FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

RANGE EXTENDERS FOR ELECTRIC AVIATION WITH LOW CARBON AND HIGH EFFICIENCY (REEACH)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002240
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	Monday, December 16
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, Monday, January 21
Submission Deadline for Concept Papers:	9:30 AM ET, Friday, January 31
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:	July 2020
Total Amount to Be Awarded	Approximately $20 million, subject to the availability of appropriated funds to be shared between FOAs DE-FOA-0002240 and DE-FOA-0002241.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 of the FOA.

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

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: ○ Concept Summary ○ Innovation and Impact ○ Proposed Work ○ Team Organization and Capabilities	Mandatory	IV.C	9:30 AM ET, Friday, January 31
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

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

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

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

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

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

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from

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

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

B. PROGRAM OVERVIEW

1. Executive SUMMARY

ARPA-E seeks to mitigate the greenhouse gas emissions associated with commercial air travel at minimum economic cost by developing elements of an ultra-high efficient aircraft propulsion system that uses Carbon Neutral Liquid Fuels (CNLFs).[2] Since these fuels generally either have lower specific-energies (kWh/kg) or are projected to have higher cost than traditional fossil-based jet fuels, ultra-high conversion efficiency is critical for the economic viability of this approach. An electrified propulsion system framework postulated by ARPA-E (Fig. 1) could potentially leverage multiple sources of stored energy (e.g. CNLF, batteries, etc.) to facilitate emerging propulsion concepts (e.g. distributed propulsion) and enable net-zero carbon emissions for long range, narrow-body, commercial aircraft.

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

[2] CNLFs are defined in this FOA as energy dense liquid fuels with no net greenhouse gas emissions or net carbon footprint. They are made by converting molecules contained in air (N_2, CO_2), water, and/or biomass using renewable energy into energy-carrying fuels that are liquid at moderate temperatures and pressures.

The objective of the **R**ange **E**xtenders for **E**lectric **A**viation with Low **C**arbon and **H**igh Efficiency (***REEACH***) program is the development of one element of the electrified propulsion system framework: a system for the conversion of chemical energy contained in energy dense CNLFs (green block in Fig. 1) to electric power for aircraft propulsion and hotel loads. (The development of the all-electric powertrain depicted in Fig. 1 is the objective of a separate ARPA-E FOA.[3])

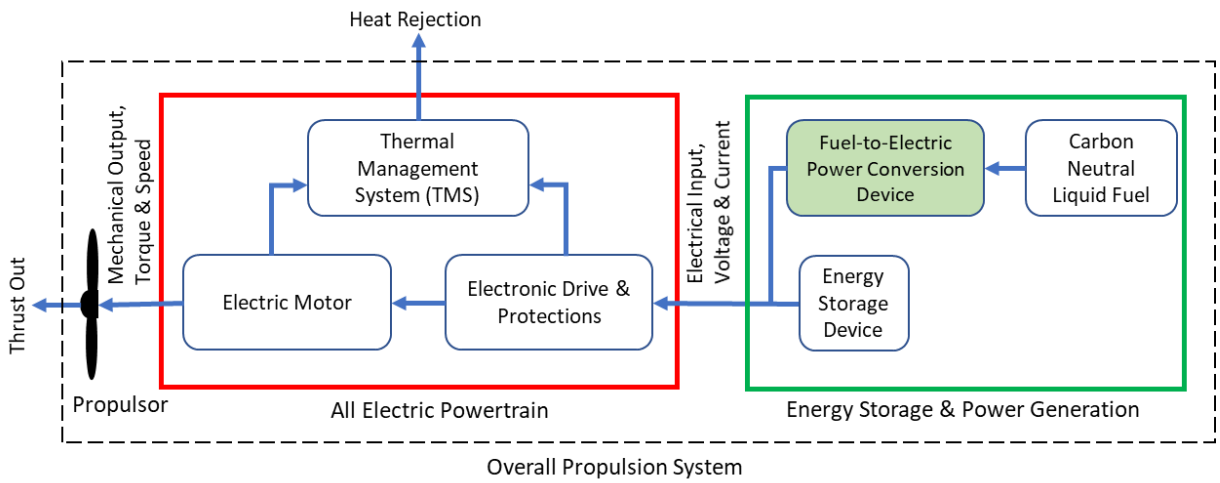

Figure 1. A block diagram of the electrified aviation propulsion system that ARPA-E is pursuing via two distinct FOAs. The energy storage and power generation sub-system boundary (this FOA) is shown in the green block. The fuel-to-electric power conversion device, which is highlighted in green, is a primary development focus of this FOA. The all-electric powertrain sub-system (ASCEND FOA)[2] is shown in the red block.

