

**FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT**



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

**UNLOCKING LASTING TRANSFORMATIVE RESILIENCY ADVANCES BY FASTER
ACTUATION OF POWER SEMICONDUCTOR TECHNOLOGIES SBIR/STTR
(ULTRAFAST SBIR/STTR)**

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002999
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	February 24, 2023
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, March 18, 2023
Submission Deadline for Concept Papers:	9:30 AM ET, March 28, 2023
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:	August 2023
Total Amount to Be Awarded	Approximately \$48 million, subject to the availability of appropriated funds to be shared between FOAs DE-FOA-0002998 and DE-FOA-0002999.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between \$295,924 and \$4,241,580.

- 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	<ul style="list-style-type: none">Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables, and must include the following:<ul style="list-style-type: none">Concept SummaryInnovation and ImpactProposed WorkTeam Organization and Capabilities	Mandatory	IV.C	9:30 AM ET, March 28, 2023
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]	Optional	IV.E	5 PM ET, TBD

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I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

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

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

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

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

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

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

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

B. SBIR/STTR PROGRAM OVERVIEW

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

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

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

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

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

C. PROGRAM OVERVIEW

1. SUMMARY

Technological advances in power electronics have enabled the unprecedented growth of renewable energy sources in the electrical power grid over the past several decades. Power electronics innovations have brought significant improvements in controllability, performance, and energy availability at a specific electronic interface, but are also fundamentally changing the nature of the grid as a system. Because of the growing proportion of *fast dynamic* electronic interfaces relative to *slow dynamic* (i.e., conventional, asynchronous, machine-controlled) interfaces, grid performance, stability, and reliability are becoming increasingly jeopardized. This phenomenon is not restricted only to the grid. Modern electronic power distribution systems for airplanes, ships, electric vehicles, data centers, and homes contain potentially hundreds of power electronics converters. The inclusion of power electronics in a multitude of new areas is driven by gains in performance, efficiency, and reliability, in concert with reductions in size, weight, and operational costs.

The goal of this FOA, entitled Unlocking Lasting Transformative Resiliency Advances by Faster Actuation of power Semiconductor Technologies (ULTRAFast), is to advance the performance limits of silicon (Si), wide bandgap (WBG), and ultra-wide bandgap (UWBG) semiconductor devices⁵ and significantly improve their actuation methods to support a more capable, resilient, and reliable future grid. This new program seeks to engage technical experts from power electronics, optoelectronics, photonics, and other related fields to support the development of next-generation ultra-fast semiconductor devices and modules for enhanced resiliency, reliability, and control of power flow at all grid interfaces.

ARPA-E expects that ULTRAFast projects will create new material, device, and/or power module technologies that enable realization of transformative power management and control

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

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

⁵ J.Y. Tsao, et al., Ultrawide-Bandgap Semiconductors: Research Opportunities and Challenges, *Adv. Electron. Mater.*, 4, 1600501 (2018) <https://doi.org/10.1002/aelm.201600501>.

not only to enable a dramatically improved grid, but also for future autonomous power distribution systems such as those for electric vehicles, all-electric aviation, and others. More specifically, ARPA-E is looking for semiconductor material, device and/or power module level advances to enable faster switching and/or triggering at higher current and voltage levels for improved control and protection of the grid.

The program will support the development of technologies that enable semiconductor devices and/or modules capable of operating at high switching frequencies, and featuring high slew-rates, current, and voltage levels while mitigating electromagnetic interference (EMI) issues.

Specific categories include: (1) device and/or module technologies targeting protection functions at high current and voltage levels by achieving very fast by-pass, shunt, or interrupt capability at as low level of integration as possible with nanosecond-level reaction time (and corresponding slew rates). (2) high switching frequency devices and/or modules which enable efficient high-power, high-speed power electronics converters. These devices, depending on the power level, are required to switch between 1 kHz and 100 kHz in order to enable improved large-signal bandwidth of power converters for grid applications. Lastly, complementary technologies in category 3 such as wireless sensing of voltage and current, high-density packaging with the integrated wireless actuators and device/module-level protection, power cell-level capacitors and inductors, and thermal management strategies to support those in categories 1 and 2.

This program supports ARPA-E mission goals to improve resilience, reliability, and security of energy infrastructure; improve energy efficiency; reduce greenhouse gas emissions; reduce reliance on energy imports; and maintain U.S. leadership in energy technologies.

2. BACKGROUND

The United States' electric grid faces a host of challenges, including aging infrastructure, increasing frequency of severe weather events, and emerging cyber and physical threats. Much of the grid is more than 60 years old⁶, weather-related power outages increased 78% in the last decade⁷, and recent cyber⁸ and physical⁹ attacks further expose grid vulnerabilities. Electricity customers in the U.S. experienced an average of seven hours of power disruptions in 2021¹⁰

⁶ Report Card for America's Infrastructure, ASCE, 2021. <https://infrastructurereportcard.org/wp-content/uploads/2020/12/Energy-2021.pdf>.

⁷ Surging Power Outages and Climate Change, Climate Central, 2022. <https://assets.ctfassets.net/cxgxtgtp8r5d/73igUswSfOhdo7DUDVLwK7/bb0a4e95e1d04457e56106355a1f74b9/2022PowerOutages.pdf>.

⁸ R. Walton, Colonial Pipeline hack highlights grid disruption risks even with IT-focused cyberattack, *Utility Dive*, May 11, 2021 <https://www.utilitydive.com/news/colonial-pipeline-hack-highlights-grid-disruption-risks-even-with-it-focus/599942/>

⁹ M. Wilson, N.C. substation attack exposes grid risks, *E&E News*, Dec. 12, 2022 <https://www.eenews.net/articles/n-c-substation-attack-exposes-grid-risks>.

¹⁰ R. Berry, Today in Energy, EIA (2022) <https://www.eia.gov/todayinenergy/detail.php?id=54639>.

with resulting impacts to health¹¹ and major economic consequences – ultimately costing the U.S. an ~\$150 billion annually¹². Emerging threats, such as electromagnetic pulses and space weather events could result in even more disastrous, large-scale impacts.

Such concerns will be greatly exacerbated in the future as the U.S. strives to achieve Net Zero Emissions (NZE) by 2050. Decarbonization efforts rely on the electrification of everything from transportation to industrial processes to urban infrastructure, causing a dramatic increase in demand for electricity. The share of electrified final power consumption is expected to increase from 20% today to 50% by 2050¹³. Widespread adoption of carbon capture and sequestration technologies will further increase future electricity demand. It has also been recognized that reaching NZE by 2050 is predicated on greater penetration of renewable energy such as intermittent wind and solar distributed energy resources (DERs)¹⁴. Increased share of DERs and electrified loads will require concomitant increases in transmission capacity and more flexible grid infrastructure. To stay on target to meet emissions reductions, electricity transmission systems must increase capacity by 60% by 2030¹⁵ and expand more than three times by 2050¹⁶.

At high and medium voltage (H/MV) levels, power flow across the grid is currently routed by substations with limited regulation capabilities, relying on traditional electromechanical gear, low-frequency transformers, and slow protection equipment with reaction times of several line cycles. As a result, the grid's ability to quickly control, absorb, reroute, and isolate power flow and react to perturbations is limited, which can result in cascading power failures. Some parts of the grid are already being challenged by the current levels of renewables in use. These challenges will only grow as more renewables are brought on-line and fossil baseload plants shut down. Consequently, new technology is needed to improve grid control, resilience and reliability, and significantly faster power electronics are a critical enabling technology to achieve these qualities. Solid-state substations¹⁷ utilizing power electronics-based conversion could address these limitations, increase grid resilience and reliability, and facilitate superior control and protection capabilities.

Growth of power electronics-based interfaces will be driven by the need to connect new DERs and new electrified loads to the grid, as it is expected that 80% of electricity will flow through

¹¹ K. Siegel, The true cost of power outages. *Yale Environmental Review*, Aug. 5, 2012, <https://environment-review.yale.edu/true-cost-power-outages-0>.

¹² Department of Energy Report Explores U.S. Advanced Small Modular Reactors to Boost Grid Resiliency, Jan. 25, 2018, <https://www.energy.gov/ne/articles/departement-energy-report-explores-us-advanced-small-modular-reactors-boost-grid>.

¹³ IEA (2022), *World Energy Outlook 2022*, IEA, Paris, CC BY NC SA 4.0 (Annex A), <https://www.iea.org/reports/world-energy-outlook-2022/an-updated-roadmap-to-net-zero-emissions-by-2050>.

¹⁴ IEA, Net-Zero-by-2050, report, 2021. <https://www.iea.org/reports/net-zero-by-2050>.

