLW, are also of interest. Significant advancements in technology and facility layout would necessitate new facility designs, and Category 3 provides a mechanism to evaluate studies considering how various factors (e.g., the reprocessing of fuel cooled more than 30 years, safeguards-by-design, adjustment of unit operations) would impact the overall facility cost and actual facility designs.

[33] Ibid.
[34] G.J. Lumetta et al. (2019), "Simulant Testing of a Codecontamination (CoDCon) Flowsheet for a Product with a Controlled Uranium-to-Plutonium Ratio," *Separation Science and Technology*, 54:12, 1977-1984, DOI: 10.1080/01496395.2019.1594899.
[35] U.S. Nuclear Regulatory Commission, "Background, Status, and Issues Related to the Regulation of Advanced Spent Nuclear Fuel Recycle Facilities, NUREG-1909, June 2008, Agencywide Document Access and Management System (ADAMS) Accession No. ML081550505.

Pyroprocessing

Pyroprocessing is a high-temperature, non-aqueous, batch electrochemical separation of UNF into different streams for re-use and/or disposal.[36] It is potentially attractive for production of fuel for some fast-spectrum AR fuel cycles from LWR UNF because the TRU elements, including plutonium, are not well separated from each other, providing a level of proliferation defense-in-depth.[37] In addition, such facilities generally have fewer unit operations, smaller footprint, fewer waste streams, are amenable to reprocessing short-cooled LWR UNF, and can potentially be co-located with other fuel cycle facilities or even reactors. For example, pyroprocessing of Experimental Breeder Reactor-II fuel was successfully demonstrated in a co-located Fuel Conditioning Facility.[38]

ARPA-E's assessment of pyroprocessing technology (Figure 3) is that, compared to the reference PUREX-based reprocessing technologies, pyroprocessing has only been demonstrated on a small scale in a research and development setting. However, its current estimated costs are closer to program goals, and in general, though research on more robust pyroprocessing waste forms is actively being pursued, it is estimated that fewer waste streams and smaller volumes of HLW will be produced. Technologies that enable co-recovery of U/TRU have also been developed, but not demonstrated with UNF, and there are material accountancy challenges that need to be addressed. For example, online monitoring of pyroprocessing separations is considered a *significant* impediment to deployment. Technologies addressing these and other challenges will be considered in Category 2.

Technologies supportive of the fuel cost metric include, but are not limited to, those that enable reduction and/or synergistic combinations of unit operations, enable continuous operations, and simplify the handling and disposition of waste streams for current pyroprocessing flowsheets. Proposals outlining new and innovative processes should improve the cost-effectiveness, safety, and/or security of the pyroprocessing. Any technology solutions proposed must not increase the presence of actinides in waste streams relative to SOTA capabilities and shall not make safeguarding more challenging.

Fluoride Volatility

Fluoride volatility is a high-temperature process that exploits the volatility of high-oxidation-state fluorides (e.g., UF_6) to achieve separation. It was used to recover more than 100,000 MT of uranium from irradiated non-commercial fuel and to reprocess Molten Salt Reactor

[36] Michael F. Simpson. "Developments of Spent Nuclear Fuel Pyroprocessing Technology at Idaho National Laboratory" (INL/EXT-12-25124). March 2012. Accessed 02/14/2022.
[37] Argonne National Laboratory, "Recycling Used Nuclear Fuel for a Sustainable Energy Future," published in 2018. Accessed 02/14/2022.
[38] https://factsheets.inl.gov/FactSheets/Fuel%20Conditioning%20Facility.pdf.

Experiment fuel[39] in the 1960s. Of the actinides useful as AR fuel feedstock, uranium, plutonium, and neptunium can form hexafluorides, and flowsheets have been designed that target these actinides. However, americium and curium, along with most of the fission products, form nonvolatile fluorides that require disposal. Fluoride volatility has not been demonstrated as a means of directly processing LWR UNF, but the smaller potential facility footprint, lower HLW volumes, ability to process high-burnup and/or short-cooled fuel, potential for actinide co-recovery, and ability to recover fission products of interest (e.g., noble precious metals and medical radioisotopes) could make fluoride volatility a commercially viable technology.

The radar chart in Figure 3 indicates that fluoride volatility can be readily scaled to meet throughput needs, and while significant technical demonstration of the technology exists, there is no demonstration of the technology with UNF directly from an LWR. In addition, though the volume of waste generated from fluoride volatility is expected to be small, it is highly radioactive, and a clear pathway for the management of these HLW fluorides (or off-gases) has not been developed. The cost of a fluoride-volatility based separation is anticipated to be comparable to a pyroprocessing facility because of its smaller footprint and simple flowsheet, but no cost estimates have been reported. Materials accountancy techniques have not been identified for fluoride volatility separations, but it may be possible that existing techniques used for uranium hexafluoride enrichment facilities, which have similar accounting concerns as a fluoride volatility separations facility, could be adapted to fluoride volatility separations of UNF. Online material monitoring also needs to be established. A pathway to producing a U/TRU product could exist through the co-oxidation of U, Np, and Pu to volatile hexafluorides, but this has not been demonstrated and co-recovery of americium through this route is not currently deemed possible.

R&D opportunities for fluoride volatility flowsheets include evaluation of less corrosive fluorination reagents (e.g., NF_3), actinide co-recovery (via fluorination or from processing fluorination ashes), head-end process technology development, and adaptation or development of online monitoring and materials accountancy technologies for fluorination flowsheets (that latter of which should be addressed in Category 2).

