FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

ULTRAHIGH TEMPERATURE IMPERVIOUS MATERIALS ADVANCING TURBINE EFFICIENCY SBIR/STTR (ULTIMATE SBIR/STTR)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002338
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	April 21, 2020
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, May 26, 2020
Submission Deadline for Concept Papers:	9:30 AM ET, June 5, 2020
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:	November 2020
Total Amount to Be Awarded	Approximately $28 million, subject to the availability of appropriated funds, to be shared between FOAs DE-FOA-0002337 and DE-FOA-0002338.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $256,580 and $3,677,642.

- For eligibility criteria, see Section III.A – III.D of the FOA.
- For cost share requirements under this FOA, see Section III.E of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.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.F.1 through III.F.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).

TABLE OF CONTENTS

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 and must include the following: ○ Concept Summary ○ Innovation and Impact ○ Proposed Work Team Organization and Capabilities	Mandatory	IV.C	9:30 AM ET, June 5, 2020
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]	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) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in—
(i) reductions of imports of energy from foreign sources;
(ii) reductions of energy-related emissions, including greenhouse gases; and
(iii) improvement in the energy efficiency of all economic sectors; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

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

ARPA-E funds research on and the development of high-potential, high-impact energy technologies that are too early for private-sector investment. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution to 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 the clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

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

B. SBIR/STTR PROGRAM OVERVIEW

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

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

between Small Business Concerns and partnering Research Institutions through Federally funded R&D activities.[2]

ARPA-E administers a joint SBIR/STTR program in accordance with the Small Business Act and the SBIR and STTR Policy Directive issued by the U.S. Small Business Administration (SBA).[3] ARPA-E provides SBIR/STTR funding in three phases (Phase I, Phase II, and Phase IIS).

C. PROGRAM OVERVIEW

1. INTRODUCTION

The ULTIMATE Program seeks to fund the development and demonstration of ultrahigh temperature materials that can operate continuously at 1300 ºC in a standalone material test environment (or with coatings, enabling gas turbine inlet temperatures of 1800 °C) or higher, targeting gas turbine applications in the power generation and aviation industries. The successful materials must be able to withstand not only the highest temperature in a turbine but also the extreme stresses of a turbine blade. This program will concurrently fund the development of manufacturing processes for turbine components using these materials, enabling complex geometries that can be seamlessly integrated in the system design. Coatings including both environmental barrier coatings (EBC) and thermal barrier coatings (TBC) are also within the scope of this program. It is expected that the development of novel ultrahigh temperature materials in combination with compatible coatings and manufacturing technologies will enable the efficiency of gas turbines to be improved by up to 7%, which will result in significant reductions in wasted energy and carbon emissions.

2. BACKGROUND

Gas turbines are widely used for electric power generation and aircraft propulsion, among other industrial applications. Today, natural gas fueled turbines produce approximately 35% of the total electricity production in US[4]. Air travel is responsible for 2% of carbon emissions and is expected to double in the next two decades globally[5]. Improving the efficiency of gas turbines is thus a very important issue for energy savings, carbon emissions, and the economy of not only those industries, but a broad breath of sectors.

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

[3] See 84 Fed. Reg. 12794 (Apr. 2, 2019).

[4] U. S. Energy Information Administration. Retrieved February 24, 2020, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

[5] Air Transport Action Group. Retrieved February 24, 2020, https://www.atag.org/facts-figures.html

Based on thermodynamic principles governing the operation of thermal mechanical systems such as turbines, the efficiency of a gas turbine depends to a large degree on the peak temperature of the working fluid (e.g. air or combustion products)[6]. The higher the peak temperature, the higher the efficiency and specific core power (Figure 1). However, the peak operating temperature of gas turbines is limited by the capability of the material used to construct the components (e.g. blades, vanes, nozzles and shrouds) in the hottest part of the cycle. Among them, the turbine blades experience the most demanding environment because they must withstand not only the highest temperatures in a turbine, but also the highest stresses during operations.

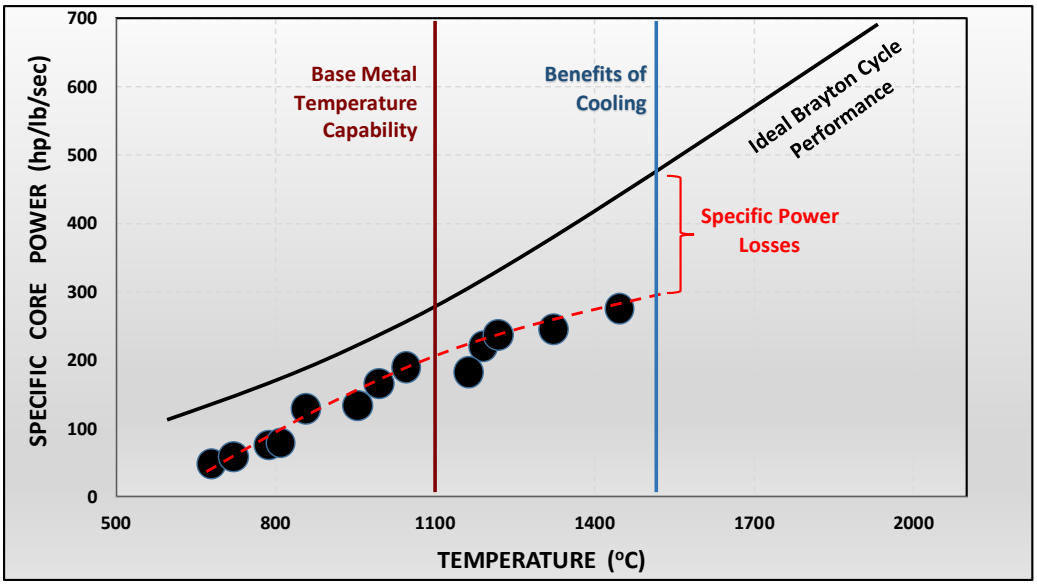

Figure 1: Plot showing specific core power of an aircraft engine as a function of temperature

Currently, turbine blades are made of single crystal nickel-based superalloys that have been developed and optimized over the past 70 years for this application. There are also cobalt (Co) based alloys with similar properties as those of Ni superalloys. Different grades of Ni superalloys are used for making components in different parts of turbines depending on the actual working temperature required, from 500 °C and up[7] [8]. Ni superalloys with the highest temperature capability include those commercially known as CMSX series, PW1484, Rene N5, and their variations. Those alloys represent the state-of-the-art of high temperature materials.

