FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

HIGH INTENSITY THERMAL EXCHANGE THROUGH MATERIALS AND MANUFACTURING PROCESSES (HITEMMP) (SBIR/STTR)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001972
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	Thursday, August 9, 2018
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, Friday, August 31, 2018
Submission Deadline for Concept Papers:	9:30 AM ET, Wednesday, September 12, 2018
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:	TBD
Total Amount to Be Awarded	Approximately $10 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $225,000 and $3.225 million.

- 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).

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REQUIRED DOCUMENTS CHECKLIST

For an overview of the application process, see Section IV.A of the FOA.

For guidance regarding requisite application forms, see Section IV.B of the FOA.

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline . The Concept Paper must not exceed four (4) pages in length including graphics, figures, and/or tables and must include the following. (Table 1, the performance targets table, provided in the Concept Paper template, will not count as part of the 4 pages.) o Concept Summary o Innovation and Impact o Proposed Work o Team Organization and Capabilities o Table 1: Performance Targets	Mandatory	IV.C	9:30 AM ET, Wednesday, September 12, 2018
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]	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 develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector and it can be spurred by early-stage R&D supported by the applied energy offices in DOE. By contrast, ARPA-E supports high-risk, potentially transformative research that has the potential to create fundamentally new learning curves. ARPA-E R&D projects typically start with cost/performance estimates for the proposed technology that are well above the level of the competitive incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly lower than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately

become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have the clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as an "original investigation undertaken in order to acquire new knowledge…directed primarily towards a specific practical aim or objective" and defines "experiemental 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 Directives 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 AND OBJECTIVES

The HITEMMP (High Intensity Thermal Exchange through Materials, and Manufacturing Processes) program will develop novel approaches and technologies for design topologies, materials, and manufacturing of high temperature, high pressure, and highly compact heat exchangers. These heat exchangers will enable efficient and power dense power generation cycles for applications in transportation, electricity generation, and industrial sectors. If successful, the materials and manufacturing advances from the HITEMMP program may also yield broader benefits in other operating regimes, and in applications beyond heat exchangers and power cycles.

The HITEMMP program targets heat exchangers to operate in environments where temperatures and pressures are simultaneously in excess of 800°C and 80 bar, with operating lifetimes of tens of thousands of hours. These heat exchangers must offer superior thermal performance and low pumping power requirements, and must also be cost competitive and durable (per metrics prescribed in Section I.E of the FOA). These performance goals are beyond the capability of any existing technologies, but ARPA-E believes that recent advances in materials, topological design methodologies, and manufacturing technologies can be leveraged to realize the desired extreme-environment heat exchanger capability. Specific developments include:

- The identification and development of materials capable of withstanding extreme temperature and pressure conditions while featuring attractive thermo-mechanical and manufacturability properties;
- Advances in additive and/or subtractive manufacturing techniques to enable the cost-effective realization of small structural feature sizes, smooth surface finishes, and other enabling heat exchanger characteristics; and
- The refinement and application of advanced design methodologies to leverage new material capabilities while incorporating manufacturing constraints.

[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* 77 Fed. Reg. 46806 (Aug. 6, 2012), as amended by 79 Fed. Reg.1303 (Jan. 8, 2014) 77 Fed. Reg. 46855 (Aug. 6, 2012), as amended by 79 Fed. Reg. 1309 (Jan. 8, 2014).

ARPA-E has issued this FOA to encourage the formation of multi-disciplinary teams to work to overcome the materials, design, and manufacturing technology barriers that have thus far prevented the realization of catalyzing the development of the desired extreme environment heat exchanger capability. ARPA-E has identified two categories of recuperator-type heat exchangers (> 800°C and > 1100°C, corresponding to metallic and to ceramic/composite materials sets, respectively) as challenge problems.

Each category has performance metrics, as described in Section I.E of this FOA. Applicants are expected to select one of the two categories. In each category, ARPA-E anticipates that teams will initially execute an analytical/computational design effort, will reduce key risks through small-scale heat exchanger module experiments, and will demonstrate a heat exchanger with the desired performance and durability at 50 kW thermal (kW_{th}) scale.

2. MOTIVATION AND TECHNICAL BACKGROUND

The objective of the HITEMMP program is to develop the design topologies, materials, and manufacturing methods for high-performance, compact, and durable heat exchangers for extreme environments. These next-generation heat exchangers must overcome two general challenges:

a) Achievable heat transfer rates (per unit mass or unit volume of the heat exchanger) are limited by the structure of the heat exchanger cores--including optimum fluid flow distribution on both the hot and cold sides--and by thermal resistance associated with the way heat sources and sinks are connected to each other.
b) Integration into larger (e.g., power generation) systems; this integration must be accomplished without compromising the performance of the heat exchanger and system through excessive pressure drops and/or thermal or other parasitic losses.

To overcome these challenges, innovative topological designs that consider both the detailed freeform optimization of the heat exchanger structure, and the suitable selection of advanced manufacturable materials and working fluid combinations for the desired range of operating conditions are needed. Equally important is the further refinement of existing, or the development of new manufacturing technologies that enable attractive performance at an acceptable cost. The opportunities and challenges offered by such heat exchangers are discussed in the remainder of this section.