Fission Products

There is also an interest in economically recovering and repurposing fission products for stakeholders other than AR vendors, such as for industrial or medical radioisotope usage. Isotopes and elements of interest include those listed in Table 2. Such isotopes and elements could serve as an additional revenue stream to help reduce the cost of the nuclear fuel cycle back-end. Technologies developed in support of fission product recovery should clearly describe the general technology-to-market case and where (or if) the fission product

[39] Oak Ridge National Laboratory, ORNL-TM-2578, "Processing of the MSRE Flush and Fuel Salts," 1969.

separations technology is anticipated to directly interface with the reprocessing facility. Any technologies considering the repurposing of fission products as a potential product stream should not include the potential revenue for this as an offset to the cost of fuel. Potential isotopes of value include ^{14}C, ^{63}Ni, ^{85}Kr, ^{90}Sr, ^{129}I, ^{133}Xe, ^{147}Pm, ^{166m}Ho, ^{241}Am, and ^{244}Cm.

2. Category II – Integrated Monitoring & Materials Accountancy

Nuclear materials accountancy, and the associated verification activities, is a key element of safeguards implementation, and is the primary reason that the detection of attempts to divert SNM is paramount. Currently, accountancy sampling occurs at specific unit operation areas, material balance areas (MBAs)[40], usually before and after the separation. The accountancy is verified by federal regulators (or IAEA) by several means, including conducting physical inventories of the materials, performing non-destructive assays locally or taking samples for destructive analysis in off-site laboratories, and reviewing surveillance system records. Each of the existing methods for validating control over the SNM is laborious and time-consuming and can involve protracted facility shutdowns to resolve discrepancies. Accurate monitoring of SNM *in situ*, as well as other chemistry and other process aspects, could serve as an opportunity to improve the operational costs of a reprocessing facility and improve alignment with pre- and post-separation materials accountancy assays. Projects supporting this category should meet the following sub-metrics:

- provide *in situ* SNM process monitoring approaches that predict, within 1%, and under representative conditions,[41] the post-process material accountancy;
- support development of UNF separations that do not produce pure plutonium streams;
- provide an overall cost benefit to the facility (i.e., added capital or operational expenditures to the technology must be offset by other decreases in capital or operational expenditures); and
- can withstand the conditions required at a reasonable lifetime relative to the cost of hardware, installation, downtime, and calibration.

Such technology could potentially minimize the number, frequency, or type of post-process *ex situ* materials accountancy assays, therefore minimizing material handling needs, aiding in reducing scheduled maintenance, or improving general in-process knowledge and control. Significant synergies exist between online monitoring and decreasing costs throughout the facility. For instance, improvements in monitoring capabilities could allow for more precise

[40] An MBA is an area in which (a) the quantity of nuclear material transferred into or out of can be determined, and (b) a physical inventory of nuclear material can be performed.
IAEA (2019) International Safeguards in the Design of Reprocessing Plants;
https://www.iaea.org/publications/13454/international-safeguards-in-the-design-of-reprocessing-plants

[41] Examples of representative conditions include relevant separations matrices and radiation fields (most likely gamma doses ~1000 R/hr or neutron emission rates ~ $10^4 – 10^5$ neutron/sec).

controls, or perhaps integrated control, of the various reprocessing stages, while ensuring improved security of materials of concern. Analysis of the cost impacts associated with in-process monitoring can and should be indicated as a part of a response using this technology. While not a requirement, integration of Category 2 efforts with novel separations efforts in Category 1 is highly encouraged.

One goal of online monitoring technologies/systems proposed in CURIE is to provide an overall cost benefit to the facility (e.g., added capital or operational expenditures to the technology must be offset by other decreases in capital or operational expenditures). Many technologies that support such a metric will fall under the general description of providing online monitoring, digital twinning, or integrating monitoring with process control, but this is not the requirement of a successful application. Any technology that supports CURIE's program metrics would be viewed as responsive.

The sophistication of monitoring solutions studied depends on the type of reprocessing technology utilized. Aqueous technologies have the highest sophistication, but outstanding questions exist regarding technology robustness, potential improvements afforded by sensor fusion and multi-block modeling, and the ability to predict post-process accountancy.[42] Fluoride volatility does not have any demonstrated solutions for actinide co-recovery or online monitoring, but current technologies such as those implemented at enrichment facilities may translate to monitoring solutions. SNM monitoring challenges are particularly acute for pyroprocessing, where the SOTA is greater than the 1% uncertainty necessary to meet materials accountancy standards. A clear pathway for pyroprocessing to meet the 1% uncertainty standard, either during process monitoring or during material accountancy, does not exist. For technologies without an acceptable (i.e., within 1% uncertainty) means of materials accountancy, projects can propose both online monitoring and materials accountancy approaches, but online monitoring of SNM must be a part of the proposed effort. **Teams applying to Category 2 also need to define the separations technology/process being targeted.**

Examples of technologies that are within the scope of this category, and generally supportive of online/*in situ* process monitoring include, but are not limited to:

- Non-destructive analysis (NDA) of fissile material, with an emphasis on unambiguous signatures, low latency, and functionality in representative environments and capable of determining

[42] Multi-block modeling – where multiple sensors are fused to provide a single material accountancy value for a given element or isotope.