Current state-of-the-art alloys used in turbines cannot operate at temperatures higher than 1100 °C. In practice, in order to increase the effective gas inlet temperature, turbine blades are coated with what is called “thermal barrier coatings” (TBC) which allow the surface

[6] J. H. Perepezko, (2009). The hotter the engine the better. *Science, 326,* pp.1068
[7] A. Nowotnik, (2016), Nickel-based superalloys, Reference module in materials science and materials engineering,
[8] T. M. Pollock and S. Tin, (2006) Nickel-Based Superalloys for Advanced Turbine Engines: Chemistry, Microstructure, and Properties, Journal of propulsion and power, 22, No. 2, pp. 361.

temperature of a coated blade to be significantly higher - up to 1500 °C. Additionally, the blades are also cooled through sophisticated interior cooling channels, which further protect the base metal and enable working fluid operating temperatures as high as 1600 °C. Although the cooling and TBC can protect the base metal while allowing the operational temperature to be higher than that of the temperature capability of the base metal, those effects are achieved at the expense of efficiency. It is estimated that anywhere from 1-3 percent efficiency is sacrificed in order to protect the base metal depending on the specific designs and operating conditions[9]. Improving the temperature capability of the base metal will not only allow for potential increases of the gas inlet temperature, but also allow for optimum designs with less dependence on cooling channels, thus increased effective efficiency.

3. MOTIVATION

Technical Performance Motivations

The motivation of this program is to improve the efficiency of gas turbines by increasing the temperature capability of the materials used in the most demanding environments such as the turbine blade. The temperature capability of Ni superalloys has been improved steadily over the last few decades from 600 °C to 1100 °C through incremental microstructure and chemistry refinement. However, the development of Ni superalloys as well as Co alloys based on similar microstructural approaches, has plateaued. There is little room to further increase the working temperature of an engine because 1100 °C is approximately 90 percent of the liquid forming temperature of Ni superalloys. Thus, there is a strong need to discover, develop, and implement novel materials that work at temperatures significantly higher than that of the Ni or Co-based superalloys if further efficiency gains are to be realized.

The proposed program aims to develop refractory metal alloys (such as Mo, Nb etc.) for high temperature components in gas turbines. Refractory metals typically have melting points above 2000 °C, high intrinsic strength at high temperatures, and good thermal conductivity. Figure 2 shows much higher elastic modulus of refractory metals as a function of temperature in comparison to standard Ni alloy (IN718)[10]. The combination of those basic attributes makes them attractive candidates for high temperature applications. However, many refractory metals are also known for being brittle at room temperature or even elevated temperatures and poor manufacturability. Most of the refractory metals are also prone to oxidation, thus the environmental stability of refractory metal alloys is a major concern[11]. Those issues have prevented the exploration and serious consideration of refractory metal alloys in the past.

[9] Z. Huda, T. Zaharinie, and H. Al-Ansary, (2014), Enhancing power output and profitability through energy-efficiency techniques and advanced materials in today's industrial gas turbines International; Journal of Mechanical and Materials Engineering, pp.1.

[10] Plansee. Retrieved February 24, 2020, https://www.plansee.com/en/materials/chromium.html

[11] B. A. Pint, (2014). Critical Assessment 4: Challenges in developing high temperature materials. *Materials Science and Technology, 30, No. 12,* pp.1387

Although the potential advantages of refractory metals have been recognized, with some reported efforts in the literature, the development of refractory metal alloys for high temperature applications is in general regarded as high risk, low priority, and in its infancy.

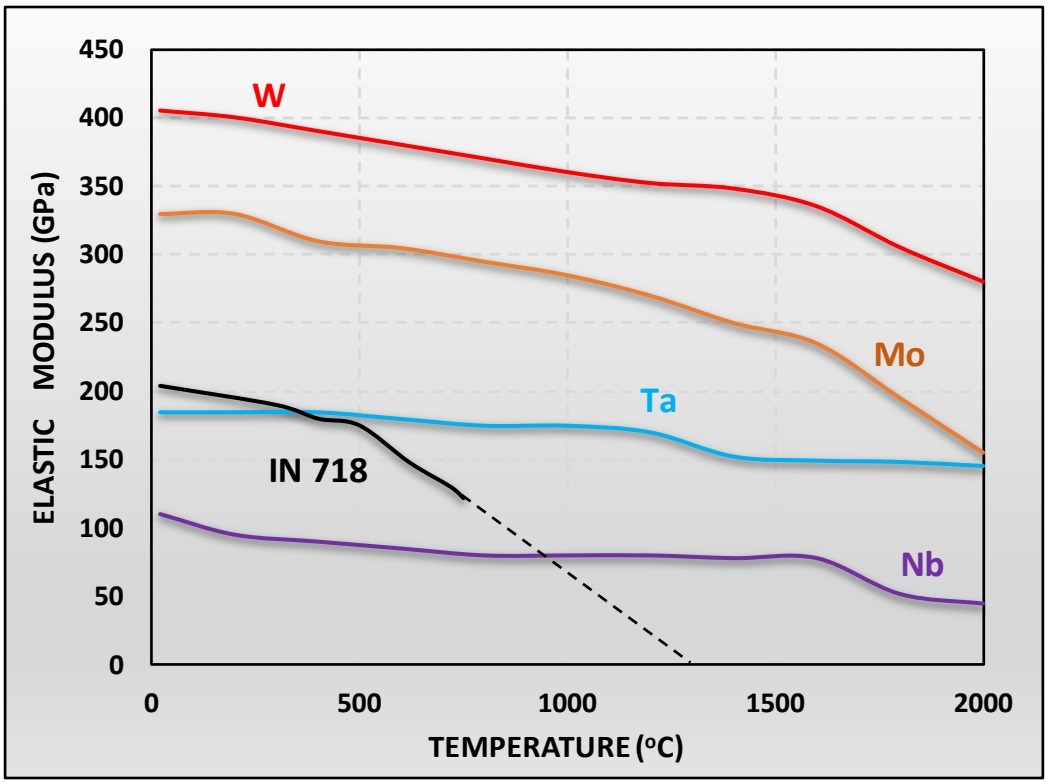

Figure 2: High temperature elastic modulus of metals

Fortunately, the landscapes of materials science and engineering have changed significantly in the most recent decade. Transformative advances in materials modeling and manufacturing are changing what is possible in the development of new materials, which may create new opportunities for discovering novel high-performance materials including refractory metal alloys. For instance, advanced manufacturing technologies such as additive manufacturing processes have only recently become available, and could provide solutions to address many of the manufacturing challenges. Rapid advancements in computational materials science now make it possible to predict microstructure and mechanical properties systematically, which can drastically shorten the time needed for discovering promising compositions and processes. Further, the emerging field of "high entropy alloys" has opened a door to an untapped compositional space for novel alloy discovery. Refractory metal alloys are prime candidates for forming high entropy alloys (HEAs) because many refractory metal elements are mutually soluble in each other, which is one of the characteristics of narrowly defined HEAs[12]. We note that HEAs are not a family of materials with similar family traits, but