***Opportunities and challenges with high temperatures*:** From an ideal thermodynamic performance perspective, the efficiency of a heat engine increases with increasing hot-side cycle temperature at a fixed cold-side cycle temperature. Consequently, the steady drive for higher efficiency electric power generation cycles mandates a continued progression of hot-side (i.e., peak cycle) temperatures. In the case of closed Brayton cycle power generation systems (e.g., sCO_2 systems), cycle efficiencies are limited by the abilities of turbines and heat

exchangers (upstream and downstream of the turbine) to survive for adequate durations in their high temperature (and pressure) operating environments. Specifically, heat exchanger operational temperatures are limited by oxidation rates, thermal stresses, creep, and fatigue.

If these limitations can be overcome, durable and affordable high-temperature heat exchangers could lead to substantially higher power conversion efficiencies that could yield reduced fuel consumption, reduced system footprint (thus reduced capital and operation costs), and reduced CO_2 and NO_X emissions, among other benefits.

Opportunities and challenges with high operating pressures: In a typical, simple Brayton power generation cycle, the cycle pressure ratio has a direct influence on thermal efficiency. It is well established that the thermal efficiency, η_B, of an ideal open Brayton cycle increases with the pressure ratio, defined as the ratio of the compressor discharge pressure (the highest pressure in the cycle) over the intake (or ambient) pressure:

$$\eta_B = 1 - \left(\frac{P_d}{P_0}\right)^{\frac{1-\gamma}{\gamma}},$$

where P_d is the compressor discharge pressure, P_0 is the intake pressure, and γ is the heat capacity ratio, (e.g., taken at 1.4 for air under ideal gas conditions). Since inception of the gas-turbine technology in the early 1940s, the trend in both aerospace and land-based power generation applications has been to increase pressure ratio[4] combined with increased Turbine Inlet Temperature (TIT).[5,6] Increasing the operating pressure increases the compressor discharge pressure, leading to an increased power density for the power generation system. This leads to appreciable reduction in size/footprint and capital as well as operational cost savings.

The operating fluid is a major determinant of what cycle pressure can be achieved. For example, use of certain fluids with proper molecular weight and under high pressure conditions can result in further elevated power density levels thus yielding component/system size reductions and additional associated benefits. These benefits are particularly attractive in applications, such as the aviation sector, that place a premium on system mass and volume. The renewed interest in fluids like supercritical CO_2 (sCO_2), supercritical helium (sHe), and others is a direct reflection of the advantages these working fluids offer. In general, the use of supercritical working fluids such as sCO_2 and sHe can reduce the size and complexity of turbomachinery components needed when compared to a Rankine steam cycle with the same power rating. The heat exchangers developed under HITEMMP will enable dramatic improvements in the efficiency and power density for power cycles, and ultimately, the choice

[4] Rohlik, H. E. (1983). Current and future technology in radial and axial gas turbines, NASA TM 83414.
[5] Trent XWB, The world's most efficient large aero engine. Retrieved July 23, 2018, from Rolls-Royce website: http://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/civil-aerospace-downloads/trent-xwb-infographic.pdf
[6] The GE90 Engine. Retrieved July 23, 2018, from GE Aviation website: https://www.geaviation.com/commercial/engines/ge90-engine

of an optimum cycle design is directly affected by the choice of its working fluid. Regardless of the working fluid selected, simultaneous application of high-temperature and high-pressure conditions present specific materials and manufacturing challenges that are more specifically addressed in Section I.D below.

D. DEFINITION OF TECHNICAL OPPORTUNITY AND CHALLENGES

Figure 1 shows a summary on the state of the art (SOA) and ongoing development in heat exchangers with respect to operating temperature and pressure. As illustrated in Figure 1, the range of operating temperatures and pressures sought in HITEMMP are beyond the goals for existing development efforts. For example, current high pressure (defined at 300 bar) heat exchangers operate at moderate temperatures (around 500°C). Research programs such as the Department of Energy Supercritical Transformational Electric Power (STEP) contribute to the development of components for operating temperatures up to 700-750°C.