    - Radiation signatures: gamma,[43] neutron and alpha spectroscopy and characteristic X-rays, nuclear resonance fluorescence, neutron interrogation including induced fission, neutron multiplicity[44]
    - Chemical/Electronic Signatures: UV-Vis-NIR, Raman, excitation of characteristic X-rays, k-edge densitometry laser-induced spectroscopy,[45] electrochemistry
- Analysis of non-fissile material if monitoring produces an overall cost-benefit to the facility. However, SNM monitoring must be a part of the proposed technology.
- Process modifications and sampling technologies that significantly improve NDA accuracy and volumetric sampling.
- Modeling, to include sensor processing and data fusion, volumetric sampling analysis, and/or artificial intelligence/machine learning (AI/ML) techniques to improve "signal" only if well justified.
- Data fusion of multiple signatures and process control variables, AI/ML and other data analysis tools that enable achievement of mass accountancy metrics, possibly through improvement in signal processing, pulse shape analysis, data fusion of complimentary isotopic signatures, or spatial and temporal correlation of measurements.
- Off-gas monitoring, bulk properties measurements, or other inferential technologies if the applicant provides a clear, quantitative description of how such measurements contribute to improved and unambiguous fissile mass accountancy.
- Increasingly, online monitoring systems are developed on a framework of more complex statistical approaches (e.g., chemometrics, machine learning, etc.). Model training for these systems can be cumbersome and a slow step in deployment. Automated instrumentation that significantly expedites the experimental data collection process by >10x is also considered in scope.

Simulation and modeling of the safeguards-by-design will be considered only if the submission puts forth a reasonable case that it significantly expands upon prior detailed studies or offers a fundamentally different and beneficial operation and measurement protocol from currently accepted practices. Such modeling should be completed as a part of broader facility design studies completed in Category III (see below) if proposed.

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[43] Fensin, Michael L., Steven J. Tobin, Howard O. Menlove, and Martyn T. Swinhoe. "Quantifying the passive gamma signal from spent nuclear fuel in support of determining the plutonium content in spent nuclear fuel with nondestructive assay" No. LA-UR-09-03900; LA-UR-09-3900. Los Alamos National Lab. (LANL). 2009. https://www.osti.gov/servlets/purl/990302.

[44] Tiitta, Antero. "NDA verification of spent fuel, monitoring of disposal canisters, interaction of safeguards and safety issues in the final disposal." In Safeguards for final disposal of spent nuclear fuel: Methods and technologies for the Olkiluoto site, pp. A1-A16. Radiation and Nuclear Safety Authority STUK, 2003. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.568.2123&rep=rep1&type=pdf.

[45] Cook, Matthew Tyler. "Hybrid K-edge densitometry as a method for materials accountancy measurements in pyrochemical reprocessing." (2015). https://trace.tennessee.edu/cgi/viewcontent.cgi?article=4694&context=utk_graddiss.

3. Category III – Facility Design & Systems Analysis

PUREX-based commercial reprocessing facilities were generally constructed over 20 to 50 years ago, with additional equipment added to the facility as demand evolved. A new reprocessing facility constructed in the U.S. should leverage lessons learned from decades of PUREX reprocessing experience while exploiting the numerous advancements in equipment design, advanced manufacturing techniques, and modularization that have been made in similar non-nuclear industries (e.g., the oil & gas (O&G) industry) since the first reprocessing facilities were constructed decades ago. Over the past few decades, the O&G and chemical industries have developed valuable expertise in process intensification and successfully transitioned to modularized construction of key unit processes that have led to substantial reductions in construction and operations & management (O&M) costs. Such approaches might lead to similar reductions for new reprocessing facilities. Examples of equipment designs within scope of this category include, but are not limited to, those that compress unit operations, reduce a facility's overall construction costs, and enable modularized operation to meet the 200 MTHM/yr UNF throughput target outlined in this FOA.

While the approaches to designing and building reprocessing equipment mentioned above, along with the technologies proposed in Categories I and II, can potentially enable construction of reprocessing facilities that provide a cost-competitive feedstock for ARs, the full impact of such design approaches on cost needs to be evaluated and optimized. In addition, siting, licensing, constructing, and operating a modern reprocessing facility in the U.S. needs to be done in a streamlined, cost-effective manner. Lastly, and perhaps most critically, the U.S. has not constructed a commercial reprocessing facility in nearly five decades and, consequently, would functionally be building a first-of-a-kind (FOAK) facility.

To address these challenges, full systems analyses that evaluate variables with respect to the CURIE global metrics should include, but are not limited to, the following topics:

- The economic impact of reprocessing on federal waste disposal burden
- Evaluation of the supply chain, construction, and flexibility afforded from a modular vs. "stick-built" approach to constructing reprocessing facilities
- Impacts of using shorter-cooled (i.e., <10 years) vs longer-cooled (i.e., >30 years) fuels on facility design
- Economics of fluoride volatility facilities co-located with enrichment facilities
- Siting considerations of reprocessing facilities (e.g., regional vs centralized facilities)
- Economic benefits of safeguards-by-design approaches, including the benefits of integrating online monitoring with automated systems control

Facility design efforts relevant to CURIE could include:

- Use of advanced digital twins to support design and construction
- Development of project engineering best practices for FOAK reprocessing facilities

- Civil and structural cost analysis tools designed to support evaluation of Category 1 and 2 technologies against the CURIE global cost metric

When appropriate, studies that integrate with Category 1 and/or 2 efforts are highly encouraged. For example, project engineering efforts from Category 3 could be integrated with Category 1 separations efforts to specifically screen their process and/or facility designs, and ultimately civil/structural costs, while the process is being developed.