[12] D. B. Miracle, O. N. Senkov, (2017) A critical review of high entropy alloys and related concepts, Acta Materialia, 122, pp. 448.

rather is an approach that was unwittingly neglected in the past for creating new alloy compositions and new microstructures. We are interested in not only the narrowly defined HEAs which require five or more principal elements of equal molar fractions and formation of a single solid solution phase, but also other multi-principal element alloys (MPEA) that may have multi-phase microstructures.

In short, given the demand for higher temperature materials, new tools and capabilities, and the compositional space for potential new alloys, there is a realistic opportunity for developing novel high temperature materials based on refractory metals and supporting manufacturing techniques, which could meet the metrics of this FOA. Figure 3 is a schematic that shows the historical performance of state-of-the-art (SOA) Ni-based superalloys as compared to this FOA's target.

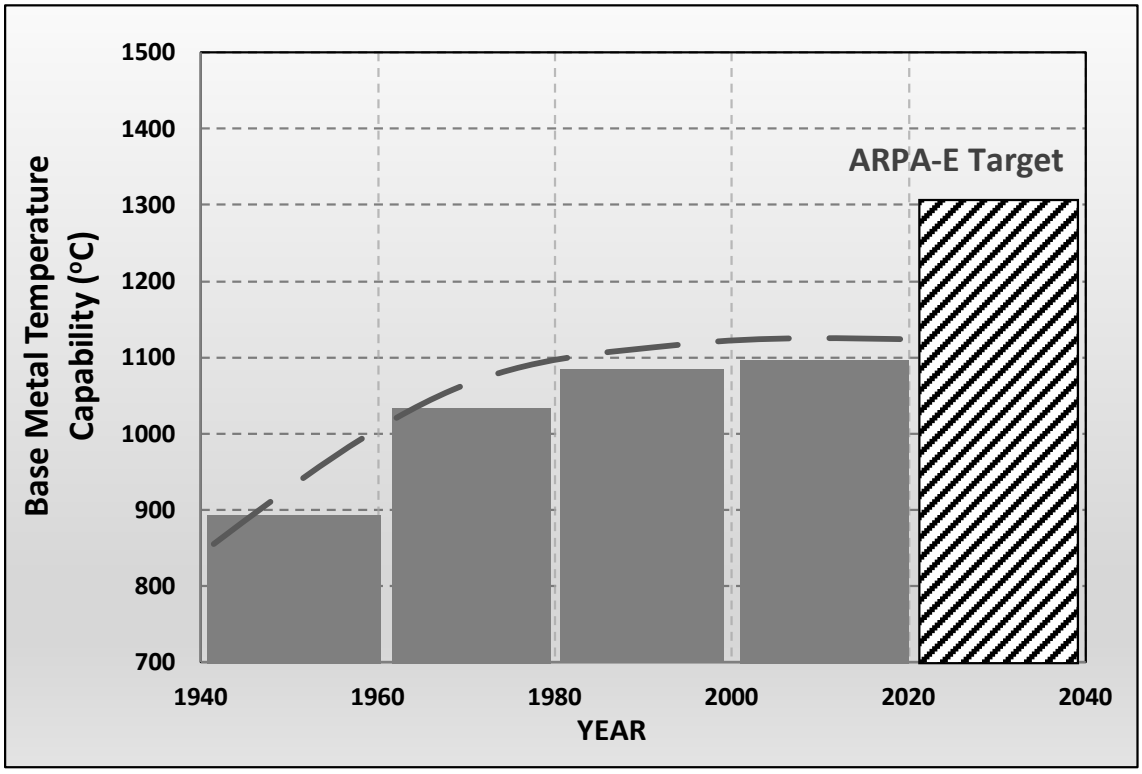

Figure 3 Temperature capability of the current SOA and the ARPA-E target for novel gas turbine-blade alloy base metals.

Market motivations

Enabling this capability for turbines and related components in the power generation and aviation industries will provide an opportunity for utilizing these materials in additional markets. These materials feed into the system designs of a broad number of use cases, including but not limited to: marine engines and components, high temperature industrial

applications, and nuclear applications. In particular, the high temperature zones of natural gas turbines offer a clear need for these types of materials. Combining this with the fact that the specifications for a gas turbine open up straightforward opportunities for not one, but two major markets, increases the positive impact of these materials on energy usage and emissions. On its own, a 7% improvement in efficiency in the natural gas turbines used for electricity generation in the U.S. represents a chance to save up to 15-16 quads of energy by 2050[13]. A similar improvement in the turbines used for civilian aircraft represents another 3-4 quads of potential savings for U.S. air travel over the same time span [14] [15]. Thus, an improvement in the turbine space could unlock significant efficiency potential across multiple sectors with the additional development of component and system designs down the road.

Beyond the energy savings aspect of this program, the economic impacts will also be significant. Electricity generation markets are currently saturated with gas generation units, as well as older coal and nuclear units that are well past their useful life. As such, the need to squeeze even a percent of efficiency out of these units is critical to ensuring that the plants can effectively deploy their capacity to the grid. Should a new unit that is 7% more efficient be launched based on this new material paradigm, it could save its owner up to $20k/MW above current SOA (the H-Series turbine) over the lifetime (assumed to be 20 yrs) of a baseload generator, or $5k/MW above SOA for a peaker plant (at a fuel cost of $3/MMBtu). These numbers could be much larger in evaluating savings over non-SOA models. Combined with the shut-down economics aspect of the market, this is a significant case for improvement.