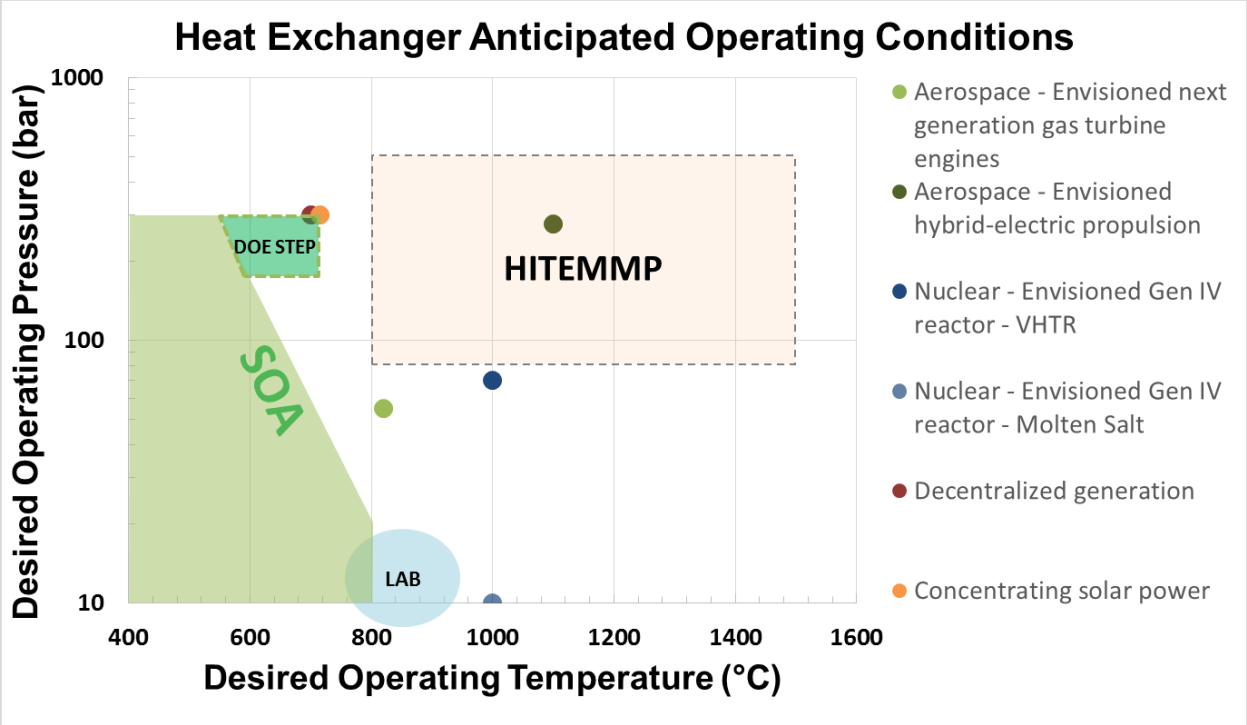

Figure 1: Operating temperatures and pressures for SOA and developmental heat exchangers compared with ARPA-E HITEMMP goals. The colored dots represent the desired operating conditions of several different potential applications.

Conversely, there is a class of commercial state-of-the-art heat exchangers that can operate at relatively high temperatures (~800°C or higher) but are restricted to low pressures (a few bars) due to structural limitations. While material creep is the main challenge at high pressures (and aggravated at higher temperatures), oxidation and thermal fatigue are also challenges

presented at higher temperatures. Simultaneous high-temperature and high-pressure conditions introduce a new class of challenges that are to be overcome in the current program.

Applications and impact for high temperature, high pressure operation

As shown in Figure 1, among other applications, the aviation industry can benefit from the existence of heat exchangers capable of operating in extreme conditions. One example of this application is the nascent field of hybrid aviation. It is envisioned that high power density systems for onboard electricity production operating at substantially higher pressures and temperatures will require durable heat exchangers capable of operating at these conditions while offering sufficient compactness, low pressure drop, low weight, and excellent thermal cycling endurance. The envisioned power/propulsion system for hybrid aircraft may replace existing power generators and improve not only the turbogenerator efficiency but also the overall aircraft efficiency (or specific fuel consumption) by enabling disruptive propulsion architectures. This paradigm shift could potentially reduce fuel burn up to 20 percent[7] compared to the current state of the art. To be competitive, these power systems, and by extension their heat exchangers, must offer very high specific power–the ratio of power delivered by the system over its weight. Low weight and small volume requirements drive the need for highly compact heat exchangers in aviation. Additionally, in order to be commercially viable, the cost of such heat exchangers must be appropriate for the performance and value proposition that they enable, and support a path to commercialization for the selected application area.

Advanced nuclear power is another area that would benefit from high-performance heat exchangers. Several Generation IV conceptual designs,[8] such as the Very High Temperature Reactor (VHTR)[9] and the Molten Salt Reactor (MSR),[10] are envisioned to drive closed Brayton power cycles at high temperatures via intermediate heat exchangers. While the operating pressures of such systems are thought to be less extreme than those typically encountered in power generation systems using fluids such as supercritical CO_2 (e.g., the VHTR can operate with helium at around 70 bars[11]), these applications would benefit from the technical advances sparked by this program. Additionally, compactness and durability are key characteristics as nuclear applications require extreme reliability and a reduced, compact foot print may directly translate to a more contained system and thus reduced operational and capital costs.

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[7] National Academies of Sciences, Engineering, and Medicine. (2016). *Commercial aircraft propulsion and energy systems research: reducing global carbon emissions.* National Academies Press. https://doi.org/10.17226/23490

[8] Behar, C. (2014, January). Technology roadmap update for generation IV nuclear energy systems. In *OECD Nuclear Energy Agency for the Generation IV International Forum*(Vol. 17, No. 2018, pp. 19-52-).

[9] Very-High-Temperature Reactor (VHTR). Retrieved July 23, 2018, from GEN IV International Forum website: https://www.gen-4.org/gif/jcms/c_42153/very-high temperature-reactor-vhtr

[10] Molten Salt Reactor (MSR). Retrieved July 23, 2018, from GEN IV International Forum website: https://www.gen-4.org/gif/jcms/c_9359/msr

[11] Generation IV Nuclear Reactors. Retrieved July 23, 2018, from World Nuclear Association website: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors.aspx

Performance and design challenges for high temperature, high pressure heat exchangers

Pressure drop: As discussed in the previous section, a key performance parameter is the pressure drop across the heat exchanger. In most applications, a large pressure drop across the heat exchanger requires higher pumping power, imposing a penalty on the primary system performance. The power requirement for pumping the fluid between two points in a fluid flow system is given as:

$$Pumping\ Power = \dot{V}\,\Delta P\,,$$

where $\dot{V}$ represents volumetric flow rate [m^3/s] and ΔP represents total pressure difference between the two points. For a heat exchanger, $\dot{V}$ represents the required fluid flow rate in the hot and cold sides of the heat exchanger to deliver the required capacity. The pressure difference, ΔP [Pa], represents the sum of static and dynamic losses in the system. For a heat exchanger, dynamic losses are associated with factors like optimum velocities in the hot and cold side flow passages, balancing the additional heat transfer gains associated with higher fluid flow velocities against the corresponding rise in pressure drops.