Understanding the cost benefits of these and other relevant areas could significantly inform design and future R&D needs. As such, the outcomes of proposed systems analyses should evaluate the most effective means to meet the CURIE global metrics. The analyses can be performed using the applicant's reprocessing technology of choice (e.g., pyroprocessing, aqueous separations, etc.) as long as they meet the program metrics outlined herein. Systems analysis proposals submitted under this category should also reflect an understanding of the regulatory needs for siting, constructing, and operating a reprocessing facility and the implications of reprocessing UNF that has been stored in spent fuel pools or in stranded or co-located independent spent fuel storage installations. Design of tools capable of such analyses would support future design optimization efforts and are especially encouraged. As with the proposals submitted under Categories I and II, ARPA-E strongly encourages forming diverse teams where possible.

4. Category IV – Other

This category is provided for submissions that do not cleanly fall into the above three categories but can potentially meet overall programmatic objectives detailed in Section I.C of this FOA. Submissions must make a compelling case for inclusion based on their ability to meet the stated program metrics.

E. TECHNICAL PERFORMANCE TARGETS

Submissions must discuss how their technologies support the global program metrics described in Section I.B of the FOA. While addressing at least one program metric would constitute a responsive application, applicants should indicate which metrics are being targeted and the impact their technology would have on other metrics perhaps not being addressed. Applicants should provide the information contained in the following table.

Metric	Effect relative to SOTA (positive/negative/neutral)	Description or Justification
>10x HLW waste reduction		
Predictive process monitoring within 1% uncertainty		
Separations technology with no pure plutonium streams		
Global system disposal in the range of 0.1¢/kWh		
Separation technology supporting a 1¢/kWh fuel cost for a 200 MTHM facility		

Estimation of the cost metric (1¢/kWh fuel cost for a 200 MTHM facility), will be completed by the applicants using the Reprocessing Cost Estimator Workbook. This tool should help potential performers complete a general assessment of their technology and the impact the technology would have on the CURIE global cost metric. ARPA-E appreciates that such a tool will perhaps not have the resolution to assess the finer benefits of a given technology, though the tool should be able to provide a first approximation of technology cost impact. Applicants are encouraged to use the tool in their technological assessments and submit their findings, as well as the justifications for adjustments made to the tool, as a part of their Full Applications. Applicants should be attentive to the significant construction/civil engineering costs associated with a particular unit operation and justifications should include some consideration facility design impacts arising from a new technology.

1. Category I – Reprocessing Technologies

Applicants proposing development of a technology for separating the components of UNF should describe how their innovation will accomplish one or more of the following targets of:

- significantly reducing the volume of LWR HLW requiring permanent disposal,
- providing appropriate fuel feedstock (70/30 U:Pu; 50/50 U/TRU by weight),
- having an actinide content in waste streams of <0.1% by weight,
- having a fission product content in product streams of <0.1%,
- having compatibility or potential compatibility with online monitoring technologies, and
- supporting a 1¢/kWh fuel cost and throughput needs for a 200 MTHM facility.

All proposed technologies must have the following characteristics:

- The proposed technology does not at any point create a pure plutonium product (i.e., it produces a co-recovered actinide stream),

- It would have an equivalent throughput processing rate of 2 kg/h for 8 h (~10% scale of 200 MTHM/year facility, assuming 100% capacity factor) without any loss of selectivity
  - Applicants may use non-radiological surrogates and minimize the use of hazardous materials during appropriate stages of process development;
- It would enable a 1¢/kWh fuel cost for a 200 MTHM/year facility, and
- The proposed technology is either compatible with at least one existing demonstrated waste form or is codeveloped with a compatible waste form suitable for final geological disposal. If neither criterion is met, the case must be made that the technology could potentially provide a significant disruption to reprocessing cost and safeguards SOTA, such that separate investment in a novel waste form would be justified.

An applicant to this Category shall provide an overview description of their proposed technology that includes:

- A comparison of the proposed technology's performance and cost to SOTA technologies applied under proposed conditions,
- The expected maturity (e.g., lab-scale, pilot-demonstration, commercialization) of the proposed technology at the completion of the project as demonstrated by process' equivalent throughput (2 kg/h), and
- Any relevant synergies with Category 2 or 3 efforts.

In addition, each Applicant to this Category must provide the following information:

Property	Description
Improvements in proliferation resistance	
Describe the composition of each waste stream, the associated waste forms expected from the proposed technology, and the need (if any) for the waste form to be co-developed?	
Provide the composition (e.g., 70/30 U/Pu) and form (e.g., oxide, metal) of the actinide feedstock that would be produced from the proposed technology.	
Estimated commercial scale processing facility capital expenditure (CapEx) and annual Operating and Maintenance (O&M) costs	

2. Category II – Integrated Monitoring & Materials Accountancy

In situ SNM process monitoring approaches that predict, within 1% uncertainty and under representative conditions, the post-process material accountancy, is an important CURIE global program metric. Proposed technical solutions under this category must support the program metric and address the following facets of the proposed technology (if relevant):

- If an inferential signature is proposed, validation data must be provided to demonstrate the accuracy of fissile mass determination.
- If a full volume of UNF is not sampled, an extrapolation methodology must be specified, and a validation procedure defined.
- The solution must be compatible with the anticipated radiation backgrounds the system would experience during UNF reprocessing.
- The technology should enable in-process monitoring.
- Maintenance and service schedules must be consistent with the overall system and cost goals of the program.