Likewise, on the Aerospace front, there is significant demand for newer, more efficient turbine designs. A newer turbine for aerospace that is 7% more efficient than the current SOA would represent a fuel savings of $0.40/thousand passenger-km-traveled ($0.88/thousand passenger km-traveled above non-SOA on average), assuming a fuel cost of $1.56/gal. This would aggregate to approximately $1.5Bn in savings per year across the U.S. fleet just from reduced fuel use alone. [16]

While each of these scenarios represents the optimal one in which material suppliers collaborate with component manufacturers and system designers to develop and deploy full, more-efficient turbines into the market, the more likely scenario in the short run is that individual turbine components are created out of these new materials and deployed individually as partial retrofits of existing turbine parts. The efficiency savings in this case would

[13] Baseline energy usage from PJM Measured H-class and F-class heat rate performance https://www.pjm.com/~/media/committees-groups/committees/mic/20180425-special/20180425-pjm-2018-cost-of-new-entry-study.ashx)

[14] U.S Fleet Growth Data per Oliver Wyman Associates https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2019-39_FAA_Aerospace_Forecast.pdf

[15] Bureau of Transportation Statistics https://www.transtats.bts.gov/Data_Elements.aspx?Data=4

[16] Based on fleet miles traveled (https://www.transtats.bts.gov/Data_Elements.aspx?Data=4) and relative efficiency gains above baseline, as defined by grams fuel/passenger mile traveled per the International Council on Clean Transportation. Retrieved February 24, 2020, https://theicct.org

be largely derived by a reduction in the cooling load needed to prevent materials from deforming under the high temperature conditions and not from an increase in the peak cycle temperature itself. However, this cooling-load-reduction-benefit alone could result in a 1 to 3% efficiency improvement.

4. PROGRAM OBJECTIVES

This program will foster research and development of novel refractory metal alloys, including refractory metal high entropy alloys, as well as necessary coatings, for high temperature turbine blade applications. This program aims to fund the development of bulk alloys that can continuously operate at 1300 °C and compatible coatings that along with cooling systems can further increase the temperature capability to enable gas turbine inlet temperatures of 1800 °C. These new alloys must be able to withstand both the high temperature and the high stresses in the most demanding environments in a turbine. The new materials must achieve equivalent or higher creep strength compared to the state-of-the-art superalloys but at a significantly higher temperature, i.e. >1300 °C. Successful coatings or the combination of an alloy and coatings must be able to maintain their high temperature strength after being exposed in specific service conditions for a specified period of time. If successful, this program will bring a step-change to the efficiency of gas turbines, ushering in a time of commercial ultrahigh temperature materials.

Another key objective of this program is the concurrent development of manufacturing processes with the materials. No materials development effort is successful without a realistic manufacturing process that can concurrently deliver both geometric designs and the desired mechanical properties, for example by the control of a specific microstructure. It is also a prerequisite that development of both the materials and manufacturing processes are conducted within the confines of the full system design, and as an integral part of the system development. Too often in the past, materials and manufacturing process developments and system designs were disconnected, which prolonged the technology development timeline, and also prevented potential high impact innovations. Therefore, concurrent development of system designs, materials, and manufacturing processes is a key requirement of this FOA.

5. TECHNICAL TOPICS OF INTEREST

Topic 1. Novel alloy development

Novel alloy development is at the core of this program. It involves modeling, experimentation, characterization, mechanical testing, and iterations of all of the above. The objective is to develop novel alloys that can operate continuously at 1300 °C. Successful alloys must have an equivalent or better creep strength compared to the state-of-the-art superalloys but at significantly higher temperatures. The alloys must also possess a robust set of other

physical, chemical, and mechanical properties that are required for service in the most demanding environments in a gas turbine, such as those for a gas turbine blade.

Alloy development should be coupled with full considerations and demonstrations of any manufacturing processes that will be used to produce the new alloys. The manufacturing processes must be able to generate the microstructure and mechanical properties that the material is designed to achieve, while being able to produce the complex geometries that are dictated by turbine system designs.

In addition to mechanical strength, fracture toughness and reliability, and other physical properties, the material development must also consider the environmental damage resistance of the alloy. The environmental resistance may be achieved as inherent in the alloy design, or it may be attained in combination with a coating. Compatibility of the base alloy with any candidate coatings must also be an integral part of the alloy design.

Topic 2. Coating development

Due to the high temperatures, oxidation, and other possible corrosive environments turbine materials are exposed to, it is expected that coatings are likely a necessary part of the total solution. Refractory metals are known to be prone to oxidation if left exposed. Therefore, project efforts that focus on the development of coatings, including both EBC and TBC coatings, for refractory metal alloys are also of interest. Potential coatings may be developed by using existing commercial refractory metal alloys as surrogates for future alloys that may be developed during this program, or in concert with Topic 1 above. However, substrate alloys must be highly akin and relevant to the potential new alloys based on the best knowledge of the time.

Topic 3. Manufacturing process development

Manufacturing process development is an integral part of the overall program objective. It is mandatory that all material developments are closely coupled with manufacturing processes and vice versa. Manufacturing processes must be able to deliver not only design topologies, operational characteristics, and system integration requirements, but also the microstructure and mechanical properties that the alloys are designed to achieve. This program recognizes that parallel efforts of alloy and manufacture process developments can be beneficial. Therefore, project efforts that focus on the manufacturing process development for refractory metal alloys are of interest. Potential manufacturing processes may be developed by using existing commercial refractory metal alloys as surrogates for future alloys that may be developed during this program. However, surrogate alloys must be highly akin and relevant to the potential new alloys based on the best knowledge of the time.

Additive manufacturing (AM) or hybrid-AM is a promising technology that could play an important role for the success of this program. Therefore, AM of refractory metal alloys are of

high interest for this program. However, this program is not limited to AM. All innovative manufacture techniques including near-net shape (NNS) manufacturing technologies such as powder metallurgy technologies are also welcome. Manufacturing processes must be able to achieve current designs for turbine blades including internal cooling channels and any necessary surface characteristics. Manufacturing processes are also important for attaining functionally graded microstructures or components. Intelligent processing technologies that can help control and optimize microstructural evolutions through machine learning or other digital data processing techniques can be an integral part of manufacturing process development. Manufacturing technologies may also include the development of feedstock materials such as powders or wires designed for AM or other manufacturing techniques.