¹⁵ M. Seltzer, Big but affordable effort needed for America to reach net-zero emissions by 2050, Princeton study shows, Dec. 15, 2020. <https://www.princeton.edu/news/2020/12/15/big-affordable-effort-needed-america-reach-net-zero-emissions-2050-princeton-study>

¹⁶ New Energy Outlook (2022), Bloomberg News & Energy Finance, <https://about.bnef.com/new-energy-outlook>.

¹⁷ Energy.gov., Solid-state Power Substation Technology Roadmap, 2020. <https://www.energy.gov/oe/downloads/solid-state-power-substation-technology-roadmap>.

power electronics by 2030¹⁸. Power electronic conversion systems are capable of decoupling dynamics between system sources, distribution, and loads, while improving system controllability, reliability, resilience, and efficiency. These benefits are already being realized in a variety of applications, such as electric cars, ships, and airplanes, where power electronics replace traditional thermal, mechanical, hydraulic, and pneumatic systems. To realize these benefits in grid applications, new approaches are needed to create power electronics with improved performance (i.e., operation at voltages and currents at H/MV levels) and faster actuation speeds (enabling more sophisticated control and protection methods and reducing converter size, weight, and power (SWaP) consumption). Increased flexibility, control and efficiency gains afforded by power electronic interfaces have the potential to minimize the required level of transmission and distribution line build out to meet NZE goals by 2050, thus resulting in significant cost savings.

a) CURRENT APPROACH

A semiconductor switching device is a key element of any power electronic system, which determines the frequency and power level of operation, as well as a significant portion of the converter loss. Silicon has been the semiconductor material of choice for power devices for quite some time due to cost, fabrication, and process maturity. Silicon devices are, however, reaching their operational limits in blocking voltage capability, temperature of operation, and switching frequency due to the intrinsic material properties of Si.

As shown in Table I, the relatively low bandgap and critical electric field of Si compare unfavorably to WBG and UWBG materials. Thus, vertical Si high voltage devices relying on majority carriers (unipolar devices such as field effect transistors, or FETs) require substantial epitaxial thicknesses, leading to higher specific on-resistance and higher conduction losses. To lower conduction losses, large device die areas are used, increasing the gate capacitance and charge, and resulting in increased switching losses and limiting switching frequency. Minority carrier-based power Si devices (bipolar devices such as insulated-gate bipolar transistors, or IGBTs, and thyristors) can have smaller device sizes but the long lifetime of minority carriers in Si reduces the usable switching frequency range to <10 kHz. The relatively low Si bandgap contributes to higher intrinsic carrier concentrations at elevated junction temperatures causing high leakage currents in p-n junctions. Current Si devices cannot reach the current and voltage levels required by H/MV grid applications, requiring series and/or parallel stacking of multiple devices in multi-level modules. This poses challenges to reliability and introduces additional complexity and cost due to increased part count.

¹⁸ Energy.gov., Solar Power Electronic Devices, <https://www.energy.gov/eere/solar/solar-power-electronic-devices>.

TABLE 1. Properties of Si and common WBG/UWBG semiconductors^{1,19,20}

Parameter	Si	GaAs	4H-SiC	GaN	AlGaN/ AlN	β -Ga ₂ O ₃	Diamond	h-BN
Bandgap, E_g (eV)	1.1	1.4	3.3	3.4	3.4-6.1	4.8	5.5	~5.9
Critical Electric Field, E_c (MV/cm)	0.3	0.4	2.2	3.9	3-12	~6.7-15	5-10.1	~12
Thermal Conductivity, λ (W/m·K)	150	46	490	230	253-319	11-27	2290-3450	~750 (in-plane)
State-of-the-Art Substrate Diameter (mm)	450	300	200	200 (on Si) 100 (Bulk)	50.8	100	25.4	100

Opportunities for higher performing devices have emerged with the development of WBG semiconductors⁵ (i.e., silicon carbide (SiC) and gallium nitride (GaN)) and UWBG semiconductors (i.e., aluminum gallium nitride (AlGaN/AlN), diamond, gallium oxide (β -Ga₂O₃), and boron nitride (h-BN)). These semiconductors have superior electrical and thermal characteristics, as shown in Table 1, that can circumvent the material limits of Si and offer attractive alternatives for realization of power devices for grid applications. However, the development of WBG and UWBG materials is relatively immature and still at a nascent stage. In particular, the latter suffer from significant challenges, for example, difficulty with doping, material quality, cost, and consequently manufacturability.

The higher critical electric fields in these semiconductors enable thinner, more highly doped voltage-blocking layers, which can reduce on-resistance by an order of magnitude in majority carrier architectures relative to equivalent Si devices. High breakdown electric field and low conduction losses mean these semiconductors can achieve the same blocking voltage and on-resistance with a smaller device area and thus lower capacitance. This reduced capacitance allows at least an order of magnitude higher frequency and faster response operation compared to a Si device. The low intrinsic carrier concentration of these semiconductors enables reduced leakage currents and robust high-temperature performance. The properties of the WBG and UWBG semiconductors permit devices to operate at much higher voltages, frequencies, and temperatures providing a pathway to more efficient, lighter, smaller, and higher temperature capable power electronics for H/MV grid applications.

While WBG semiconductors can push device performance to higher voltage and current levels, relative to Si, UWBG semiconductors are even more attractive due to their superior properties, specifically higher bandgap energy (E_g). Because many of the figures-of-merit for device performance scale with increasing E_g in a highly non-linear manner, the UWBG materials have the potential for far superior performance.

Despite superior performance relative to Si devices, WBG devices have been slow to penetrate the market, and commercial-off-the-shelf (COTS) parts are limited to 3.3 kV. Both COTS or

¹⁹ O. Slobodyan, et al. Analysis of the dependence of critical electric field on semiconductor bandgap, Journal of Materials Research, 2022. <https://doi.org/10.1557/s43578-021-00465-2>.

²⁰ A. Ranjan, et al. Dielectric Breakdown in Single-Crystal Hexagonal Boron Nitride, ACS Applied Electronic Materials, 2021. <http://doi.org/10.1021/acsaelm.1c00469>.

engineering samples (up to 10 kV) have not been widely adopted in the grid applications, mostly due to cost²¹, immaturity and scarcity of reliability data, and lack of manufacturing and supply ecosystem, although that is beginning to change, driven by rapid growth of electrified vehicles²². Thus, improvements in performance are expected to facilitate adoption in multiple applications providing more reliability data, supporting growth in manufacturing and supply chain, and eventually bringing the cost down through economies of scale.

A promising approach to realization of future solid-state substations relies on converter implementation using Modular Multi-level Converters (MMC)²³ architectures. Today's power converters for H/MV levels commonly employ MMC architectures due to their modular structure and scalability to much higher voltage through stacking of power cells (Fig. 1a). Each power cell (Fig. 1b), a basic building block of the MMC, can be independently controlled and consists of a power module (Fig. 1c) and local energy storage unit that contributes a portion of the full stack voltage of the MMC as well as protection, sensing and control elements. Half-bridge (shown in Fig. 1b) or full-bridge power cell architectures are typically used for MMC structures. Power modules (Fig. 1d) themselves are comprised of semiconductor devices/dies. Due to their superior flexibility, modularity, and scalability, MMCs have been displacing other converter topologies in industrial applications. For grid applications, practically all voltage source modular converters contain power modules utilizing many 3.3 kV, 4.5 kV, or 6.5 kV Si IGBT devices/dies in parallel to enable conduction of hundreds, even thousands of amperes. However, reliability of modular multi-level converters (including cascaded H-bridge, flying capacitor, and other) significantly declines when number of components that comprise them increases²⁴. Another significant performance limiter is related to Electromagnetic Interference (EMI)²⁵ associated with operation at high power and frequency. EMI issues are partially responsible for underutilization of current WBG devices as additional circuit complexity is needed to mitigate them.

²¹ <https://www.eetimes.com/examining-whats-behind-sic-market-growth>

²² <https://www.statista.com/outlook/mmo/electric-vehicles/worldwide>

²³ Szytkiel et al. - Modular Multilevel Converter Modelling, Control and Analysis under Grid Frequency Deviations. 2013 https://backend.orbit.dtu.dk/ws/portalfiles/portal/18266187/Modular_Multilevel_Converter.pdf

²⁴ Alavi, O.; Hooshmand Viki, A.; Shamlou, S. A Comparative Reliability Study of Three Fundamental Multilevel Inverters Using Two Different Approaches. *Electronics* 2016. <https://doi.org/10.3390/electronics5020018>.

²⁵ F. Zare - EMI Issues in Modern Power Electronic Systems. <https://www.emcs.org/acstrial/newsletters/spring09/pp2.pdf>.