The approach taken in the **REEACH** program is to pursue the development of the energy storage and power generation sub-system in a four-year effort with two distinct phases:

Phase I: Energy Storage and Power Generation (ESPG) system conceptual design and fuel conversion component risk reduction.

Phase II: Design and developmental prototype demonstration of a sub-scale fuel-to-electric power conversion device using a CNLF.

The current FOA and associated funding applies only to Phase I. However, ARPA-E requires that applicants include proposed task descriptions and budgets for both Phase I and II. Subject to the availability of appropriated funds, projects that achieve technical success in Phase I may, at ARPA-E's sole discretion, proceed to the second phase of the program to

[3] Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives (ASCEND) FOA to be released by ARPA-E.

develop, fabricate, and test a fuel conversion to power conversion device with power output defined in Section I.F of the FOA.

The propulsion system and its supporting ESPG sub-system—depicted in Fig. 1—must be capable of providing adequate thrust to the aircraft through all phases of flight (taxi, take-off, climb, cruise, and descent) while storing enough energy to support the entire aircraft mission with adequate safety reserves. Furthermore, for such a CNLF-powered system to be commercially successful, it must be economically competitive with incumbent fossil fuel approaches.

In the design of their ESPG sub-systems, applicants are free to select the CNLF, the system architecture, and the individual component technologies. Such components may include, for example, the fuel-to-electric power conversion device(s), fuel tanks, energy storage device(s), and any necessary balance of plant items (e.g. compressors, blowers, heat exchangers).

ARPA-E has established performance metrics for the ESPG sub-system that it believes, if achieved, would result in adoption of the technology in the 150-200 passenger single aisle commercial aircraft market (e.g. Boeing 737-class), which is arguably the most impactful commercial aircraft application. Furthermore, these metrics allow applicant teams to trade-off between performance and economic characteristics of their selected CNLFs and ESPG sub-system designs. These target metrics were derived from the system anticipated performance over a nominal mission.[4] The resulting target program metrics are as follows:

- ESPG sub-system specific energy: $\geq 3\ kWh_{delivered}/kg_{total}$
- ESPG sub-system specific peak power: $\geq 0.75_{electric}\ kW_{delivered}/kg_{total}$
- Operating cost of delivered electric energy: $\leq \$0.15/kWh_{delivered}$
- Capital cost of the ESPG sub-system: $\leq \$1000/kW_{delivered}$

2. PROGRAM MOTIVATION

Air travel accounts for a considerable and growing portion of U.S. energy usage and associated GHG emissions.[5,6] In 2017, the U.S. consumed nearly 3.5 quadrillion BTUs (quads) of jet fuel[7], which accounted for roughly 3.5% of primary energy consumption and 16% of petroleum (crude oil and products) imports[8]. In the same year, air travel accounted for about 174.8 million metric tons of CO_2 equivalent in the U.S., or about 2.6% of domestic GHG emissions[9]. These energy

[4] The nominal mission is specified in Section 1.E, Table 2
[5] S.J. Davis et al., "Net-zero emissions energy systems", *Science* 360(6396), 29 June 2018.
[6] National Academies of Sciences, Engineering, and Medicine, Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions, The National Academies Press, 2016. https://doi.org/10.17226/23490.
[7] https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_jf.html
[8] https://www.eia.gov/totalenergy/data/monthly/pdf/sec3_9.pdf
[9] https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

usage and emissions burdens have been growing rapidly, and this trend is expected to continue—with the number of airline passengers forecast to grow at a compound annual growth rate of 4.7 percent.[10] The motivation for the REEACH program is to reduce the emissions associated with this projection.

The narrow body aircraft type constitutes the majority of airplanes worldwide. Furthermore, this type accounts for the most passenger-miles traveled (and associated GHG emissions) in the U.S[11] and the most anticipated growth globally. Consequently, a decarbonized B737-like aircraft would provide the greatest energy and emissions impact from a single aircraft type.

Several possible pathways to a decarbonized aviation sector leverage partially or fully-electrified propulsion systems**Error! Bookmark not defined.**, though these pathways face many technical challenges—including low specific energy and low specific power energy storage and conversion systems. However, such electrified aircraft propulsion systems have the potential to achieve ultra-high fuel-to-propulsive power conversion efficiencies compared with existing turbofan and turboprop systems. For example, hybridized architectures, which may combine engines with generators, fuel cells, and batteries can capitalize on the performance strengths of individual technologies to address the disparate power and energetic demands of the different flight stages, leading to increased overall efficiency and reduced fuel consumption while substantially reducing GHG emissions.

Furthermore, the greater flexibility of employing electric motors as prime movers can facilitate revolutionary aircraft architecture paradigms with greater engine-airframe integration, such as blended wing body, distributed electric and boundary layer ingestion propulsion systems. These new design paradigms[12] could substantially improve the overall aerodynamic efficiency of the airframe, further reducing the energy required to carry a given payload for a given mission[13]. Electrified architectures can also reduce noise and increase reliability by increasing redundancy via the use of multiple electric motors and connected ESPG sub-systems.