Topic 4. Comprehensive solutions

This program supports project efforts that aim to provide comprehensive solutions that enable turbines to be able to run at higher temperatures to achieve higher efficiencies. Comprehensive solutions are technology packages that address the challenge by integrating the capability of the base alloy, coatings, and manufacturing techniques to meet the requirements of the overall system design. Project efforts that aim to provide comprehensive solutions consist of efforts in alloy design and development, coatings, and compatible manufacturing process, all of which are driven by component and system designs. Comprehensive solutions also address supply chain technologies and testing and validation of the technologies developed. It is expected that such project efforts will involve multiple partners with complementary expertise, skills, and processing capabilities.

Topics 1-4 applicants must provide a plan to accomplish needed testing, manufacturing research, and modeling described in Topic 5 (Section I.B.5) of DE-FOA-0002337.

ARPA-E recognizes that some awardees may not have access to these capabilities, which are required for this Program. ARPA-E will provide funding to Resource Support/Topic 5 Project Teams (under DE-FOA-0002337) with capabilities and expertise on high-temperature testing of materials. SBIR/STTR awardees are encouraged to utilize those resources to support testing requirements of their projects. Data generated by these Topic 5 Project Team(s) about individual Topics 1-4 awardees' technology will only be provided to the specific Topics 1-4 awardees whose technology is being evaluated, and to ARPA-E.

6. PROGRAM STRUCTURE

ULTIMATE is a program offered in two separate programmatic phases. Applicants must provide detailed budgets and task descriptions that cover both ULTIMATE Phase 1 and ULTIMATE Phase 2. . Details of ULTIMATE Phases 1 and 2 are provided below.

Phase 1. ULTIMATE Phase 1 (SBIR/STTR Phase I and portion of SBIR/STTR Phase II) focuses on an initial lab-scale feasibility demonstration of the design of alloy compositions, coatings, and manufacturing processes, with proof-of-concept laboratory data demonstrating the potential of the new alloy compositions and manufacturing processes. ULTIMATE Phase 1 (SBIR/STTR Phase I and portion of SBIR/STTR Phase II) will conclude with laboratory test data reports that meet the specific performance metrics as described in Table I in the next section (Technical Performance Targets). ULTIMATE Phase 1 (SBIR/STTR Phase I and portion of SBIR/STTR Phase II) can be proposed for a maximum of 18 months, based on the Applicant's individual assessment and the proposed project's schedule. All selected projects will incorporate the ULTIMATE Phase 1 criteria as a milestone and Go/No-go criteria in the Statement of Project Objectives (SOPO).

Based on each individual project's technical success, including meeting technical targets of ULTIMATE Phase 1 (SBIR/STTR Phase I and portion of SBIR/STTR Phase II), ARPA-E may select projects to continue to ULTIMATE Phase 2 (remainder of SBIR/STTR Phase II and SBIR/STTR Phase IIS), subject to the availability of appropriated funds.

Phase 2. During ULTIMATE Phase 2 (remainder of SBIR/STTR Phase II and SBIR/STTR Phase IIS), successful projects will conduct comprehensive optimization and testing of selected alloy compositions, coatings, and manufacturing processes at a slightly larger scale. The investigations shall evaluate a suite of physical, chemical, and mechanical properties that collectively determine the performance of turbine blades at high temperatures. ULTIMATE Phase 2 (remainder of SBIR/STTR Phase II and SBIR/STTR Phase IIS) can be proposed for a maximum of 24 months. The technical metrics for the comprehensive set of properties are detailed in Table II in the next section (Technical Performance Targets).

7. TECHNICAL PERFORMANCE TARGETS

7.1 Novel Alloy Development (Topic 1)

7.1.1 ULTIMATE Phase 1 Targets

Table I contains a list of basic threshold and qualitative metrics required for successful completion of ULTIMATE Phase 1. Alloy development teams must provide statistically significant data as proof that the ULTIMATE Phase 1 threshold metrics are clearly met before they are allowed to progress to ULTIMATE Phase 2.

Table I: Basic threshold of mechanical properties for base alloys and coatings, and manufacturability criteria

Properties	Qualifying/benchmark threshold	Comments

Creep strain at 1300 ºC, 200 MPa, 100 hours	<2%	Use relevant ASTM E139 – 11 test method, or equivalent.
Room temperature (RT) tensile ductility	>1.5%	
RT fracture toughness	>10 MPa/$m^{1/2}$	Use relevant ASTM E399, E1820, or equivalent.
Coating performance [a]	Base alloy with coating must retain its ductility at RT after exposure to 1700 °C in air.	See 7.2.1 for details of test methods and metrics
Manufacturability	Standard tensile mechanical test specimens are manufactured using the same process as would be used for manufacturing turbine blades and must meet critical dimensional requirements.	See 7.3.1 for details of test methods and metrics

[a] Required in ULTIMATE Phase 1 only for projects that include coating as a part of project scopes.

7.1.2 ULTIMATE Phase 2 targets

The alloys and alloys in combination with coatings that meet the ultimate goal of this program, which is ultrahigh temperature alloys capable of continuously operating at a minimum of 1300 °C or [simulating 1800 °C gas inlet temperature with coatings] above, must also meet a suite of mechanical, physical, and environmental resistance property metrics, which are listed in Table II below.

ARPA-E recognizes that the assessment of the potential of a new alloy can be complicated. Specific alloy compositions may satisfy most of the metrics in Table II while not meeting one or two of them. In such circumstance performers are required to submit written requests for deviation from the technical metrics listed in Table II. The justifications for deviations shall include specific potential applications and/or how such alloys can be incorporated in a turbine system. The requested deviations will be considered on a case-by-case basis.