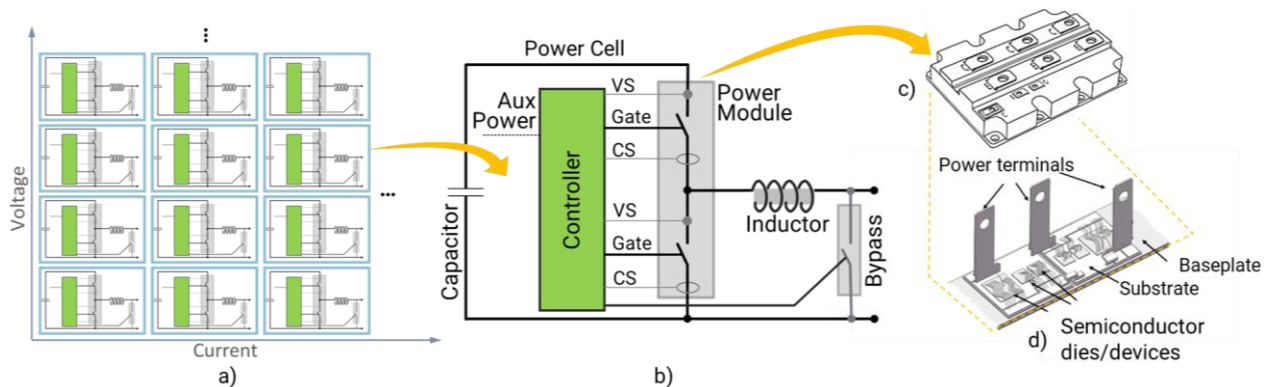


Figure 1. a) Modular Multi-level Converter structure, b) Half-bridge power cell, and Illustrations of c) Power module, and d) Devices/dies

Increasing the operating current and voltage rating of power electronic devices, while decreasing the switching times, results in increased current and voltage slew-rates (dv/dt and di/dt) during on-off transitions as shown in Fig. 2a. Rapid switching offers a big opportunity for reduction of device switching (and consequently overall) losses, relaxes stringent thermal management requirements, and improves converter power density, but causes radiated and conducted high-frequency EMI. This leads to noise generation and its propagation through gate drivers, sensors, controller boards, etc., unpredictably altering their functions and degrading converter reliability to the point where the system ceases to function properly or experiences catastrophic failures²⁶. This problem (Fig. 2b) is mostly caused by wires, or printed circuit board traces located in the vicinity of noise sources (devices), in which pulsating magnetic flux caused by high di/dt can inflict significant high frequency noise, and where any capacitive coupling establishes a path to high frequency currents driven by high dv/dt . This is one of the main factors preventing widespread adoption of WBG devices in circuits. A common mitigation involves “slowing down” of switching performance by adding sufficiently large gate resistance²⁷ into driving circuitry, thus negating key advantages of WBG-based devices. Some other “patches” or attempts to deal with the unwanted noise consist of filtering, shielding, and noise cancellation schemes.

²⁶ B. Zhang and S. Wang, "A Survey of EMI Research in Power Electronics Systems With Wide-Bandgap Semiconductor Devices," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 8, no. 1, pp. 626-643, March 2020, doi: 10.1109/JESTPE.2019.2953730.

²⁷ W. Ma, et. al., "Investigation of the Gate Resistance and the RC snubbers on the EMI Suppression in Applying of the SiC MOSFET," IEEE ICMA, 2019.

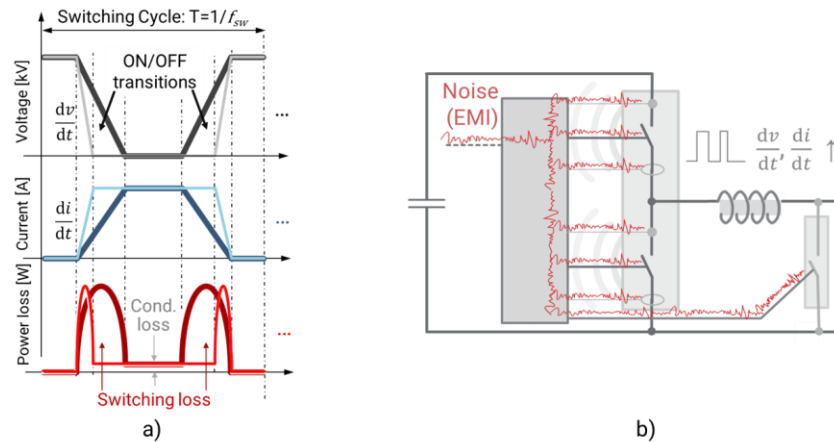


Figure 2. a) Switching transitions (slew-rates), b) Noise (EMI) propagation through power cell components

Because individual devices are not capable of achieving required current levels, they are commonly stacked in parallel configuration inside the power module package. Although both unipolar and bipolar devices can be paralleled, this is easier for unipolar devices as their positive temperature coefficient supports natural current sharing.

Stacking dies inside the power modules to achieve higher voltages is not a common practice due to difficulties with dynamic voltage balancing. Some attempts to stack SiC metal–oxide–semiconductor field-effect transistor (MOSFET) modules required additional, active gate control circuitry for each device in the stack to implement a closed-loop controlled voltage balancing²⁸. While effective, this method significantly increases system complexity and EMI susceptibility.

b) OTHER SIMILAR ACTIVITIES

Since its inception, ARPA-E has been a catalyst for applied technological breakthroughs in the domain of WBG and UWBG devices, launching SWITCHES²⁹, PNDIODES³⁰, CIRCUITS³¹, BREAKERS³², and other programs in the past decade. It invested more than \$200 Million dollars in over 100 projects, not only enabling significant technological progress in power electronics, but advancing commercialization and supporting the U.S. technological leadership in advanced power conversion technologies.

²⁸ K. Sun et al., "Modeling, Design, and Evaluation of Active dv/dt Balancing for Series-Connected SiC MOSFETs," in IEEE Transactions on Power Electronics, vol. 37, no. 1, pp. 534-546, Jan. 2022, doi: 10.1109/TPEL.2021.310024.

²⁹ "Strategies for Wide Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems," ARPA-E, U.S. Department of Energy, <https://arpa-e.energy.gov/technologies/programs/switches>.

³⁰ "Power Nitride Doping Innovation Offers Devices Enabling SWITCHES", ARPA-E, U.S. Department of Energy, <https://arpa-e.energy.gov/technologies/programs/pndiodes>.

³¹ "Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors", ARPA-E, U.S. Department of Energy, <https://arpa-e.energy.gov/technologies/programs/circuits>.

³² "Building Reliable Electronics to Achieve Kilovolt Effective Ratings Safely", ARPA-E, U.S. Department of Energy, <https://arpa-e.energy.gov/technologies/programs/breakers>.

The goals of this FOA are complemented by other previous and current program activities. The scope of this program, however, is distinct from all programs described below, in that it seeks to build upon and advance the current state of the art in materials, devices, and modules developed with the support of previous programs; in particular, the simultaneous focus on improved power handling and temporal performance *while mitigating EMI limitations* distinguishes this FOA from other efforts, and is critical to solving applied problems with respect to the grid. Successful outcomes will enable converters significantly less susceptible to EMI due to wireless/optical implementation of actuation, sensing, and auxiliary power supply. This minimizes paths for high-frequency noise generation and propagation through control circuitry, as well as facilitates higher switching slew-rates resulting in higher efficiency and better converter performance. Such capabilities will ultimately support realization of transformative power management, protection, and control for the new microgrids/grids as well as other autonomous power distribution systems, such as those for electrified transportation. A summary of complementary past and current programs by other offices at the DOE and Department of Defense (DOD) is presented below.

The DOE Office of Electricity's (OE) Transformer Resilience and Advanced Components (TRAC)³³ research program is focused on grid modernization by addressing two main goals: increasing resilience of aging assets and identification of new requirements for future grid components, and acceleration the research, development, and field validation of next-generation grid hardware technologies. The program focused on challenges with Solid-State Power Substations (SSPS)²⁰ and their components, such as advanced power routers, medium-voltage direct-current (MVDC) converters, high performance devices, as well as sensing elements. Recently, OE announced a solar innovations program³⁴ targeting development of the next generation of wide-bandgap power-electronic systems specifically to support integration of solar generation with energy storage and/or electric vehicle charging, as well as capabilities for quick recovery response to weather or cyber threat related grid outages.

DOE's Advanced Manufacturing & Industrial Decarbonization Offices founded PowerAmerica³⁵ Institute in 2015 to accelerate the commercialization of WBG semiconductor technology by developing advanced manufacturing processes for large-scale production of WBG semiconductors.

DOD's Office of Naval Research (ONR) investments under basic research focus on the development and improved reliability/availability of next-generation WBG semiconductors, advanced insulation systems and their prognostics, and development of improved, light-weight magnetic materials. Their applied research focuses on development and application of improved SWaP WBG-based Power Electronics Building Blocks (PEBB), and innovative Power

³³ <https://www.energy.gov/sites/default/files/2019/12/f70/TRAC-Program-Overview.pdf>

³⁴ <https://www.energy.gov/eere/solar/solar-topics-small-business-innovation-research-and-small-business-technology-transfer>

³⁵ <https://poweramericainstitute.org>.