Fully-electric aviation could potentially eliminate emissions, but thus far the application of electrified propulsion technologies has been restricted to relatively smaller and shorter-range aircraft due to the limited specific energy of current batteries (e.g. 250 Wh/kg) and batteries that are currently under development (e.g. 500 Wh/kg). For comparison, these levels are an order of magnitude lower than that of jet fuel, which has a specific energy of >12,000 Wh/kg. In a recent study, NASA concluded that minimum requirement for full electric regional aircraft

[10] https://www.iata.org/publications/store/Pages/20-year-passenger-forecast.aspx
[11] https://www.transtats.bts.gov/tables.asp?DB_ID=130, Table T2
[12] https://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-technology-roadmap-environment.pdf
[13] K. Moore, A. Ning, "Distributed Electric Propulsion Effects on Traditional Aircraft Through Multidisciplinary Optimization", AIAA Structure, Structural Dynamics and Materials Conference, Kissimmee, FL, 2018

energy storage system is 2000 Wh/kg.[14] Results of a modeling study showed that for full-electric aircraft, there is no battery (or even advanced future concepts) that can provide competitive payloads and flight ranges when compared to incumbent technologies.[15] It should also be noted that charging batteries on the ground – either hybridized with a turbofan or in a fully electric battery-only aircraft, is likely to increase aircraft turnaround times, and hence decreasing their economic viability and passengers' convenience. Furthermore, the delivery of GW-scales of electric power to charge on-board batteries in a timely manner will require the massive and expensive reconstruction of our airport infrastructure.

The success of this program is contingent upon the development of ultra-high efficiency and specific power (e.g. kW/kg) CNLF-to-electric-power conversion devices, such as fuel cells and advanced combustion engines. Furthermore, higher specific power energy storage devices (e.g. batteries, supercapacitors, or other such commercially available electric energy storage devices) may be leveraged to further boost their power output for take-off and climb, if necessary.

In sum, to address the anticipated increase in GHG emissions associated with the rapidly growing and difficult to decarbonize aviation sector, ARPA-E seeks to develop enabling technologies for electrified aircraft propulsion systems that would be capable of powering narrow-body, single-aisle aircraft that operate on carbon-neutral liquid fuels in an economically attractive manner. This objective is being pursued simultaneously under two ARPA-E programs that target two of the major elements of the electrified propulsion framework depicted in Fig. 1:

1) **The development of ultra-high-efficiency and -specific power systems for energy storage and power generation (ESPG) utilizing CNLFs (this FOA); and**
2) **The development of a lightweight and ultra-efficient all-electric powertrain that converts electric power to mechanical shaft power (ASCEND FOA)[3].**

A primary focus in each of these areas will be substantial improvements in the specific power output and energy efficiency of the two systems and their components.

While the two aforementioned technological thrusts will result in integrated systems specifically designed for subsonic narrow-body aircraft capable of missions extending several thousands of nautical miles, at cruise speeds and altitudes commensurate to existing narrow-body aircraft (such as the Boeing 737), it is anticipated that the technology developed will also find direct application into UAVs, the nascent Urban Air Mobility[16] and regional aircraft markets[17]. In addition, this technology will be applicable to other long-haul, heavy duty

[14] A. Misra. "Energy Conversion and Storage Requirements for Hybrid Electric Aircraft", 2016. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160010280.pdf
[15] M. Happerle, "Electric Flight – Potential and Limitations", 2012https://www.mh-aerotools.de/company/paper_14/MP-AVT-209-09.pdf
[16] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190001472.pdf
[17] Roland Berger, Think, Act: Aircraft Electrical Propulsion – Onwards and Upwards, 2018

transportation applications such as ground airport equipment, maritime, and on- and off-road medium and heavy-duty vehicles.

C. PROGRAM OBJECTIVES

The objective of the **REEACH** program is to develop novel, high specific power, high specific energy, cost-effective technologies for the conversion of chemical energy stored in CNLFs into electric power for use in electrified aircraft powertrains. If successful, these technologies could make economically viable the development of net-zero GHG emitting, long-range (i.e. greater than 2800 nautical miles), narrow-body electric aircraft.