Table II: Comprehensive benchmark metrics of ultrahigh temperature alloys, coatings, and manufacturability criteria

ID	Property	Benchmark metrics	Rationale [4 5 17 18 19 20 21 22]
1	0.2% Tensile Yield Strength at 1300°C [a]	≥ 400 MPa	Current SOA is 450MPa at 1050°C (Use relevant ASTM E21 - 17e1 test method)
2	Solidus Temperature	≥ 1500°C	Current SOA is 1200 - 1350°C.
3	Density at RT [b]	≤ 9.0 g/c.c	Current SOA is < 9.0 g/c.c.
4	Thermal Conductivity	RT: 9 - 12 W/m. K 1300°C: ≥ 24 W/m.K	Typical Ni superalloys: RT: 11 W/m.K 800°C: 22 W/m.K 1250°C: 23.5 W/m.K (Use relevant ASTM E1225 – 13 test method)
5	Linear thermal expansion (RT – 1300°C)	≤ 2 %	Current SOA is 2.2% (RT – 1200°C); CTE: 8 - 18 x 10^{-6}/°C (Use relevant ASTM E228-17 test method)
6	Thermo-mechanical Fatigue (TMF)[c]	0.45% strain; R= -1; 100-1300°C; ≥1000 cycles	Current SOA is 0.45% strain; R= -1; 100-950°C; 1000 cycles
7	Coating performance	Base alloy with coating must retain creep strength after exposure to 1700 °C in air.	See 7.2.2 for details of test methods and metrics

[17] E. Balikci, R. A. Mirshams and A. Raman, (2000), Tensile Strengthening in the Nickel-Base Superalloy IN738LC, Journal of Materials Engineering and Performance, 9, pp. 324
[18] Product Handbook of High Performance Nickel Alloys, Special Metals, Alloys Handbook 2
[19] R. E. Aune, R. Brooks, I. Eery, J. J. Fecht,(2005), Thermophysical properties of IN738LC, MM247LC and CMSX-4 in the liquid and high temperature solid phase, Superalloys 718, 625, 706 and Derivatives 2005, TMS, Edited by E. A. Loria
[20] M. Zielinska, M. Yavorska, M. Poreba, J. Sieniawski, (2010), Thermal properties of cast nickel based superalloys, Archives of Materials Science and Engineering, 44, 1, pp. 35
[21] R. L. Amaro, S. D. Antolovich, R. W. Neu, A. Staroselsky, (2010), On thermos-mechanical fatigue in single crystal Ni-base superalloys, Procedia Engineering 2, pp. 815
[22] J. J. Moverare, (2007), Thermal-mechanical fatigue behavior of CMSX-4 in virgin and long term aged conditions, Materials Science and Technology, 23, 12, pp. 1450

ID	Property	Benchmark metrics	Rationale [4 5 17 18 19 20 21 22]
8	Manufacturability	Manufacture a generic small turbine blade as a demonstration.	See 7.3.2 for details of test methods and metrics

[a] In general, the higher the better as long as ductility or fracture toughness is not compromised. Use industry standard strain rate (change in strain with respect to time).
[b] Density of < 9.0 g/cc is preferred in a new alloy to be compatible with current gas turbine designs. However, density values higher than 9 are possible and allowable during the course of the alloy development.
[c] R is the strain ratio. Use industry standard strain-rate and temperature ramp rate and other criteria for testing

7.2 Coating Development (Topic 2)

Technical targets for coatings development are given in Table II. Specifically, the following two tests must be met: 7.2.1 is the threshold test to meet ULTIMATE Phase 1 target, and 7.2.2 is the requirement for ULTIMATE Phase 2.

7.2.1 Test of room temperature ductility after exposure to high temperatures in air (ULTIMATE Phase 1)

To evaluate the basic effectiveness of coatings including EBC and TBC, mechanical tensile samples of appropriate (research or commercial refractory) alloys are to be coated with proposed new coatings. The coated samples are to be exposed to 1700 °C in laboratory air for 100 hours. Tensile ductility at room temperature (RT) should be tested and compared with those without coatings and without the high temperature exposure. The proposed coating is deemed effective if the coated samples show >1.5% RT ductility or if the relative change in RT ductility between coated and uncoated samples is <10%.

7.2.2 Test of creep strength after exposure to high temperatures in air (ULTIMATE Phase 2)

To evaluate the effectiveness of coatings including EBC and TBC on the high temperature properties of the base alloy, creep strength test samples of appropriate (research or commercial) refractory alloys are to be coated with the proposed new coatings. The coated samples are to be exposed to 1700 °C in laboratory air for 100 hours. Upon completion of the exposure, creep strength tests will be conducted at 1300 °C under 200 MPa stress for 100 hours. Creep strain data under those conditions should be tested and compared with those without coatings and without the high temperature exposures. If the relative change of the creep strain data is less than 10%, the coating is deemed effective.

7.3 Manufacturing Process Development (Topic 3)

Manufacturability of lab scale samples must be demonstrated using the same manufacturing process that would be used to manufacture a turbine blade with geometric design complexities. Justification for the selected technique and the specific manufacturing path for successful fabrication needs to be clearly outlined in the proposal. Design parameters such as minimum feature size requirement, dimensional accuracy, and surface finish quality are parameters of key importance. Specifically, manufacturability can be demonstrated via the following two tests: 7.3.1 is the threshold test to meet the ULTIMATE Phase 1 target and 7.3.2 is the requirement to meet the ULTIMATE Phase 2 target.

7.3.1 Manufacture of mechanical test coupons (ULTIMATE Phase 1)

The basic manufacturability shall be demonstrated by manufacturing tensile mechanical test bars as specified by appropriate ASTM E8 / E8M method. Five bars should be fabricated. Consistency of as-fabricated specimens will be measured by measuring the diameter and length of the specimens. The largest variations among the five samples must be less than 0.1mm.

7.3.2 Manufacture of turbine blade demos (ULTIMATE Phase 2)

Manufacturability shall be demonstrated by fabrication of a generic turbine blade with dimensions between 3 to 6 inches. Generic turbine blade designs can be obtained through publicly available sources or private sources. Internal cooling channels are expected. Three turbine blades should be fabricated using the manufacturing method approved during ULTIMATE Phase 1. The critical dimensional variations shall be less than 1% among three samples.

7.4 Comprehensive Solutions (Topic 4)

Teams that aim to develop a comprehensive technology package including novel alloys, coatings, and manufacturing processes are required to meet the threshold targets as listed in Table I at the end of ULTIMATE Phase 1, and the comprehensive set of properties as given in Table II at the end of ULTIMATE Phase 2.