Electronic Power Distribution System (PEPDS) technology and concepts that surpass conventional MVDC and MVAC³⁶.

ONR's interests complement those of ARPA-E to surpass state-of-the-art performance and further advance the power electronics field. These include development of methods, tools and materials to control electric field concentration in highly integrated, compact and power dense converters; advancement of WBG materials and devices for very high frequency, voltage and power applications; investigation of WBG semiconductor device failure modes; development of new materials for high temperature (>200° C), high electric field and low dielectric loss operation; improvement of reliability of power electronic devices, power density of power systems, and risk reduction for future application of MVDC systems³⁷.

The DOD's Defense Advanced Research Project's Agency (DARPA) has invested in WBG semiconductors for Radiofrequency (RF) applications in the Wide Bandgap Semiconductors for RF Applications (WBGs-RF) program that aimed to deliver higher power RF for electronic warfare and advanced radar systems in 2001. Beyond wide bandgap materials DARPA has invested in photonics and heterogeneous integration of materials that have the potential to impact this program. DARPA recently held a workshop on "UWBG Materials for High Performance Applications" at the 2021 Electronics Resurgence Initiative Summit & Microsystems Technology Office (MTO) symposium to address the outlook for UWBG materials for power electronics and RF in DOD and commercial applications³⁸.

The DARPA Photonics in the Package for Extreme Scalability (PIPES) program is combining photonics with packaged integrated circuits to enable performance gains in data transfer rates. With the goal of delivering 100 Tbps per package at energies of less than 1 picojoule per bit PIPES aims to disrupt current microelectronics and fully realize the potential of optical interconnects for advanced computing applications.³⁹ The Lasers for Universal Microscale Optical Systems (LUMOS) program aims to advance integrated photonics technology through intimate integration of optical gain sources such as lasers and amplifiers with capable photonics platforms. LUMOS is bringing complex, scalable optical gain to commercial foundries, as well as funding the integration of high-power Watt class gain and gain across the visible spectrum.⁴⁰ Both programs involve heterogeneous integration of electronic and photonic materials and devices which could provide useful partnering opportunities for potential applicants.

Like DARPA's PIPES program, ARPA-E's ENLITENED program targets development and co-packaging of photonic integrated circuits (PICs) and microelectronic integrated circuits for reduction of energy consumption of data centers and enablement of novel data center

³⁶ <https://www.esrdc.com/library/pepds-plan>.

³⁷ <https://www.nre.navy.mil/organization/departments/code-33/division-331/power-electronics-and-electromagnetism>.

³⁸ [Kazior_UWBG_Workshop.pdf \(darpa.mil\)](#)

³⁹ [Photonics in the Package for Extreme Scalability \(darpa.mil\)](#)

⁴⁰ [Lasers for Universal Microscale Optical Systems \(darpa.mil\)](#)

architectures supporting emerging computational requirements of artificial intelligence and machine learning with optimized energy consumption. Performers and technologies associated with this program offer a rich opportunity for collaboration.

Similarly, NSF's Electronics, Photonics and Magnetic Devices (EPMD) Program⁴¹ supports innovative research on fundamental research on novel (micro-, nano-, and quantum-) devices based on the principles of electronics, optics and photonics, optoelectronics, magnetics, electromagnetics, and related physical phenomena looking to advance, among others, wide/extreme-bandgap semiconductor devices. Another office funding fundamental research is DOE's Basic Energy Sciences (BES) office with their recent Energy Frontier Research Center (EFRC) effort⁴², bringing together disciplinary scientific teams to tackle the toughest scientific challenges in energy technologies including those related to ultra-wide-bandgap and wide-bandgap materials.

D. PROGRAM OBJECTIVES

1. TECHNOLOGY DEVELOPMENT

The target of this program is to support the development of devices and/or modules and supporting material technologies to create more capable building blocks for the future grid, as shown in Fig. 3. More specifically, ARPA-E is looking to provide support for material, device, and/or module level advances to enable faster switching and triggering at higher current and voltage levels to realize improved control and protection capabilities. Separate categories targeting faster switching for control and higher current and voltage slew rates for triggering and protection, both at higher voltage and current ratings, are envisioned to allow for the broadest range of approaches, although technology developments that can simultaneously address both necessary functions are preferred.

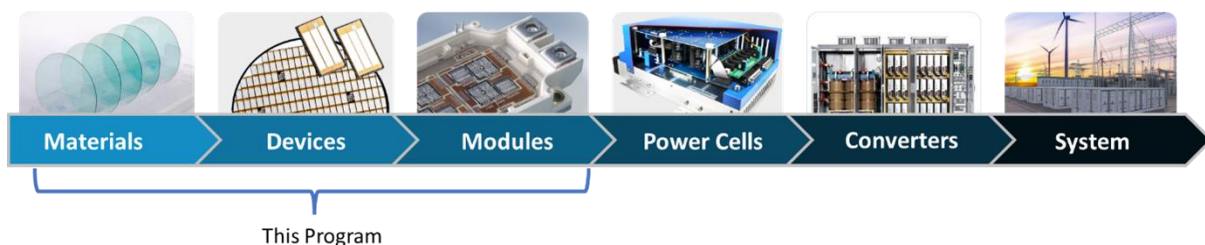


Figure 3. Scope of this program, relative to higher levels of integration

Individual device performance at higher voltage and current ratings is desired to reduce the number of devices stacked in series and parallel combinations in modules, and in stacked modules in power cells/converters, required to achieve H/MV power levels in grid applications. Reducing the required number of devices and modules will be necessary to improve overall

⁴¹ <https://beta.nsf.gov/funding/opportunities/electronics-photonics-magnetic-devices-epmd-0>

⁴² <https://science.osti.gov/bes/efrc>

system reliability, complexity, and cost. Increased switching speed is desired to continue the trend of shrinking converter sizes with increased switching frequencies, as has been demonstrated by replacing slower Si devices with faster switching WBG devices. This is a consequence of devices/modules switching at higher frequencies, while keeping the loss low, and subsequent reduction in the required sizes of passives.

One approach to this problem (although not an exclusive one) involves the utilization of UWBG materials. UWBG materials have been long predicted to enable operation of devices at higher reverse blocking voltages and lower forward specific on-resistances than devices realized with WBG materials. This is due to the superior UWBG material properties, as indicated in Table I and discussed in Section I.C.

Despite such promising material characteristics, UWBG devices and fabrication techniques suffer from several issues. Some of these problems stem from their relative immaturity, and thus lower material quality, smaller, more expensive substrates, supply chain maturity, and manufacturability issues. They also suffer from more fundamental problems, such as doping difficulties, due to their ultra large bandgaps (~5-6 eV) and deep dopant states which result in incomplete room temperature ionization.

One way to address this problem is through optical excitation of carriers from their deep dopant states into the conduction and valence bands, where they are available to conduct current. This has been reported in the literature⁴³. ARPA-E is interested in supporting projects that use this approach (or others, as there are other ways to address this problem) to accelerate realization of devices utilizing UWBG materials and can operate at elevated power levels and at higher switching speed, with low loss. Applicants choosing this approach should consider the power devices and the required optical source as a system and discuss its integration and packaging, as well as operation and functional requirements of both the power device and the optical source. These functional requirements include wavelength, optical power, temporal characteristics, electrical power consumption, thermal management, cost, reliability, and other relevant parameters.

To take advantage of increased switching speeds such as those possible with WBG and UWBG material-based devices, novel EMI mitigation solutions are desired. Increased switching speed is desired to continue reducing converter SWaP and decreasing switching losses (through decreasing switching times). Increasing the operating current and voltage while decreasing the switching time results in increased current and voltage slew rates (di/dt and dv/dt), exacerbating EMI problems. ARPA-E is interested in supporting the development of scalable, broadly applicable solutions which mitigate this issue, while simultaneously providing control and protection capabilities that operate at high switching rates, high slew rates, and current and voltage levels.

⁴³ M.A. Bryushinin, et. al, Optically Induced Space-charge and Conductivity Gratings in Wide-bandgap Semiconductors, Physics Procedia, Volume 86, 2017. <https://doi.org/10.1016/j.phpro.2017.01.035>

One way to minimize EMI impact is to eliminate or minimize wires, wire-loops, and printed circuit board traces from the driving and sensing circuitry located in proximity and/or electrically connected to high dv/dt nodes. Instead, wireless power and data transfer would occur between the control stage and the device/module gates, as well as to/from associated sensors. One of the more promising approaches to address this involves optical power and data transfer^{44,45}, although operation at other portions of the electromagnetic spectrum is of interest as well. In any case, ARPA-E expects that Applicants justify and explain how their solution helps improve the EMI immunity without introducing additional filters or shielding.