Typically, at a given Reynolds number, increased roughness leads to higher pressure drop. As such, it is important to control it. The roughness, ε—or more accurately, the relative roughness, ε/D_h—is a characteristic of the surface finish, controlled by the different manufacturing processes involved in the fabrication of the surface.

The heat duty, Q, which represents the heat exchanged from the hot side to the cold side of a heat exchanger, is a function of the temperature difference between the two sides (*ΔT)*, the overall heat transfer coefficient (*U)*, and the heat transfer area (*A)* via the relation:

$$Q = UAF\Delta T,$$

where *ΔT* is typically the logarithmic mean temperature difference (LMTD) and *F* is the configuration factor, which is unity for parallel and counterflow configurations. One way to increase heat duty is to improve the heat transfer area.

An important heat exchanger design feature is compactness (β), which represents the ability to transfer heat between two fluids in a given footprint and is a measure of the surface area density of a heat exchanger, m^2/m^3. Compactness and desirable pumping power requirements are often achieved through a combination of optimum design topologies, distribution of fluid in both the hot and cold sides, creation of additional heat transfer surface area per unit volume through use of micro structures and/or engineered surface features, enhanced mixing of the flow in both the hot and cold sides, and minimal resistances between the hot and cold sides to enhance heat exchange rates.

Materials Challenges: Given the extreme conditions of the simultaneous high temperatures and high pressures sought in this program, material selection and proper characterization are important to the economical design and manufacturability of the heat exchanger. Materials

selected for a heat exchanger are typically based on a combination of mechanical properties (e.g., strength, creep resistance, fatigue), thermal properties (e.g., thermal expansion, thermal conductivity), chemical properties (e.g., oxidation, corrosion), manufacturability (e.g., machining, joining), and cost.

Material selection may depend upon the heat exchanger design and its targeted application. For example, a design that requires moderately high temperatures and pressures can use lower-cost materials (such as SS347) with inferior creep properties in place of the expensive alloys (e.g., Ni-based alloys) required in extremely high pressure and/or high temperature applications. In addition, applications such as those in the aerospace sector may be sensitive to the overall weight and shape/conformity of the heat exchanger.

Materials challenges for the current program include the use of materials capable of withstanding extreme temperature and pressure conditions while featuring attractive thermo-mechanical and manufacturability properties. As shown in Figures 2 and 3, the strength of most commonly-known metals decreases with increasing temperature. For a heat exchanger, the additional requirement of a thin-walled fin structure to promote the UA value adds to the complexity of the material selection. For example, creep properties of thin-walled components (~100 µm) are often different from those of respective bulk materials. Depending on the operating temperature and pressure, high temperature materials can vary from ferritic steels to Ni-based alloys and ceramics. However, there is a substantial cost increase as one shifts from materials such as ferritic steel to Ni-based alloys.[12] Additional details on these challenges may be found in "Recent Developments in High Temperature Heat Exchangers: A Review."[13]

[12] Brun, K., Friedman, P., & Dennis, R. (Eds.) (2017). *Fundamentals and applications of supercritical carbon dioxide (sCO2) based power cycles*. Woodhead Publishing.

[13] Zhang, X., Keramati, H., Arie, M., Singer, F., Tiwari, R., Shooshstari, A., & Ohadi, M. (2018). Recent Developments in High Temperature Heat Exchangers: A Review. *Frontiers in Heat and Mass Transfer*, Vol. 11.