Each applicant to this category shall provide a schematic with all major system components identified, including required ancillary equipment, and provide the information below to the best of the applicant's ability.

Description of the separations process and technology design-basis	
The sensor location(s) within the separations process	
Estimate of material uncertainty & accuracy (including how this was determined)	
Anticipated capital and operational costs and savings of the proposed system	
Latency and/or measurement throughput	
Scale of technology demonstration relative to actual operating conditions	
Comparison to State-of-the-Art	
Mean Time Before Failure (include basis)	
Schedule for, and cost estimates of, maintenance (include all types of maintenance required, time required for actual servicing, operational or chronological time periods between required maintenance, and any replacement components or consumables needed)	
Description of mass accountancy validation (must include realistic sensor data rates, for both signal and backgrounds both from target mass and external sources)	
Number of sensors and sensor types required to support program metrics	
Sampling methodology (include approach, units of measurement, fraction of volume sampled, and scale)	
Experimental validation methodology for accuracy determination (including recalibration schedule)	
Software validation methodology for accuracy determination (including recalibration schedule)	

3. Category III – Facility Design & Systems Analysis

System design and analysis approaches must provide a clear description of what reprocessing technology(ies) and variables are considered, the justification for their selection, and/or basis for design approach with a clear indication of how these efforts support the CURIE program metrics and goals.

4. Category IV – Other

The target values for this category must be directly tied to the global program goals and specific targets from Categories I, II and/or III. Comparison must be made to the state-of-the-art relative to the proposed solution. It is important to provide a clear description of why the proposed solution does not fit cleanly into Categories I, II or III and how the selected targets from the other categories satisfy the global requirements of the program. All relevant information requested in the tables must be included in a Category IV submission, where applicable.

F. RESEARCH RESOURCES AND TEAMING PARTNERSHIPS

ARPA-E is in the process of developing a listing of DOE National Labs and other resources that may be available at the Full Application stage of this FOA to applicants that have not identified sufficient capabilities to complete activities proposed in their Concept Paper submission to this FOA.

It is anticipated that each applicant will either be in possession of the research resources or establish the requisite teaming partnerships needed to complete R&D activities proposed in their Full Applications. Applicants without access to required research resources or teaming relationships that enable access to required research resources **will not be disqualified,** nor will they be deemed nonresponsive at the Concept Paper stage for that reason alone; however, applicants at the Full Application stage will need to be able to demonstrate that they have access to the research resources needed to successfully complete R&D activities under this FOA.

To facilitate the teaming arrangements described above, ARPA-E urges applicants and other interested parties to review the CURIE Team Partner List and to provide pertinent information described therein. The CURIE Team Partner List can be found at https://arpa-e-foa.energy.gov/TeamingPartners.aspx. A list of DOE National Laboratories is available at https://science.osti.gov/sbir/Applicant-Resources/National-Labs-Profiles-and-Contacts.

For help in contacting personnel at other Federal agency laboratories, go to www.federallabs.org, or contact DOE's Federal Laboratory Consortium for Technology Transfer (FLC, https://federallabs.org/) Management Support Office by phone at (856) 667-7727 or by email at flcmso@utrs.com.

Awardees could also leverage DOE Office of Nuclear Energy (DOE-NE) programs, such as the GAIN (Gateway for Accelerated Innovation in Nuclear) initiative (https://www.inl.gov/research-program/gain) and the Nuclear Science User Facilities (NSUF) Network (https://nsuf.inl.gov/), to perform strategic experiments–either during or after completion of the Program.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $48 million available for new awards under this FOA, to be shared between FOAs DE-FOA-0002691 and DE-FOA-0002692, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 10-12 awards under FOAs DE-FOA-0002691 and DE-FOA-0002692. ARPA-E may, at its discretion, issue one, multiple, or no awards.

Individual awards may vary between $250,000 and $10 million in Federal share.

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects the start date for funding agreements to be January 2023, or as negotiated.

ARPA-E encourages submissions stemming from ideas that still require proof-of-concept R&D efforts as well as those for which some proof-of-concept demonstration already exists.

Submissions requiring proof-of-concept R&D can propose a project with the goal of delivering on the program metric at the conclusion of the period of performance. These submissions must contain an appropriate cost and project duration plan that is described in sufficient technical detail to allow reviewers to meaningfully evaluate the proposed project. If awarded, such projects should expect a rigorous go/no-go milestone early in the project associated with the proof-of-concept demonstration. Alternatively, submissions requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, the Applicants are required to provide a convincing vision how these partial solutions can enable the realization of the program metrics with further development.

Applicants proposing projects for which some initial proof-of-concept demonstration already exists should submit concrete data that supports the probability of success of the proposed project.

ARPA-E will provide support at the highest funding level only for submissions with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

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

ARPA-E plans to fully fund your negotiated budget at the time of award.