8. COST METRICS

The goal of this program is to enable greater energy efficiency savings through higher performance turbine materials. As such, some additional costs above State of the Art (SOA) materials are allowable, as long as the return on this additional upfront investment is warranted. Based on the projected energy savings of the successful program, we estimate that an overall cost premium of 110% above SOA will return a 4 year or less payback under the

majority of likely deployment scenarios (both retrofit and new turbine design). This premium is allocated across the various factors that will drive cost into the end alloy solution – raw materials, coatings, and/or new manufacturing processes as shown in Table III. There may be allowable tradeoffs between categories under Topic 4, where there may be higher tolerance for more expensive raw materials or coatings if savings could be found in advanced manufacturing processes, for example (or vice versa).

As a part of the Technology-to-Market approach for each category, an assessment of the supply chain for all key materials must be considered by the team to validate that there is a viable source of these materials at the potential scale of the end use applications. Materials that are difficult to source or unable to be scaled to meet commercial demands without significant additional investment in a new supply chain will require additional explanation as to why they should be considered.

Table III. Overview of Cost Targets for New Materials

Topic #	Title	Cost (% allowable over current State of the Art)
1	Novel Alloy Development	< 80%
2	Coating Development	< 20%
3	Manufacturing Process Development	< 10%
4	Comprehensive Solutions	< 110%

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $28 million available for new awards, to be shared between FOAs DE-FOA-0002337 and DE-FOA-0002338, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 10-20 awards under DE-FOA-0002337 and DE-FOA-0002338, combined. ARPA-E may, at its discretion, issue one, multiple, or no awards.

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

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

Applicants must apply for a Combined Phase I/II/IIS Award. Combined Phase I/II/IIS Awards are intended to develop transformational technologies with disruptive commercial potential. Such commercial potential may be evidenced by (1) the likelihood of follow-on funding by private or non-SBIR/STTR sources if the project is successful, or (2) the Small Business Concern's record of successfully commercializing technologies developed under prior SBIR/STTR awards. Phase IIS awards are a "sequential" (i.e., additional) Phase II award, intended to allow the continued development of promising energy technologies. Combined Phase I/II/IIS awards may be funded up to $3,677,642. Funding amounts will be consistent with the Phase I and Phase II limits posted on the SBA's website.[23]

ARPA-E reserves the right to select all or part of a proposed project (i.e. only Phase I, or only Phase I and Phase II). In the event that ARPA-E selects Phase I only or Phase I/II only, then the maximum award amount for a Phase I award is $256,580 and the maximum amount for a Phase I/II award is $1, 967,111.

The period of performance for funding agreements may not exceed 42 months for a Combined Phase I/II/IIS Award. ARPA-E expects the start date for funding agreements to be February 2021, or as negotiated.

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 a new award. Renewal funding is contingent on: (1) availability of funds appropriated by Congress for the purpose of this program; (2) substantial progress towards meeting the objectives of the approved application; (3) submittal of required reports; (4) compliance with the terms and conditions of the award; (5) ARPA-E approval of a renewal application; and (6) other factors identified by the Agency at the time it solicits a renewal application.

C. ARPA-E FUNDING AGREEMENTS

Through 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.

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

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

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

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

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

D. 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. §§ 200.338 and 200.339.
- 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

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

provided by ARPA-E may include coordination with other Government agencies and nonprofits[25] 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.

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

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

1. SBIR ELIGIBILITY

SBA rules and guidelines govern eligibility to apply to this FOA. For information on program eligibility, please refer to SBA's "Guide to SBIR/ STTR Program Eligibility" available at http://sbir.gov/sites/default/files/elig_size_compliance_guide.pdf.

A Small Business Concern[26] may apply as a Standalone Applicant[27] or as the lead organization for a Project Team.[28] If applying as the lead organization, the Small Business Concern must perform at least 66.7% of the work in Phase I and at least 50% of the work in Phase II and Phase IIS, as measured by the Total Project Cost.[29]

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

2. STTR ELIGIBILITY

SBA rules and guidelines govern eligibility to apply to this FOA. For information on program eligibility, please refer to SBA's "Guide to SBIR/ STTR Program Eligibility" available at http://sbir.gov/sites/default/files/elig_size_compliance_guide.pdf.

Only a Small Business Concern may apply as the lead organization for a Project Team. The Small Business Concern must perform at least 40% of the work in Phase I, Phase II, and/or Phase IIS, as measured by the Total Project Cost. A single Research Institution must perform at least 30% of the work in Phase I, Phase II, and/or Phase IIS, as measured by the Total Project

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

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

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

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

Cost. Please refer to Section III.B.1 of the FOA for guidance on Research Institutions' participation in STTR projects.

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

3. JOINT SBIR AND STTR ELIGIBILITY

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

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

B. ELIGIBLE SUBRECIPIENTS

1. RESEARCH INSTITUTIONS

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

2. OTHER PROJECT TEAM MEMBERS

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

- For-profit entities, including Small Business Concerns

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

- Nonprofits other than Research Institutions[31]
- Government-Owned, Government Operated laboratories (GOGOs)
- State, local, and tribal government entities
- Foreign entities[32]

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

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

C. ELIGIBLE PRINCIPAL INVESTIGATORS

1. SBIR

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

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

2. STTR

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

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

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

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

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

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

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

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

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

- The Commercialization Rate Benchmark sets the minimum Phase III[33] commercialization results that an Applicant must have achieved from work it performed under prior Phase II awards (i.e. this measures an Applicant's progress from Phase II or Phase IIS to Phase III awards). **This benchmark requirement applies only to Applicants that have received more than 15 Phase II awards during the last 10 fiscal years, excluding the two most recently completed fiscal years.**

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

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

- On June 1 of each year, SBIR/STTR awardees registered on SBIR.gov are assessed to determine if they meet the Phase II Transition Rate Benchmark requirement. (At this time, SBA is not identifying companies that fail to meet the Commercialization Rate Benchmark requirement). Companies that fail to meet the Phase II Transition Rate Benchmark as of June 1 of a given year will not be eligible to apply to an SBIR/STTR FOA for the following year. For example, if SBA determined on June 1, 2017 that a small business failed to meet the Phase II Transition Rate Benchmark requirement, that small business would not be eligible to apply to an ARPA-E SBIR/STTR FOA from June 1, 2017 to May 31, 2018.

E. COST SHARING[34]

Cost sharing is not required for this FOA.

F. 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.

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

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 have been submitted in response to currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to currently issued ARPA-E FOAs.