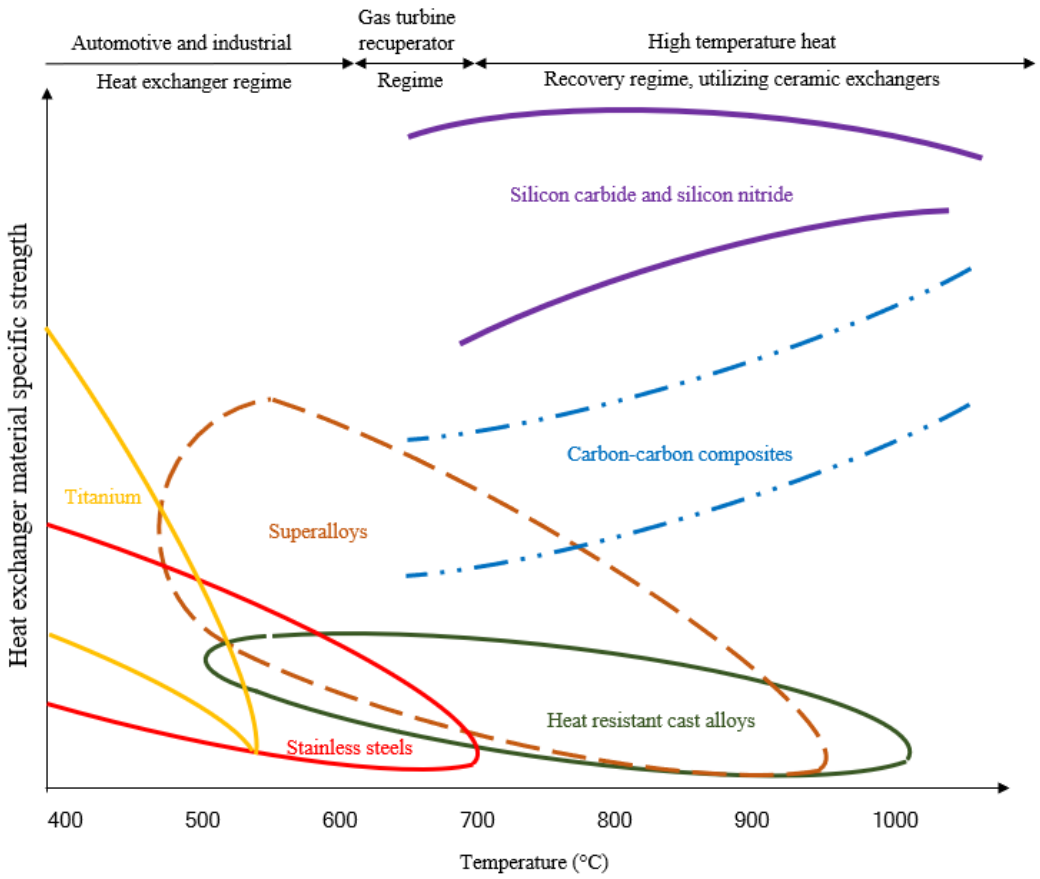

Figure 2: Temperature ranges for heat exchanger materials (adapted from[14]).

[14] Thulukkanam, K. (2013). *Heat exchanger design handbook*. CRC Press.

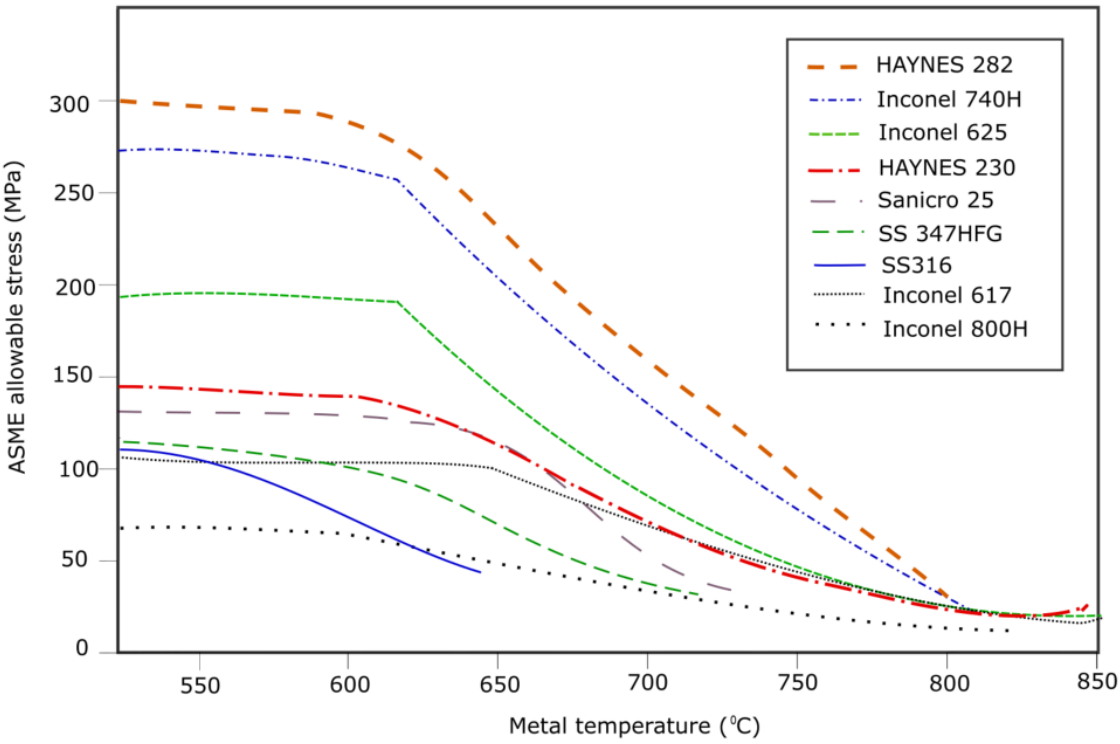

Figure 3: Strengths of various iron- and nickel-based alloys showing that most of the materials lose strength at higher temperatures (adapted from[12,15]).

In addition to the high temperature and pressure requirements, the desired heat exchangers present unique challenges in materials and manufacturing due to the difficulty of finding the optimum balance between enhanced heat transfer rates without excessive pressure drop penalties and high heat exchanger effectiveness with desirable volumetric and gravimetric power densities. These interrelated materials and manufacturing challenges are discussed below.