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 issuing 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 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.

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."[46] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.D below.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[47]

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.

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

[46] U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).
[47] The Prime Recipient is the signatory to the funding agreement with ARPA-E.

2. FUNDING AGREEMENTS WITH FFRDCS/DOE LABS, GOGOS, AND FEDERAL INSTRUMENTALITIES

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

When a FFRDC/DOE Lab (including the National Energy Technology Laboratory or NETL) is the *lead organization* for a Project Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with the lead entity for the rest of the Project Team. Notwithstanding the use of multiple agreements, the FFRDC/DOE Lab is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

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

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

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

3. OTHER TRANSACTIONS AUTHORITY

ARPA-E may use its "other transactions" authority under the America COMPETES Reauthorization Act of 2010 to enter into an other transaction agreement with Prime Recipients, on a case-by-case basis.

ARPA-E may negotiate an other transaction agreement when it determines that the use of a standard cooperative agreement, grant, or contract is not feasible or appropriate for a project.

In general, an other transaction agreement normally requires a minimum cost share of 50%. See Section III.B.2 of the FOA.

D. STATEMENT OF SUBSTANTIAL INVOLVEMENT

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

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- ARPA-E may, at its sole discretion, modify or terminate projects that fail to achieve predetermined Go/No Go decision points or technical milestones and deliverables.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.339 - 200.343.
- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits[48] to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

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

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

This FOA is open to U.S. universities, national laboratories, industry and individuals.

1. INDIVIDUALS

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[49] as the lead for a Project Team,[50] or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. DOMESTIC ENTITIES

For-profit entities[51], educational institutions[52], and nonprofits[53] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

FFRDCs/DOE Labs are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team that includes institutions of higher education, companies, research foundations, or trade and industry research collaborations, but not as a Standalone Applicant.

State, local, and tribal government entities are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

Federal agencies and instrumentalities (other than DOE) are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

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[49] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[50] A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.
[51] For-Profit Organizations (Other than Small Businesses) (or *large businesses*): Means entities organized for-profit other than small businesses as defined elsewhere in this Glossary.
[52] Institutions of Higher Education (or educational institutions): Has the meaning set forth at 20 U.S.C. 1001.
[53] 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 Prime Recipient or Subrecipient.

3. FOREIGN ENTITIES

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or otherwise formed or to be formed) under the laws of a State or territory of the United States to receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. All work under the ARPA-E award must be performed in the United States. The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application and can be found at https://arpa-e-foa.energy.gov/ (see "View Template Application Documents"). Refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. CONSORTIUM ENTITIES

Consortia, which may include domestic and foreign entities, must designate one member of the consortium as the consortium representative to the Project Team. The consortium representative must be incorporated in the United States. The eligibility of the consortium will be determined by reference to the eligibility of the consortium representative under Section III.A of the FOA. Each consortium must have an internal governance structure and a written set of internal rules. Upon request, the consortium entity must provide a written description of its internal governance structure and its internal rules to the Contracting Officer (ARPA-E-CO@hq.doe.gov).

Unincorporated consortia must provide the Contracting Officer with a collaboration agreement, commonly referred to as the articles of collaboration, which sets out the rights and responsibilities of each consortium member. This collaboration agreement binds the individual consortium members together and shall include the consortium's:

- Management structure;
- Method of making payments to consortium members;
- Means of ensuring and overseeing members' efforts on the project;
- Provisions for members' cost sharing contributions; and
- Provisions for ownership and rights in intellectual property developed previously or under the agreement.

B. COST SHARING[54]

Applicants are bound by the cost share proposed in their Full Applications.

1. BASE COST SHARE REQUIREMENT

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.C.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime Recipient must provide at least 20% of the Total Project Cost[55] as cost share, except as provided in Sections III.B2 or III.B.3 below.[56]

2. INCREASED COST SHARE REQUIREMENT

Large businesses[57] are strongly encouraged to provide more than 20% of the Total Project Cost as cost share. ARPA-E may consider the amount of cost share proposed when selecting applications for award negotiations (see Section V.B.1 of the FOA).

Under an "other transaction" agreement, the Prime Recipient is normally expected to provide at least 50% of the Total Project Cost as cost share. ARPA-E may reduce this cost share requirement, as appropriate.

3. REDUCED COST SHARE REQUIREMENT

ARPA-E has reduced the base cost share requirement for the following types of projects:

- A domestic educational institution or domestic nonprofit applying as a Standalone Applicant is required to provide at least 5% of the Total Project Cost as cost share.
- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs/DOE Labs/Federal agencies and instrumentalities (other than DOE) are required to provide at least 5% of the Total Project Cost as cost share.Small businesses – or consortia of small businesses – may provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[58] If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the

[54] Please refer to Section VI.B.3-4 of the FOA for guidance on cost share payments and reporting.
[55] 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.
[56] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988(c)
[57] The term "For-Profit Organizations (Other than Small Businesses)" or "large business" is defined in Section IX.
[58] The term "small business" is defined in Section IX.

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 share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.
- Project Teams where domestic educational institutions, domestic nonprofits, small businesses, and/or FFRDCs perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.
- Projects that do not meet any of the above criteria are subject to the base cost share requirements described in Sections III.B.1 and III.B.2 of the FOA.

4. 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 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.

5. 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.