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

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- Submissions seeking improvements to current Ni or Co based superalloys.
- Submissions seeking to improve currently known structural ceramics and ceramic matrix composites (CMC).
- Submissions seeking incremental improvements to additive manufacturing techniques independent of refractory metal alloys development.
- Submissions that focus on components that operate in less harsh environments than turbine blades.
- Isolated materials development without full considerations of compatible manufacturing methods are discouraged.

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.

However, small businesses that qualify as a "Small Business Concern" may apply to only one of the two ARPA-E ULTIMATE FOAs: ARPA-E FOA DE-FOA-0002338 (SBIR/STTR), Ultrahigh

Temperature Impervious Materials Advancing Turbine Efficiency SBIR/STTR (ULTIMATE SBIR/STTR) (SBIR/STTR), or ARPA-E FOA DE-FOA-0002337, Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency (ULTIMATE). Small businesses that qualify as "Small Business Concerns" are strongly encouraged to apply under the former (SBIR/STTR FOA). To determine eligibility as a "Small Business Concern" under DE-FOA-0002338, please review the eligibility requirements in Sections III.A – III.D above.

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN SBA COMPANY REGISTRY

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

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

Applicants must submit their Registration Certificate in ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov) as part of their Full Application (see Section IV.D.5 of the FOA).

2. REGISTRATION IN ARPA-E eXCHANGE

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

3. 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.F 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.

4. 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.F of the FOA. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A and V.B of the FOA.

5. 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.F.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.

6. 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.

7. 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 7 pages in length (inclusive of the Operational Plan and System Cost Section, which is not to exceed two pages) 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.

Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award (see Section III.F 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. 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.
- Clearly identify which particular topic (from the available list of topics 1-5 in section I.C.5 of the FOA) is 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.C.7 of the FOA for the appropriate Technology Category in Section I.C.5 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.

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.

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

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 JULY 2020]

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.F.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

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

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

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

ARPA-E performs a preliminary review of Concept Papers and Full Applications to determine whether they are compliant and responsive (see Section III.F 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:

- he 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.C.7 of the FOA for the appropriate technology Category in Section I.C.5 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 following:

- 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. The above criteria will be weighted as follows:

Impact of the Proposed Technology Relative to FOA Targets	50%
Overall Scientific and Technical Merit	50%

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

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 domestic manufacturing/U.S. Manufacturing Plan;
   c. Reduction of energy-related emissions;
   d. Increase in U.S. energy efficiency;
   e. Enhancement of U.S. economic and energy security; or
   f. Promotion of U.S. advanced energy technologies competitiveness.

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

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

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

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

2. ARPA-E REVIEWERS

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

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in 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 contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. ANTICIPATED ANNOUNCEMENT AND AWARD DATES

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

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 JULY 2020]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2020]

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 approximately one business day 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. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions. If Prime Recipients/Subrecipients elect to retain title, they must file a patent application in a timely fashion, generally one year from election of title, though: a) extensions can be granted, and b) earlier filing is required for certain situations ("statutory bars," governed by 35 U.S.C. § 102) involving publication, sale, or public use of the subject invention.
- All other parties: The Federal Non-Nuclear Energy Research and Development Act of 1974, 42. U.S.C. 5908, provides that the Government obtains title to new inventions unless a waiver is granted (*see below)*.
- Class Waiver: Under 42 U.S.C. § 5908, title to subject inventions vests in the U.S. Government and large businesses and foreign entities do not have the automatic right to elect to retain title to subject inventions. However, ARPA-E typically issues "class patent waivers" under which large businesses and foreign entities that meet certain stated requirements, such as cost sharing of at least 20%, may elect to retain title to their subject inventions. If a large business or foreign entity elects to retain title to its subject invention, it must file a patent application in a timely fashion. If the class waiver does not apply, a party may request a waiver in accordance with 10 C.F.R. §784.
- GOGOs are subject to the requirements of 37 C.F.R. Part 501.
- Determination of Exceptional Circumstances (DEC): DOE has determined that exceptional circumstances exist that warrant the modification of the standard patent rights clause for small businesses and non-profit awardees under Bayh-Dole to maximize the manufacture of technologies supported by ARPA-E awards in the United States. The DEC, including a right of appeal, is dated September 9, 2013 and is available at the following link: http://energy.gov/gc/downloads/determination-exceptional-circumstances-under-bayh-dole-act-energy-efficiency-renewable. Please see Section IV.D and VI.B for more information on U.S. Manufacturing Requirements.

B. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

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

1. GOVERNMENT USE LICENSE

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

2. MARCH-IN RIGHTS

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

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

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

C. RIGHTS IN TECHNICAL DATA

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

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

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

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

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

E. FOAS AND FOA MODIFICATIONS

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA 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 on the cover page with the following:

> Notice of Restriction on Disclosure and Use of Data:
>
> *This document contains trade secrets or commercial or financial information that is privileged or confidential and exempt from public disclosure and is submitted only for the*

purposes of internal agency review of this Application. The Government may not use or disclose any information herein without permission.

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."

J. ADDITIONAL NOTICES

- This FOA is intended for informational purposes and reflects current planning. If there is any inconsistency between the information contained herein and the terms of any resulting SBIR or STTR funding agreement, the terms of the funding agreement are controlling.
- Before award of an SBIR or STTR funding agreement, ARPA-E may request the selectee to submit certain organizational, management, personnel, and financial information to assure responsibility of the Prime Recipient. In addition, selectees will be required to make certain legal commitments at the time of execution of funding agreements resulting from this FOA. ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement for SBIR/STTR Awards, which is available at https://arpa-e.energy.gov/?q=site-page/funding-agreements.
- ARPA-E will not pay a fee or profit on Cooperative Agreements resulting from this FOA to recipients or subrecipients.
- Actual or suspected fraud, waste, or abuse may be reported to the DOE Office of Inspector General (OIG) at 1-800-541-1625.

K. COMPLIANCE AUDIT REQUIREMENT

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

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

IX. GLOSSARY

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

Application: The entire submission received by ARPA-E, including the Concept Paper, Full Application, and Reply to Reviewer Comments.

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

Cost Sharing: is the portion of project costs not paid by Federal funds (unless otherwise authorized by Federal statue). Refer to 2 C.F.R. § 200.29.

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

DOE: U.S. Department of Energy.

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

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

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

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

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

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

SBA: U.S. Small Business Administration.

SBIR: Small Business Innovation Research Program.

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

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

STTR: Small Business Technology Transfer Program.

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.