Manufacturing challenges and overall performance expectations: The class of materials currently most suitable for the extreme temperature and pressure conditions sought in the current program—including superalloys, ceramics, and carbon matrix composites—are difficult to process, machine, weld, and braze due to their higher toughness, low thermal conductivity, and tendency to crack during welding or the unavailability of suitable brazing materials.[16,17,18]

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[15] Chordia, L., Portnoff, M. A., & Green, E. (2017). *High Temperature Heat Exchanger Design and Fabrication for Systems with Large Pressure Differentials* (No. DE-FE0024012). Thar Energy, LLC, Pittsburgh, PA (United States).
[16] Steel, M. (2016, September 29). *4 Inconel Machining Tips You Need to Know*. Retrieved July 23, 2018, from https://www.marlinwire.com/blog/inconel-machining-tips
[17] Considerations when Machining Nickel Alloys. (2015, February 10). Retrieved July 23, 2018, from Continental Steel & Tube Company website: https://continentalsteel.com/blog/considerations-when-machining-nickel-alloys/
[18] David, S. A., Siefert, J. A., DuPont, J. N., & Shingledecker, J. P. (2015). Weldability and weld performance of candidate nickel base superalloys for advanced ultrasupercritical fossil power plants part I: fundamentals. *Science and Technology of Welding and Joining*, *20*(7), 532-552.

Specialized equipment and highly-trained operators are often needed to process such materials.

Advances in additive manufacturing (AM), or three-dimensional (3D) printing techniques have broadened the heat exchanger design space by enabling cost-effective manufacturing of design topologies and small-scale features, less than 200 µm. Additive manufacturing also enables low-cost and rapid design customization and shorter time to market, and may eliminate traditional economy-of-scale constraints. Such manufacturing technologies, which build up metal components layer-by-layer to improve both heat transfer features and design compactness, are attractive for manufacturing high temperature, high pressure heat exchangers, whose materials can be difficult to machine.

One major challenge associated with AM is the large surface roughness that is inherent with most of the state-of-the-art metal printing of materials to high-temperature, high-pressure heat exchangers.[19] As an example, the common roughness values reported for the Direct Metal Laser Sintering (DMLS) process range between 5 – 50 µm.[20] This elevated roughness translates to increased pressure drop in an additively-manufactured heat exchanger and a departure from smooth pipe behavior.[21][20]. The increased roughness is exacerbated by the small diameters of the hydraulic channels in compact heat exchangers, causing disproportionate increases in relative roughness.

To reap the benefit of advanced manufacturing technologies for these heat exchangers, new design topologies, manufacturing processes, and advancements in manufacturing machinery are needed. While new developments in advanced manufacturing techniques, such as additive manufacturing and photochemical etching processes, and the use of specialized bonding techniques have overcome some of the challenges faced by conventional manufacturing, substantial challenges remain. To overcome these challenges, innovative designs, materials, and manufacturing techniques must work together collectively, as shown in Figure 4.

[19] Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering, 143, pp-172-196*
[20] Stimpson, C. K., Snyder, J. C., Thole, K. A., & Mongillo, D. (2016). Roughness effects on flow and heat transfer for additively manufactured channels. *Journal of Turbomachinery*, *138*(5)
[21] *See* Ngo et.al., *supra* note 19.

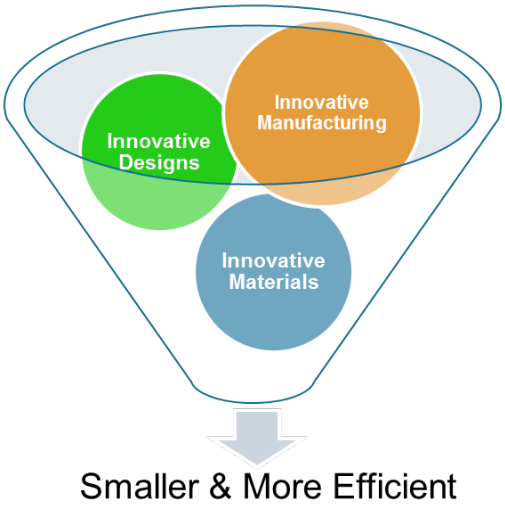

Figure 4: Nexus Design/Material/Manufacturing.

Among the most important aspects of this program are design for manufacturability, utilization of advanced design topologies, and advanced manufacturing techniques. To achieve the broader goals of this FOA, ARPA-E requires that a dedicated and specifically-budgeted portion of the efforts will focus on enhancing the capabilities of materials and manufacturing machines and processes. This includes aspects such as applicable fabrication process monitoring strategies in support of enhanced surface finish quality, manufacturing time, and minimization of post processing requirements.

E. TECHNICAL CATEGORIES AND PROGRAM METRICS

The HITEMMP FOA includes two technical categories, defined by materials and the hot-side temperature. The metrics in Table 1 constitute a set of design requirements for a heat exchanger capable of operating in extreme conditions, and Applicants must address all metrics for the selected Category in the proposal. Applicants must also define a targeted application (e.g., aviation, modular power, or industrial) with appropriate design choices for flow rates, power density, etc. to meet application needs.