6. COST SHARE TYPES AND ALLOWABILITY

Every cost share contribution must be allowable under the applicable Federal cost principles, as described in Section IV.G 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;
- Appropriated 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[59] 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.

[59] As defined in Federal Acquisition Regulation SubSection 31.205-18.

7. 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.

8. 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.

C. OTHER

1. COMPLIANT CRITERIA

Concept Papers are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Concept Paper 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 deadline stated in the FOA.

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

Full Applications are deemed compliant if:

- The Applicant submitted a compliant and responsive Concept Paper;
- 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.D 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 deadline stated in the 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.

Replies to Reviewer Comments are deemed compliant if:

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

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

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Concept Papers and 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 this FOA.
- Submissions that do not address the required technical information (i.e., information that "must" be included), as specified in Sections I.D and I.E of the FOA.
- Submissions that have been submitted in response to currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.

- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA.
- Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by any other office within Department of Energy, by other government agencies, or by 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.

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- Submissions explicitly targeting reprocessing to support the currently deployed LWR fleet. While backwards compatibility is permissible, the technology must have a clear connection to supporting ARs.
- Marketing solutions.
- Discourse or policy papers about reprocessing technologies.

4. LIMITATION ON NUMBER OF SUBMISSIONS

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

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. 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.H.1 of the FOA and the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

2. CONCEPT PAPERS

Applicants must submit a Concept Paper by the deadline stated in the FOA. Section IV.C of the FOA provides instructions on submitting a Concept Paper.

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Concept Papers 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 Concept Paper based on the criteria and program policy factors in Sections V.A.1 and V.B.1 of the FOA.

ARPA-E will encourage a subset of Applicants to submit Full Applications. Other Applicants will be discouraged from submitting a Full Application in order to save them the time and expense of preparing an application submission that is unlikely to be selected for award negotiations. By discouraging the submission of 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. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

3. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 45 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D 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.C 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.2 and V.B.1 of the FOA.

4. REPLY TO REVIEWER COMMENTS

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, 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.2 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 Concept Paper, 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 CONCEPT PAPERS

The Concept Paper is mandatory (i.e. in order to submit a Full Application, a compliant and responsive Concept Paper must have been submitted) and must conform to the following formatting requirements:

- The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables.
- The Concept Paper must be submitted in Adobe PDF format.
- The Concept Paper 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.
- The first paragraph must include the Lead Organization's Name and Location, Principal Investigator's Name, Technical Category, Proposed Funding Requested (Federal and Cost Share), and Project Duration.
- Applicants must fill out the Reprocessing Cost Estimator Workbook (Microsoft Excel), as it relates to their proposal.

Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award (see Section III.C of the FOA).

Each Concept Paper must be limited to a single concept or technology. Unrelated concepts and technologies must not be consolidated into a single Concept Paper.

A fillable Concept Paper template is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

Concept Papers must conform to the content requirements described below. If Applicants exceed the maximum page length indicated above, ARPA-E will review only the authorized number of pages and disregard any additional pages.

1. FIRST COMPONENT: CONCEPT PAPER

a. CONCEPT SUMMARY

- Describe the proposed concept with minimal jargon, and explain how it addresses the Program Objectives of the FOA.

b. INNOVATION AND IMPACT

- Clearly identify the problem to be solved with the proposed technology concept.
- Describe how the proposed effort represents an innovative and potentially transformational solution to the technical challenges posed by the FOA.
- Explain the concept's potential to be disruptive compared to existing or emerging technologies.
- To the extent possible, provide quantitative metrics in a table that compares the proposed technology concept to current and emerging technologies and to the Technical Performance Targets in Section I.E of the FOA for the appropriate Technology Category in Section I.D of the FOA.

c. PROPOSED WORK

- Describe the final deliverable(s) for the project and the overall technical approach used to achieve project objectives.
- Discuss alternative approaches considered, if any, and why the proposed approach is most appropriate for the project objectives.
- Describe the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach. Provide specific examples of supporting data and/or appropriate citations to the scientific and technical literature.

- Describe why the proposed effort is a significant technical challenge and the key technical risks to the project. Does the approach require one or more entirely new technical developments to succeed? How will technical risk be mitigated?
- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.
- Estimated federal funds requested; total project cost including cost sharing.

d. TEAM ORGANIZATION AND CAPABILITIES

- Indicate the roles and responsibilities of the organizations and key personnel that comprise the Project Team.
- Provide the name, position, and institution of each key team member and describe in 1-2 sentences the skills and experience that he/she brings to the team.
- Identify key capabilities provided by the organizations comprising the Project Team and how those key capabilities will be used in the proposed effort.
- Identify (if applicable) previous collaborative efforts among team members relevant to the proposed effort.
- Indicate if the team is planning to coordinate with other proposals.

2. SECOND COMPONENT: REPROCESSING COST ESTIMATOR

In addition to the Concept Paper, Applicants must fill out and submit the Reprocessing Cost Estimator Workbook, CURIE_ReprocessingCostEstimator.xlsx, which is available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/).

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

F. INTERGOVERNMENTAL REVIEW

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

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

H. 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). Concept Papers, 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 submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Concept Paper, or 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 deadline stated in the FOA. Such applications may be deemed noncompliant (see Section III.C.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 Concept Papers and Full Applications to determine whether they are compliant and responsive (see Section III.C of the FOA). ARPA-E also performs a preliminary review of Replies to Reviewer Comments to determine whether they are compliant.