An important feature enabled by optical triggering is independent control of device voltage and current slew-rates achieved via a simple optical modulation. Independent control of dv/dt and di/dt enables fast dynamic voltage balancing and current sharing, facilitating not only simpler module stacking for higher voltages and currents but also combination of die-level cascading and paralleling inside the same package, potentially with a minimal EMI impact⁴⁶.

Multiple approaches to achieve the optical control and powering of devices and modules are possible. Fig. 4 shows some options, although these are intended only for illustrative purposes as many other different approaches could be realized.

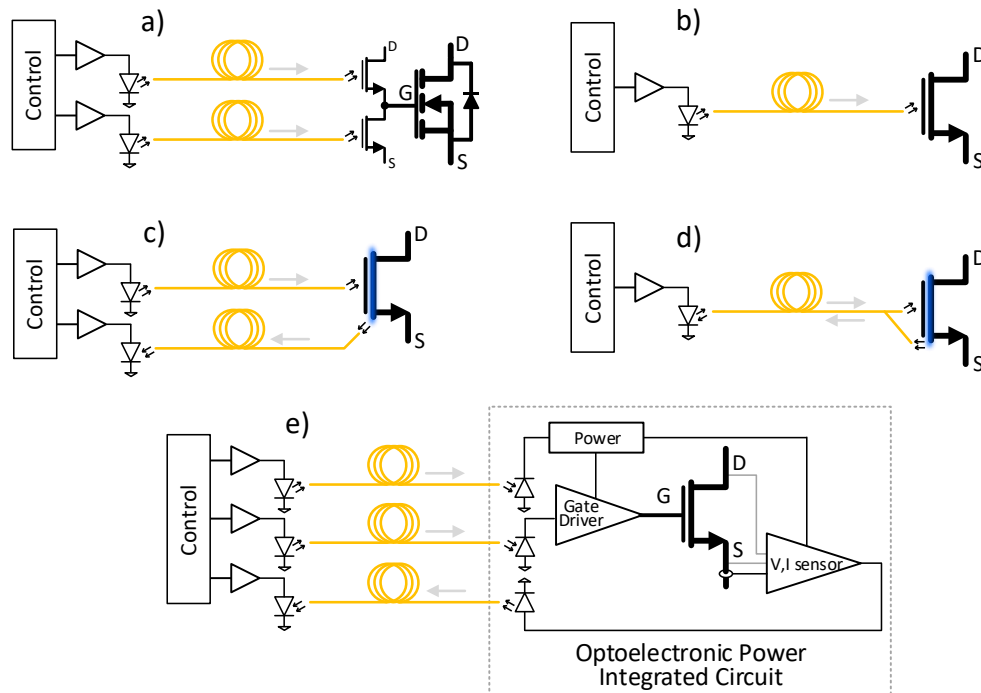


Figure 4. Various possible approaches to optical control and sensing

⁴⁴ X. Wang, H. Pu, Q. Liu, L. An, X. Tang and Z. Chen, "Demonstration of 4H-SiC Thyristor Triggered by 100-mW/cm² UV Light," in IEEE Electron Device Letters, vol. 41, no. 6, pp. 824-827, June 2020, doi: 10.1109/LED.2020.2988913.

⁴⁵ S. K. Mazumder and T. Sarkar, "Optically Activated Gate Control for Power Electronics," in IEEE Transactions on Power Electronics, vol. 26, no. 10, pp. 2863-2886, Oct. 2011, doi: 10.1109/TPEL.2009.2034856.

⁴⁶ H. Riazmontazer and S. K. Mazumder, "Optically Switched-Drive-Based Unified Independent dv/dt and di/dt Control for Turn-Off Transition of Power MOSFETs," in IEEE Transactions on Power Electronics, 2015.

It is possible to supply power and data signal to an intermediate device which then drives the power device gate, as shown in Fig. 4a, as well as to control the device gate directly optically as shown in Fig. 4b. Fig. 4c, and Fig. 4d illustrate the possibility of optical sensing of the power device, either with a separate fiber from optical gate control (Fig. 4c) or with the same fiber (Fig. 4d).

Fig. 4e shows an intermediate option, where gate drive is optically powered as well as receives drive data optically, and then electrically drives the device, while optically sensing the device, via a dedicated fiber. In this case power devices, sensors, and gate driver are all integrated on a single chip, shortening the remaining electrical connections between them to minimize coupled EMI. Such functionality integrated on a single chip could be transformational, if it could show sufficient reduction of EMI effects, operation at desired speeds and power levels, and a path to scalability and eventual cost reduction. Leveraging technology from areas such as optoelectronics and PICs could provide interesting cross pollination opportunities for power electronics.

Photoconductive Semiconductor Switches (PCSS)^{47,48,49} and Light-Triggered Thyristors (LTT)⁵⁰ operate in a manner illustrated in Fig. 4b, and although PCSS have not yet reached performance targets of this program, they are very promising candidates. One of the key difficulties in reaching targeted performance levels will be showing sufficient charge to switch required current and voltage levels of the power device can be delivered to a power device gate in the prescribed amount of time. Additionally, the required optical (or other) system to execute this, should not be excessively bulky, complicated, inefficient, or incapable of eventual cost reduction.

2. TECHNOLOGY-TO-MARKET (T2M)

As an impact-focused agency, ARPA-E is interested in not only supporting the development of transformative technologies, but also enabling and facilitating their commercialization.

With over \$70 billion per year in capital investment by U.S. electric transmission and distribution utilities, there is a significant commercial opportunity for grid hardware that dramatically improves performance. However, development, testing, regulatory approval, and deployment of new power technologies for the grid takes time. Adjacent markets may provide earlier commercial entry points crucial for development of supply chains, sales and service infrastructure, and operational experience. Some examples of these market segments include, Industrial, Aerospace & Defense, Automotive and Transportation, as well as Information and

⁴⁷ <https://www.osti.gov/biblio/522404>.

⁴⁸ <https://www.kymatech.com/about/faqs/425-what-is-a-photoconductive-semiconductor-switch-pcss>.

⁴⁹ <https://www.nist.gov/noac/technology/quantum-optics-and-radiometry/photoconductive-switches>.

⁵⁰ Triggering Light-Triggered Thyristors, Infineon Application Note. https://www.infineon.com/dgdl/Infineon-AN2018-07_Triggering_LTTs-ApplicationNotes-v07_00-EN.pdf?fileId=5546d4626cb27db2016cdce3b8e72e3d

Communication Technology. This overall market is projected to grow from \$34.7 billion in 2017 to \$46.8 billion in 2027⁵¹.

Grid expansion is included in the 'Industrial' category of the market segments. Though not a major contributor in this decade, grid expansion will become a major segment of the market as the nation progresses towards 'Grid 3.0'⁵². Nonetheless, commercial barriers for market entry are significant and may include:

- Risk-averse industry with very high safety and reliability requirements for market entry.
- Heavily regulated market with complex capital investment approval processes and extensive new technology demonstration and piloting requirements.
- Competitive supplier base subject to public procurement processes focused on cost minimization.

As part of the T2M section in the Full Application, applicant teams should identify the intended new products and use cases for the electric power grid that will result from their proposed technologies.

Submissions should provide an assessment of the system impact enabled by the proposed device/module technology, discussion of reliability issues and potential mitigations⁵³, and system-level cost benefit. It is expected that performers consider the cost assessment of the technology they are proposing including but not limited to the cost of manufacturing process, equipment, material, etc. As part of the tech-to-market strategy, selected submissions are expected to continue these types of efforts for the entire period of performance. To facilitate success in these areas, ARPA-E strongly encourages early and consistent engagement with system integrators, end users, and relevant stakeholders. Partnering with existing manufacturers of power electronics and associated systems is encouraged to streamline supply chain development and identify future sales and servicing capabilities. Outreach to end users, including grid equipment providers, system integrators, and utilities, is also encouraged as Applicants develop their T2M plans.

E. TECHNICAL CATEGORIES OF INTEREST

Category 1 seeks submissions for devices and/or modules for protection functions. As such, ARPA-E desires functionality that enables very fast bypass, shunt, or interrupt capability at as low a level of integration as possible. The type of operation will drive efficiency and reliability requirements. For example, protection device/module operating in-line is expected to function with efficiencies higher than 99% to minimize conduction loss and consequent thermal management requirements. For protection devices that are shunt-connected, voltage

⁵¹ <https://www.kbvresearch.com/power-electronics-market>

⁵² <https://smartgrid.ieee.org/about-ieee-smart-grid/history/news/a-summary-of-the-grid-3-0-workshop>

⁵³ H. Wang and F. Blaabjerg, "Power Electronics Reliability: State of the Art and Outlook," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 9, no. 6, pp. 6476-6493, Dec. 2021, doi: 10.1109/JESTPE.2020.3037161.

withstand capability, very low leakage current, and extremely fast turn-on are essential attributes. Experimental validation of developed device and/or module performance is expected for both types of protection devices, and product lifetime of fault handling should be illustrated through at least 30,000 operating (on-off) cycles with specified reliability. Because advances in category 1 target protection functions, they are expected to operate infrequently, thus their temporal performance is characterized by how quickly they can reach their final state, that is by the current and voltage slew rates rather than by switching speed. Targeted voltage and current levels are fully described in the next section.