Table 1: Program targets for Category A: Metallic-based Structures (Hot-side Temperature of > 800°C) and Category B: Ceramic-based or other composite structures (Hot side Temperature > 1,100°C)

ID	Metric Name	Category A Target (Metallic-based structures)	Category B Target (Ceramic-based or other composite structures)	Description and rationale
1	Targeted applications			For use in high efficiency, high temperature and pressure modular power generation systems as a recuperator for an application area(s) defined by Applicant (e.g., aviation, modular power, or industrial).
2	Hot-side inlet temperature	≥ 800°C	≥ 1,100°C	
3	Hot-side inlet pressure	≥ 80 bar	≥ 80 bar	
4	Cold-side inlet temperature	300°C	300°C	The hot and cold side conditions provided may be close to that of a high temperature recuperator in a typical closed supercritical CO_2 Brayton cycle. However, the choice of working fluid is not restricted to supercritical CO_2 and is left open to the applicant's choice so long as performance metrics of the FOA can be met.
5	Cold-side inlet pressure	≥ 250 bar	≥ 250 bar	
6	Hot-side pressure drop, $(\Delta P/P_{inlet})_{,hot}$	≤ 2%	≤ 4%	
7	Cold-side pressure drop, $(\Delta P/P_{inlet})_{,cold}$	≤ 2%	≤ 4%	
8	Hot-side mass flow rate	kg/sec	kg/sec	Left to the designer's choice. However, the mass flow rate of the hot-side and the cold-side must be taken as equal to represent the case of a high temperature recuperator in a closed Brayton cycle.

ID	Metric Name	Category A Target (Metallic-based structures)	Category B Target (Ceramic-based or other composite structures)	Description and rationale
9	Cold-side mass flow rate	kg/sec	kg/sec	Left to the designer's choice. However, the mass flow rate of the hot-side and the cold-side must be taken as equal to represent the case of a high temperature recuperator in a closed Brayton cycle.
10	Heat exchanger effectiveness	≥ 80%	≥ 50%	
11	Heat exchanger thermal duty (capacity)	≥ 50 kW_{th}	≥ 50 kW_{th}	The selected capacity recognizes the need for scalability for the high temperature applications.
12	Heat exchanger mass-based power density	kW_{th}/kg	kW_{th}/kg	This is a required design outcome parameter. It may vary based on the selected design and the targeted application area.
13	Heat exchanger volume-based power density	kW_{th}/m^3	kW_{th}/m^3	This is a required design outcome parameter. It may vary based on the selected design and the targeted application area.
14	Heat exchanger material(s)			Left to the designer's choice. However, justification for its selection and its characterization/qualification procedure needs to be clearly outlined in the proposal.
15	Working fluid			Left to the designer's choice. However, one objective of this program is the development of heat exchangers that can utilize supercritical fluids such as sCO_2 and sHe due to the advantages they offer in high efficiency power generation cycles.

ID	Metric Name	Category A Target (Metallic-based structures)	Category B Target (Ceramic-based or other composite structures)	Description and rationale
16	Heat exchanger manufacturing technique			Left to the designer's choice. However, 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, built volume, and surface finish quality are parameters of key importance.
17	Materials and performance characterization			Applicants must define a comprehensive set of parameters that characterize the selected material's performance for the metrics required in this FOA, and must also identify the experimental and analytical tools necessary to quantify material and component performance. If characterization requires specialized resources to which the Applicant does not have access, ARPA-E may assist to make such materials characterization resources available to Selectees under this FOA.
18	Durability	Hours MTBF	Hours MTBF	The proposed heat exchanger is expected to have a path to commercialization. As such, for the selected application area, an explicit path toward a targeted MTBF (mean time between failures) of 40,000 hours of operation before a major overhaul is required.

ID	Metric Name	Category A Target (Metallic-based structures)	Category B Target (Ceramic-based or other composite structures)	Description and rationale
19	Cost	$/UA, [$°C/kW$_{th}$]	$/UA, [$°C/kW$_{th}$]	The proposed heat exchanger and its associated manufacturing techniques are expected to have a path to commercialization in the application area of the Applicant's choice and as such needs to exhibit potential for cost competitiveness. For example, high power density systems for aviation applications may target production level cost of $5,000°C/kW, whereas stationary modular systems may target $2,000°C/kW. Applicants must specify a projected $/UA for their selected design and manufacturing process and demonstrate the basis to have arrived at the projected cost estimate.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $10 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 3-5 awards under this FOA. ARPA-E may 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 $3,225,000 and may have a period of performance up to 48 months (4 years).

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 $225,000 and the maximum amount for a Phase I/II award is $1,725,000.

The period of performance for funding agreements may not exceed 48 months. ARPA-E expects the start date for funding agreements to be June 2019, or as negotiated.

B. ARPA-E FUNDING AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[22]

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.

[22] The Prime Recipient is the signatory to the funding agreement with ARPA-E.

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 for SBIR/STTR Awards, which is available at https://arpa-e.energy.gov/?q=site-page/funding-agreements.

C. 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.
- 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 provided by ARPA-E may include coordination with other Government agencies and nonprofits 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.

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[23] may apply as a Standalone Applicant[24] or as the lead organization for a Project Team.[25] 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.[26]

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

[23] 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.

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

[25] 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 or otherwise supporting work under an ARPA-E funding agreement.

[26] 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[27] 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.

[27] 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.

2. OTHER PROJECT TEAM MEMBERS

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

- For-profit entities, including Small Business Concerns
- Nonprofits other than Research Institutions[28]
- Government-Owned, Government Operated laboratories (GOGOs)
- State, local, and tribal government entities
- Foreign entities[29]

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.

[28]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.
[29] 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.