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

1. CRITERIA FOR CONCEPT PAPERS

(1) *Impact of the Proposed Technology Relative to FOA Targets* (50%) - This criterion involves consideration of the following:

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- Achievement of the technical performance targets defined in Section I.E of the FOA for the appropriate technology Category in Section I.D of the FOA;
- Identification of techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and
- Demonstration of awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

(2) *Overall Scientific and Technical Merit* (50%) - This criterion involves consideration of:

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;
- Sufficiency of technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;
- Clearly defined project outcomes and final deliverables; and
- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

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

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

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 Concept Papers to encourage to submit a Full Application and which Full Applications to select for award negotiations:

I. **ARPA-E Portfolio Balance**. Project balances ARPA-E portfolio in one or more of the following areas:
   a. Diversity of technical personnel in the proposed Project Team;
   b. Technological diversity;
   c. Organizational diversity;
   d. Geographic diversity;
   e. Technical or commercialization risk; or
   f. Stage of technology development.

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

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

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

V. **High-Leveraging of Federal Funds**. Project leverages Federal funds to optimize advancement of programmatic goals by proposing cost share above the required minimum or otherwise accessing scarce or unique resources.

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

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

2. ARPA-E REVIEWERS

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

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

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

3. ARPA-E SUPPORT CONTRACTOR

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

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of ARPA-E's support contractors 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

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

Noncompliant and nonresponsive Concept Papers and 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 Concept Paper or Full Application was rejected.

2. CONCEPT PAPER NOTIFICATIONS

ARPA-E promptly notifies Applicants of its determination to encourage or discourage the submission of a Full Application. ARPA-E sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. ARPA-E provides feedback in the notification letter in order to guide further development of the proposed technology.

Applicants may submit a Full Application even if they receive a notification discouraging them from doing so. By discouraging the submission of 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. The purpose of the Concept Paper phase is to save Applicants the considerable time and expense of preparing a Full Application that is unlikely to be selected for award negotiations.

A notification letter encouraging the submission of a Full Application does not authorize the Applicant to commence performance of the project. Please refer to Section IV.G of the FOA for guidance on pre-award costs.

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2022]

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

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

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

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

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

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

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

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings. ARPA-E provides Applicants with a notification encouraging or discouraging the submission of a Full Application based on ARPA-E's assessment of the Concept Paper. In addition, ARPA-E provides Applicants with reviewer comments on Full Applications before the submission deadline for Replies to Reviewer Comments.

VIII. OTHER INFORMATION

A. TITLE TO SUBJECT INVENTIONS

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

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions;
- All other parties: The federal Non-Nuclear Energy Act of 1974, 42. U.S.C. 5908, provides that the government obtains title to new subject inventions unless a waiver is granted (see below):
  - Class Patent Waiver for Domestic Large Businesses: DOE has issued a class patent waiver that applies to this FOA. Under this class patent waiver, domestic large businesses may elect title to their subject inventions similar to the right provided to the domestic small businesses, educational institutions, and nonprofits by law. In order to avail itself of the class patent waiver, a domestic large business must agree to the U.S. Competitiveness Provision in accordance with Section VI.B.8. of this FOA.
  - Advance and Identified Waivers: For applicants that do not fall under the class patent waiver or the Bayh-Dole Act, those applicants may request a patent waiver that will cover subject inventions that may be made under the award, in advance of or within 30 days after the effective date of the award. Even if an advance waiver is not requested or the request is denied, the recipient will have a continuing right under the award to request a waiver for identified inventions, i.e., individual subject inventions that are disclosed to DOE within the time frames set forth in the award's intellectual property terms and conditions. Any patent waiver that may be granted is subject to certain terms and conditions in 10 CFR 784.
- DEC: On June 07, 2021, DOE approved a DETERMINATION OF EXCEPTIONAL CIRCUMSTANCES (DEC) UNDER THE BAYH-DOLE ACT TO FURTHER PROMOTE DOMESTIC MANUFACTURE OF DOE SCIENCE AND ENERGY TECHNOLOGIES. In accordance with this DEC, all awards, including sub-awards, under this FOA made to a Bayh-Dole entity (domestic small businesses and nonprofit organizations) shall include the U.S. Competitiveness Provision in accordance with Section VI.B.8 of this FOA. A copy of the DEC may be found on the DoE website. Pursuant to 37 CFR § 401.4, any Bayh-Dole entity affected by this DEC has the right to appeal it by providing written notice to DOE within 30 working days from the time it receives a copy of the determination.

B. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

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

1. GOVERNMENT USE LICENSE

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

2. MARCH-IN RIGHTS

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

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

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

C. RIGHTS IN TECHNICAL DATA

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

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to twenty years 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 are also posted to these websites. You can receive an e-mail when a modification is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

F. OBLIGATION OF PUBLIC FUNDS

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

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

G. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

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

- The rejection of a Concept Paper, 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 Concept Papers, 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 Concept Papers, Full Applications, and Replies to Reviewer Comments strictly for evaluation purposes.

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

The cover sheet of the Concept Paper, 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. 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 Preliminary Application, Full Application, Reply to Reviewer Comments, and Small Business Grant Application (if applicable).

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

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

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

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

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

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

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

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

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

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

PI: Principal Investigator.

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

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

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

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

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

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

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