Category 2 addresses the need for switching devices and/or modules which will be used to realize building blocks of the control infrastructure for the future grid. Thus, depending on the power level, devices and/or modules are required to switch between 1 kHz and 100 kHz to enable increased large-signal bandwidth of power electronics converters for grid applications. High efficiency is paramount, and total loss (both switching and conduction) of device/module must be at least 30% lower than state of the art (SOTA), and Applicants need to provide justification (preferably backed by experimental or simulation evidence) in their submissions that this improvement is achievable. Product life will be assessed through a device/module lifetime with 168 hours of continuous operation with proposed reliability relevant to target application. Category 2 devices or modules can additionally feature some or all protection functions from category 1, offering a switch with unparalleled performance specifications. Experimental validation of device and/or module performance is expected. This can encompass verification of performance at the next level of system integration, such as a circuit, for example a buck, boost, half/full-bridge or other, relevant, converter structure. Teams should have an experimental plan and justification considering a potential technology application. There is not an explicit metric on the EMI mitigation, as meeting existing standards⁵⁴ is insufficient to ensure reliable, false trigger free operation of multiple devices and modules integrated into a converter. However, it is expected that final experimental validation will showcase EMI mitigation through reliable operation of multiple devices and/or modules in the next level of integration. Successful submissions should include adequate discussion of EMI issues specific to the SOTA in proposed work, chosen mitigation strategy, its scalability, as well as means of showing improved EMI performance, while meeting other program metrics.

Category 3 targets supporting technologies for category 1 and category 2, such as wireless sensing of device voltage and current, high-density packaging of multi-die power modules with the integration of wireless actuators and device/module-level protection, power cell-level capacitors and inductors, and thermal management strategies. While category 3 is distinct, it is expected that capabilities developed therein will be realized in a system context corresponding to the next level of integration, such as devices/modules developed in categories 1 and 2, or via suitable alternatives and overall experiment strategy. Thus, performance targets for category 3 encompass and support those for categories 1 and 2.

⁵⁴The EMC Standards List: Common Standards and Their Significance. <https://resources.system-analysis.cadence.com/blog/msa2021-the-emc-standards-list-common-standards-and-their-significance>.

ARPA-E is also interested in submissions that propose innovations on the device concepts that promise performance at the required levels. Novel device concepts that span across categories are encouraged, as are ideas that allow incorporation of protection functions within a device or module. Applicants are expected to provide some evidence that the proposed approach will be successful, either in the form of prior experimental results, calculations, simulations, or models. While new approaches are desired, ARPA-E will consider ideas based on prior art but expects an explanation as to what is different and why it is expected to succeed where others have failed. The following gives examples of potential areas of interest for this FOA. These examples are meant to be illustrative and are by no means exhaustive (all must target required performance levels):

- (U)WBG devices (and compact models, validated by experimental performance)
- Novel device structures (and compact models, validated by experimental performance) that offer improved functionality for control and triggering, ideally integrated at lowest possible level
- Wireless means of control and/or triggering (possibly optical, but other methods may be considered) of power electronic devices/modules
- Wireless sensing of parameters relevant to device/module control and triggering
- On-chip integration of optical (or other) and electrical functionality required
- Modeling coupled with experimental validation to elucidate fundamental device performance understanding
- Advances in passives technology experimentally validated in the context of appropriate device/module
- Thermal management approaches experimentally validated in the context of appropriate device/module
- Advances in electric field and partial discharge management at a package level

See Section III.F.3 for Submissions Specifically Not of Interest.

F. TECHNICAL PERFORMANCE TARGETS

Desired device/module voltage and current ratings are depicted in Figs. 5a and 5b, corresponding respectively to devices/modules for protection under category 1, and switching devices/modules for control under category 2. Axes limits shown in Figs. 5a and 5b, are notional and should not be interpreted as device/module rating limits, hence exceeding them is encouraged. Voltages on both y-axes represent the voltage at which a device/module can operate indefinitely, without significant device/module performance degradation (for instance, a negligible change in leakage current can be reported after the device has been exposed to this voltage for several hours). The current rating on both x-axes represents a continuous device/module current under which the junction temperature stays under certain limits determined by the device material properties, module structure, choice of the thermal management, etc.

In addition to voltage and current ratings, Fig. 5b defines a desired device/module switching frequency spanning from 1 kHz to 100 kHz. The blue shaded area follows a color gradient defined by constant power isolines along which the device power rating is constant, and all voltage-current products feature the same switching frequency. As an example, the dotted line in the graph represents an isoline for a device/module rating of 1 MW, and where all of the rating options falling on this isoline should feature the same switching frequency defined by a colored bar guide shown to the right of Fig. 5b. ARPA E will consider applications that trade off switching frequency and switching power, within specified limits, to allow performers flexibility in management of device/module loss without significant negative impact on the performance. However, favorable consideration will be given to technically aggressive submissions with well-justified, realistic plan to meet or exceed all technical targets within the time frame of the award.

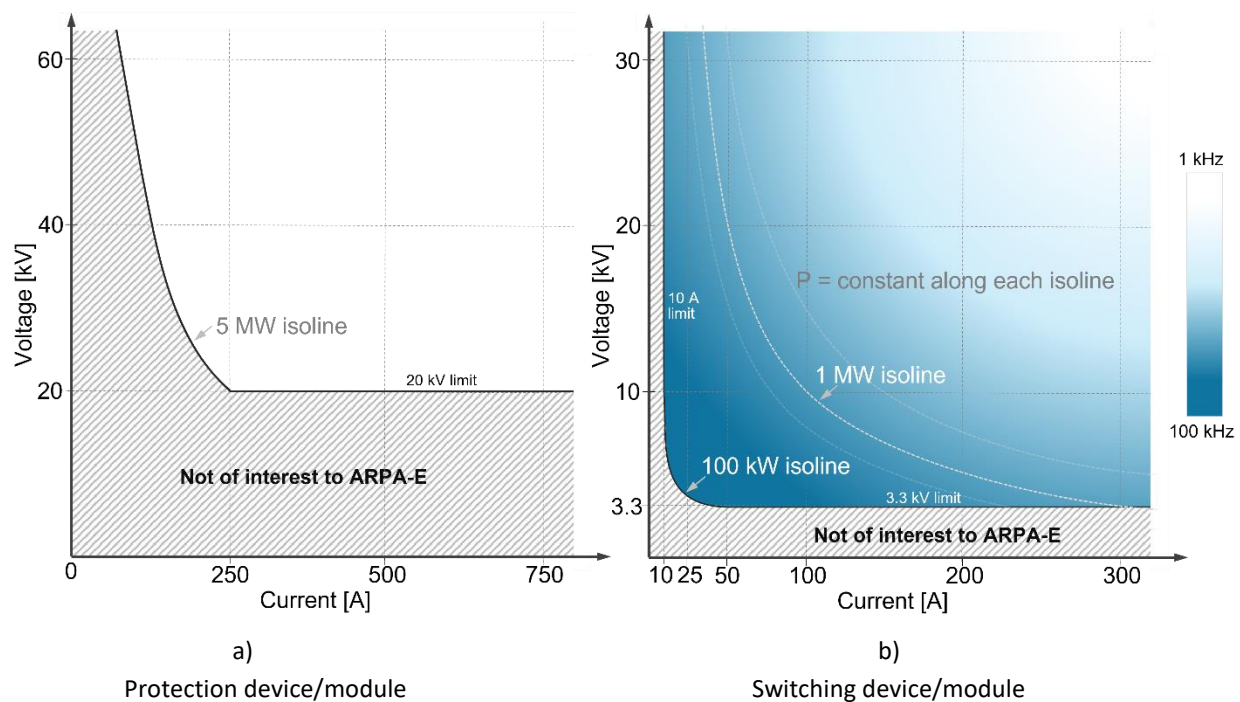


Figure 5. Device/module ratings domain

Definitions of device/module performance properties are shown in Fig. 6. Waveforms shown below are arbitrary and used here only as an example.