2. STTR

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

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

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

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

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

- The DOE Phase II Transition Rate Benchmark sets the minimum required number of Phase II awards the Applicant must have received for a given number of Phase I awards received during the specified period. **This Transition Rate Benchmark applies only to Phase I Applicants that have received more than 20 Phase I awards during the last five (5) year period, excluding the most recently completed fiscal year**. DOE's Phase II Transition Rate Benchmark requires that 0.25 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[30] commercialization results that an Applicant must have achieved from work it performed under prior Phase II awards (i.e. this measures an Applicant's progress from Phase II or Phase IIS to Phase III awards). **This benchmark requirement applies only to Applicants that have received more than 15 Phase II awards during the last 10 fiscal years, excluding the two most recently completed fiscal years.**

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

E. COST SHARING[31]

Applicants are bound by the cost share proposed in their Full Applications. Specific cost-sharing requirements for this FOA are as follows:

1. PHASE I

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

2. PHASE II AND IIS COST SHARE REQUIREMENT

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

- Small businesses – or consortia of small businesses - will provide 0% cost share from the outset of the Phase II project through the first 12 months of Phase II (referred to as the "Cost Share Grace Period"). If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost[32] (including the costs

[30] SBIR Phase III refers to work that derives from, extends or completes an effort made under prior SBIR funding agreements, but is funded by sources other than the SBIR Program. Phase III work is typically oriented towards commercialization of SBIR research or technology. For more information please refer to the Small Business Administration's "Small Business Innovation Research (SBIR) Program Policy Directive" at https://www.sbir.gov/sites/default/files/sbir_pd_with_1-8-14_amendments_2-24-14.pdf.

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

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

incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.

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

3. LEGAL RESPONSIBILITY

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

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

4. COST SHARE ALLOCATION

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

5. COST SHARE TYPES AND ALLOWABILITY

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

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

funding or property was not provided to the state or local government by the Federal Government.

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

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

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

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

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

6. COST SHARE CONTRIBUTIONS BY FFRDCS AND GOGOS

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

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

7. COST SHARE VERIFICATION

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

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.

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, and those identified below in Section III.F.3 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 other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to other currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.
- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA.
- Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.

- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by any other office within Department of Energy.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by other government agencies or the private sector.
- Submissions that do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- Analytical and computer simulations work only without any materials and manufacturing efforts and experimental work
- Similar work that is being sponsored by DOE or other federal government agencies
- "Paper studies" of novel material, design, or heat exchanger
- Turbomachinery development
- Pure materials research or projects involving discovery and development of new materials

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 HITEMMP FOAs: ARPA-E FOA DE-FOA-0001972 (SBIR/STTR), High Intensity Thermal Exchange Through Materials and Manufacturing Processes (HITEMMP) (SBIR/STTR), or ARPA-E FOA DE-FOA-0001970, High Intensity Thermal Exchange Through Materials and Manufacturing Processes (HITEMMP). 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-0001972, 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 Applicant 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.C of the FOA. Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria and program policy factors in Sections V.A.1 and V.B.1 of the FOA.

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

discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

4. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 40 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA.

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.C.1 of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

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 4 pages in length including graphics, figures, and/or tables (except the performance targets table, provided as Table 1 in the Concept Paper template, which will not count as part of the 4 pages).
- 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 and Subcategory, 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.C of the FOA).

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

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

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

1. 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 state the targeted application of 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.

- For the Applicant's targeted application, select the category (Category A or B) you are responding to and provide quantitative metrics in Table 1 located in Section I.E. of the FOA. Please use the Table 1 template provided at the end of the Concept Paper template. To the extent possible and as applicable provide comparison against the current and emerging technologies for all of the Technical Performance Targets detailed in Section I.E of the FOA.
- Describe the innovation and quantify the advancement over state-of-the-art in the manufacturing machines and processes.

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?
- Briefly describe a path to commercialization of the proposed technology concept for the selected application area(s).
- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.
- Estimated federal funds requested; total project cost including cost sharing.

d. TEAM ORGANIZATION AND CAPABILITIES

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

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]

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 NOVEMBER 2018]

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 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:

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- 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 NOVEMBER 2018]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]

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 US dependence on foreign energy sources;
   b. Stimulation of domestic manufacturing/U.S. Manufacturing Plan;

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

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

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

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

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 NOVEMBER 2018]

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.2 of the FOA for guidance on pre-award costs.

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN NOVEMBER 2018]

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 they elect to retain title, they must file a patent application in a timely fashion.

- 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.7 and VI.B.8 for more information on U.S. Manufacturing Requirements.

B. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

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

1. GOVERNMENT USE LICENSE

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

2. MARCH-IN RIGHTS

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

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

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

C. RIGHTS IN TECHNICAL DATA

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

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an

award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.

- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to five years in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

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

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

E. FOAs AND FOA MODIFICATIONS

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

F. OBLIGATION OF PUBLIC FUNDS

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

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

G. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

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

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

H. RETENTION OF SUBMISSIONS

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

I. MARKING OF CONFIDENTIAL INFORMATION

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

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

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

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

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

J. 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 within the U.S. Department of Energy.

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

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

DOE: U.S. Department of Energy.

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

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

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

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

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

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

PI: Principal Investigator.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing inventive supportive work that is part of an ARPA-E project.

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.