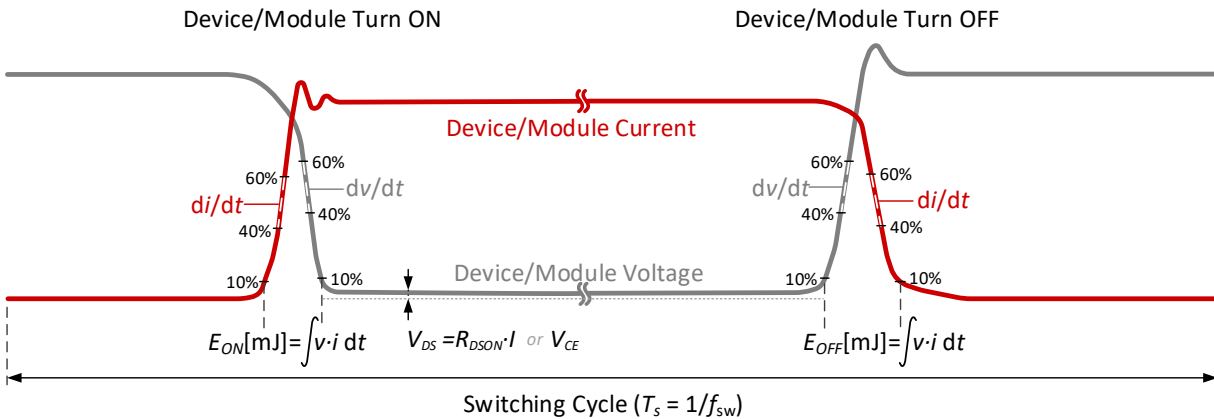


Figure 6. Device/module temporal properties

Program performance metrics summary:

CATEGORY 1		
Fast triggering for improved protection		
Voltage rating	≥ 20 kV	See Fig. 5a for further clarification. <i>Examples:</i> Single (discrete) device, multi-die power module with series and/or stacked dies, anti-series, anti-parallel device/module, bidirectional device, etc.
Current rating (continuous)	≥ 250 A	
Current rating (peak)	≥ 2500 A	
Efficiency for current carrying device/module (in-line) with infrequent switching	$\geq 99\%$	Efficiency metric applies to a device/module Please justify based on use case. <i>Examples:</i> Series protection switch, solid-state circuit breaker, current limiting diode, commutation switch, etc.
Efficiency for voltage holding device/module (shunt) with infrequent switching	n/a	<i>Examples:</i> Solid-state surge arrester/transient voltage suppressor, voltage limiting diode, shunt protection switch, etc.
Voltage slew-rate	≥ 500 V/ns	Trading between the two slew-rates possible but requires justification.
Current slew-rate	≥ 200 A/ns	
Lifetime	$\geq 30,000$ cycles	Testing to be done in a relevant circuit with justification of the methodology.

CATEGORY 2 <i>Fast switching for improved control (higher bandwidth) and higher power density integration</i>		
Voltage rating	≥ 3.3 kV	See Fig. 5b for further clarification. <i>Examples:</i> Single (discrete) device, multi-die power module with series and/or stacked dies, anti-series, anti-parallel device/module, bidirectional device, etc.
Current rating (continuous)	≥ 10 A	
Switching frequency	1 kHz (10 MW) - 100 kHz (100 kW)	
Maximum total loss (switching and conduction)	≥ 30% lower than SOTA	Please justify. Where applicable, SOTA datasheet and/or publication information may be used for comparison.
Voltage slew-rate	≥ 250 V/ns	Trading between the two slew-rates possible but requires justification.
Current slew-rate	≥ 100 A/ns	
Lifetime	≥ 168 hours	Testing to be carried out in a relevant circuit with justification of the methodology.

CATEGORY 3 <i>Supporting technologies for categories 1 and 2</i>
<p><i>Examples:</i> Wireless sensing of device voltage and current, high-density packaging of multi-die power modules with the integration of wireless actuators and device/module-level protection, power cell-level capacitors and inductors, thermal management strategies, etc.</p> <p>Developed capabilities are expected to be experimentally validated in a system context corresponding to the next level of integration, such as devices/modules developed in categories 1 and 2, or via suitable alternatives (for example COTS devices/modules). Performance targets for category 3 encompass and support those for categories 1 and 2, depending on the application.</p>

NOTE (relevant for all project categories):

ARPA-E is looking for technically aggressive, well-justified, submissions that achieve transformative advancements beyond the current state-of-the-art.

ARPA-E expects that technology developed with the support of this program will meet or exceed the reliability of SOTA. Thus, at a minimum, submissions should include a discussion of reliability assessment, influencing factors, and substantiated pathways to desired reliability for a relevant application. Quantitative analyses and/or experimental evidence are encouraged.

Efficiency target of 99% for category 1 is purposely chosen to encourage novel solutions (for example PCSS), but thermal considerations may favor higher efficiency performance.

Experimental validation of device and/or module should be carried out in a relevant circuit with justification of the chosen testing platform and the methodology. For example, devices/modules from category 1 can be tested in a double-pulse circuit, while devices from the category 2 can be tested in a converter (simple buck or boost converters are acceptable). Testing conditions and thermal management are not prescribed by ARPA-E, however, the use of a regenerative (pump-back⁵⁵) testing structure is deemed most effective and is highly encouraged.

Applicants can propose to address Category 1, Category 2, Category 3, or any combination thereof if proposal is compliant with the requirements specified in this FOA.

⁵⁵ D. Pan, D. Zhang, C. Immer, M. Dame and J. He, "Pump-Back Validation of a Medium Voltage High-Frequency "SiC+Si" Hybrid Three-Level ANPC Inverter for Hybrid-Electric Propulsion Application," 2019 IEEE International Electric Machines & Drives Conference (IEMDC), 2019, pp. 1647-1654, doi: 10.1109/IEMDC.2019.8785332.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately \$48 million available for new awards, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 15-20 awards under FOAs DE-FOA-0002998 and DE-FOA-0002999. ARPA-E may, at its discretion, issue one, multiple, or no awards.

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

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

Applicants must apply for a Combined Phase I/II Award or a Combined Phase I/II/IIS Award. Combined Phase I/II and I/II/IIS Awards are intended to develop transformational technologies with disruptive commercial potential. Such commercial potential may be evidenced by (1) the likelihood of follow-on funding by private or non-SBIR/STTR sources if the project is successful, or (2) the Small Business Concern's record of successfully commercializing technologies developed under prior SBIR/STTR awards. Phase IIS awards are a "sequential" (i.e., additional) Phase II award, intended to allow the continued development of promising energy technologies. Combined Phase I/II/IIS awards may be funded up to \$4,241,580. Funding amounts will be consistent with the Phase I and Phase II limits posted on the SBA's website.⁵⁶

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 \$295,924 and the maximum amount for a Phase I/II award is \$2,268,752.

The period of performance for funding agreements may not exceed 36 months for a Combined Phase I/II/IIS Award. ARPA-E expects to issue funding agreements in December 2023, or as negotiated.

B. RENEWAL AWARDS

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

⁵⁶ For current SBIR Phase I and Phase II funding amounts, see <https://www.sbir.gov/about/about-sbir>. For current STTR Phase I and Phase II funding amounts, see <https://www.sbir.gov/about/about-sttr>. Phase IIS funding amounts are equal to Phase II funding amounts for both SBIR and STTR awards.

approved application; (3) submittal of required reports; (4) compliance with the terms and conditions of the award; (5) ARPA-E approval of a renewal application; and (6) other factors identified by the Agency at the time it solicits a renewal application.

C. ARPA-E FUNDING AGREEMENTS

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

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."⁵⁷ Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.C below.

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

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

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

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

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs (including NETL), and Federal instrumentalities (e.g., Tennessee Valley Authority) will be consistent with the sponsoring agreement between the U.S.

⁵⁷ U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).

Government and the Laboratory. Any funding agreement with an FFRDC or GOGO will have similar terms and conditions as ARPA-E's Model Cooperative Agreement (<https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/funding-agreements>).

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

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

D. STATEMENT OF SUBSTANTIAL INVOLVEMENT

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

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- ARPA-E may, at its sole discretion, modify or terminate projects that fail to achieve predetermined Go/No Go decision points or technical milestones and deliverables.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.339 – 200.343.
- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercialization of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits⁵⁸ 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 commercialization 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 commercialization of ARPA-E-funded technologies.

⁵⁸ The term "nonprofit organization" or "nonprofit" is defined in Section IX.

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

1. SBIR ELIGIBILITY

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

A Small Business Concern⁵⁹ may apply as a Standalone Applicant⁶⁰ or as the lead organization for a Project Team.⁶¹ 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.⁶²

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

2. STTR ELIGIBILITY

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

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

⁵⁹ A Small Business Concern is a for-profit entity that: (1) maintains a place of business located in the United States; (2) operates primarily within the United States or makes a significant contribution to the United States economy through payment of taxes or use of American products, materials or labor; (3) is an individual proprietorship, partnership, corporation, limited liability company, joint venture, association, trust, or cooperative; and (4) meets the size eligibility requirements set forth in 13 C.F.R. § 121.702. Where the entity is formed as a joint venture, there can be no more than 49% participation by foreign business entities in the joint venture. Small Business Concerns that are majority-owned by multiple venture capital operating companies, hedge funds, or private equity firms are eligible to apply to this FOA.

⁶⁰ A “Standalone Applicant” is an Applicant that applies for funding on its own, not as part of a Project Team.

⁶¹ The term “Project Team” is used to mean any entity with multiple players working collaboratively and could encompass anything from an existing organization to an ad hoc teaming arrangement. A Project Team consists of the Prime Recipient, Subrecipients, and others performing any of the research and development work under an ARPA-E funding agreement, whether or not costs of performing the research and development work are being reimbursed under any agreement.

⁶² 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 Institution⁶³ may apply only as a member of a Project Team (i.e., as a Subrecipient to a Small Business Concern). In STTR projects, a single Research Institution must perform at least 30%, but no more than 60%, of the work under the award in Phase I, Phase II, and/or Phase IIS (as applicable), as measured by the Total Project Cost.

2. OTHER PROJECT TEAM MEMBERS

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

- For-profit entities, including Small Business Concerns

⁶³ Research Institutions include FFRDCs, nonprofit educational institutions, and other nonprofit research organizations owned and operated exclusively for scientific purposes. Eligible Research Institutions must maintain a place of business in the United States, operate primarily in the United States, or make a significant contribution to the U.S. economy through the payment of taxes or use of American products, materials, or labor.

- Nonprofits other than Research Institutions⁶⁴
- Government-Owned, Government Operated laboratories (GOGOs)
- State, local, and tribal government entities
- Foreign entities⁶⁵

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

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

C. ELIGIBLE PRINCIPAL INVESTIGATORS

1. SBIR

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

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

2. STTR

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

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

⁶⁴Nonprofit 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.

⁶⁵ All work by foreign entities must be performed by subsidiaries or affiliates incorporated in the United States (see Section IV.G.6 of the FOA). However, the Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form submitted with the Full Application.

D. ELIGIBILITY OF PRIOR SBIR AND STTR Awardees: SBA Benchmarks on Progress Towards Commercialization

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

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

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

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

- The Commercialization Rate Benchmark sets the minimum Phase III⁶⁶ 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.**

⁶⁶ Phase III refers to work that derives from, extends or completes an effort made under prior SBIR/STTR funding agreements, but is funded by sources other than the SBIR/STTR Program. Phase III work is typically oriented towards commercialization of SBIR/STTR research or technology. For more information please refer to the Small Business Administration's "Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program Policy Directive" at https://www.sbir.gov/sites/default/files/SBIR-STTR_Policy_Directive_2019.pdf.

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

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

E. COST SHARING

Cost sharing is not required for this FOA.

F. OTHER

1. COMPLIANT CRITERIA

Concept Papers are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Concept Paper complies with the content and form requirements in Section IV.C of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the “Submit” button in ARPA-E eXCHANGE by the deadline stated in the FOA.

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

Full Applications are deemed compliant if:

- The Applicant submitted a compliant and responsive Concept Paper;
- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Full Application complies with the content and form requirements in Section IV.D of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the “Submit” button in ARPA-E eXCHANGE by the deadline stated in the FOA.

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

Replies to Reviewer Comments are deemed compliant if:

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

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

2. RESPONSIVENESS CRITERIA

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

- Submissions that fall outside the technical parameters specified in this FOA.
- Submissions that have been submitted in response to currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to currently issued ARPA-E FOAs.

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

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- System-level control schemes and algorithms that do not include advances in device/module technologies of interest to this FOA
- Material advances that do not result in a passive component, package, device and/or module (i.e., pure material studies that do not progress to the next level of integration)
- Strictly software/algorithm development

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.

Small business Applicants that qualify as a “Small Business Concern” may apply to only one of the two ARPA-E ULTRAFast FOAs: DE-FOA-0002999 (ULTRAFast SBIR/STTR), or DE-FOA-

0002998 (ULTRAFAST). 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-0002999, 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 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.6 of the FOA).

2. REGISTRATION IN ARPA-E eXCHANGE

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

3. CONCEPT PAPERS

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

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

ARPA-E will encourage a subset of Applicants to submit Full Applications. Other Applicants will be discouraged from submitting a Full Application in order to save them the time and expense of preparing an application submission that is unlikely to be selected for award negotiations. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

4. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 45 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.F of the FOA. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.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.F.1 of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

6. PRE-SELECTION CLARIFICATIONS AND “DOWN-SELECT” PROCESS

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

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

7. SELECTION FOR AWARD NEGOTIATIONS

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA. The Selection Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

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

B. APPLICATION FORMS

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

C. CONTENT AND FORM OF CONCEPT PAPERS

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

- The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables.
- The Concept Paper must be submitted in Adobe PDF format.
- The Concept Paper must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right

corner of the header of every page. Page numbers must be included in the footer of every page.

- The first paragraph must include the Lead Organization's Name and Location, Principal Investigator's Name, Technical Category, Proposed Funding Requested (Federal and Cost Share (not required for this SBIR/STTR FOA), and Project Duration.

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

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

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

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

1. CONCEPT PAPER

a. CONCEPT SUMMARY

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

b. INNOVATION AND IMPACT

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

c. PROPOSED WORK

- Describe the final deliverable(s) for the project and the overall technical approach used to achieve project objectives.

- Discuss alternative approaches considered, if any, and why the proposed approach is most appropriate for the project objectives.
- Describe the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach. Provide specific examples of supporting data and/or appropriate citations to the scientific and technical literature.
- Describe why the proposed effort is a significant technical challenge and the key technical risks to the project. Does the approach require one or more entirely new technical developments to succeed? How will technical risk be mitigated?
- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.
- Estimated federal funds requested; total project cost including cost share (if cost share is being provided – cost share is not required under this FOA).

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 MAY 2023]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

F. INTERGOVERNMENTAL REVIEW

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

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

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;

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).

- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Failing to click the “Submit” button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

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

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

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

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

1. CRITERIA FOR CONCEPT PAPERS

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

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

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

- The feasibility of the proposed work, as justified by appropriate background, theory,

simulation, modeling, experimental data, or other sound scientific and engineering practices;

- Sufficiency of technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;
- Clearly defined project outcomes and final deliverables; and
- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

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

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

In addition to the above criteria, ARPA-E may consider the following program policy factors in determining which Concept Papers to encourage to submit a Full Application and which Full Applications to select for award negotiations:

- I. **ARPA-E Portfolio Balance.** Project balances ARPA-E portfolio in one or more of the following areas:
 - a. Diversity of technical personnel in the proposed Project Team;
 - b. Technological diversity;
 - c. Organizational diversity;
 - d. Geographic diversity;
 - e. Technical or commercialization risk; or
 - f. Stage of technology development.
- II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
 - a. Reduction of U.S. dependence on foreign energy sources;

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

III. **Synergy of Public and Private Efforts.**

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

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

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

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

2. ARPA-E REVIEWERS

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

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in 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 MAY 2023]

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

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

2. CONCEPT PAPER NOTIFICATIONS

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

Applicants may submit a Full Application even if they receive a notification discouraging them from doing so. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. The purpose of the Concept Paper phase is to save Applicants the considerable time and expense of preparing a Full Application that is unlikely to be selected for award negotiations.

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

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

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).

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

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

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

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

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

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

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

B. DEBRIEFINGS

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

VIII. OTHER INFORMATION

A. TITLE TO SUBJECT INVENTIONS

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

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

B. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

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

1. GOVERNMENT USE LICENSE

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

2. MARCH-IN RIGHTS

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

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

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

C. RIGHTS IN TECHNICAL DATA

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

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

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

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

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

E. FOAs AND FOA MODIFICATIONS

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

F. OBLIGATION OF PUBLIC FUNDS

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

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

G. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

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

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

H. RETENTION OF SUBMISSIONS

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

I. MARKING OF CONFIDENTIAL INFORMATION

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

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

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

Notice of Restriction on Disclosure and Use of Data:

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

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

J. ADDITIONAL NOTICES

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

K. 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.

L. PAYMENT OF FEE OR PROFIT

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

IX. GLOSSARY

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

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

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

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

Covered Individual: an individual who contributes in a substantive, meaningful way to the scientific development or execution of an R&D project proposed to be carried out with a award from DOE, i.e. senior/key personnel. ARPA-E may further designate covered individuals during award negotiations or the award period of performance.

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

DOE: U.S. Department of Energy.

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

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

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

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

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

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

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

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

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

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

PI: Principal Investigator.

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

SBA: U.S. Small Business Administration.

SBIR: Small Business Innovation Research Program.

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

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. Such joint ventures must submit the VCOC/FJV Certification (the seventh component of the Full Application).

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.

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