The two mission-critical performance parameters for the energy storage and power generation (ESPG) system are: (1) specific power, and (2) specific energy. The estimated weight of the proposed system must include all ESPG components, such as fuel conversion device(s), energy storage device(s), necessary balance of plant components (e.g. compressors, pumps, heat exchangers, etc.), fuel tank(s), and the CNLF itself. Meeting or exceeding the targets for these performance parameters is a tremendous challenge and may be addressed via improvements in the fuel conversion device design, improvements at the sub-component level (e.g. increasing the areal power density of fuel cells within a stack), as well as by improving the integration of components within the ESPG system (e.g. taking advantage of operational synergies to shed balance of plant requirements). Separate tuning of delivered power and energy from the ESPG system may be beneficial, as the power requirements for takeoff and climb (short duration) are typically 3-4 times the cruise power requirement (long duration). This decoupling of power and energy may be achieved, for example, through hybridization of the fuel-to-electric power conversion device(s) with high specific power electric energy storage device(s).

The proposed ESPG system must demonstrate the potential to achieve cost competitiveness at target production volumes relative to incumbent and emerging technologies. A preliminary ESPG system cost model is required for a narrow-body-sized aircraft, such as the Boeing 737, and must be based on an initial analysis of the cost structure for projected large-scale manufacturing of all proposed components, including the fuel tanks and any required balance of plant.

D. POTENTIAL TECHNICAL APPROACHES

The **REEACH** program will support the development of ESPG systems capable of providing the required power during all stages of flight with sufficient energy on-board to support current narrow-body aircraft mission profiles. ARPA-E welcomes all innovative solutions that meet the technical performance targets in Section 1.E of the FOA. The applicant is allowed to select any CNLF, fuel-to-electric power conversion device(s), and ESPG configuration so long as it conforms to the "fuel in – electric power out" program concept and meets performance and cost targets defined in section 1.E. The following subsections provide technology examples.

Carbon neutral liquid fuels (CNLF)

We define CNLFs responsive to this FOA as renewable energy dense liquid fuels (e.g. sustainable hydrocarbons and oxygenates) that meet three specific criteria: (1) enable the cost of delivered energy < $0.15/kWh at the 100 MWh scale; (2) are produced commercially, or have a feasible pathway to production, at > 1000 metric tons per year; and (3) are liquid over a practical range of temperatures under moderate (up to 10 bar) storage pressure, stable for storage and compatible with existing methods and infrastructure for liquid storage and transportation. Many of the hydrogen fuel cell and hydrogen storage, generation, and delivery technologies supported by the Fuel Cell Technologies Office within the DOE Office of Energy Efficiency and Renewable Energy (EERE)[18] could also be beneficial for aviation. However, hydrogen fuel and the related conversion, storage, and delivery technologies are outside the scope of this FOA, which is focused on higher energy-density liquid fuels with established infrastructures.

Technical success requires not only a high **primary** specific energy, but moreover high **delivered** specific energy, which is defined as the product of primary energy and fuel conversion efficiency. The lower the primary specific energy of the fuel, the higher the conversion efficiency required to provide the same delivered specific energy. For a reasonable fuel conversion efficiency (~35-55%), which is achievable with state-of-the-art fuel cells and combustion engines, the fuel primary specific energy must exceed 7 kWh/kg to meet the ESPG sub-system-level specific energy target. A list of example CNLFs for this FOA, provided alongside liquid hydrogen and jet fuel for comparison, can be found in Table 3 (Technical Performance Targets section, 1.E).

Direct conversion of CNLFs to electric power

Chemical energy stored in CNLFs can be converted to electricity in appropriately designed fuel cells using oxygen from air as the oxidant. Several types of fuel cells, such as proton exchange membrane (PEM), alkaline exchange membrane (AEM), solid oxide fuel cells (SOFC), and proton ceramic fuel cells (PCFC), may be considered for this purpose. On-board CNLF reforming may be accomplished to generate hydrogen, which can be efficiently utilized in such fuel cells. Existing DOE programs run by EERE[19] and the Office of Fossil Energy[20] have focused on low temperature PEM fuel cells and high temperature SOFCs for transportation and stationary power applications, respectively. Over the past ten years, these programs have resulted in advanced PEM and SOFC technologies with both improved performance and reduced cost. High efficiencies up to 70% have been demonstrated, albeit at power densities that are 30-35% lower than peak power density. In contrast, the rate of electrochemical oxidation of CNLFs is much slower and requires higher temperatures than typical for PEM fuel cells (<100°C) can handle, and/or internal or external reforming. Nevertheless, liquid fuels have been used directly

[18] http://energy.gov/eere/office-energy-efficiency-renewable-energy
[19] http://energy.gov/eere/office-energy-efficiency-renewable-energy
[20] http://energy.gov/fe/office-fossil-energy

(e.g. ethanol in SOFC) [21] with performance comparable to hydrogen.[22] Synthetic diesel,[23] as well as palm-derived biodiesel,[24] have been shown to operate stably at 700 – 800 °C. However, long-term, stable performance of such systems will likely be a challenge due in part to an anticipated increase in ohmic resistance from coke formation. Key challenges with direct conversion technology are to (1) increase the power density of the electrochemical stack, and (2) improve its thermal management. These needs require an innovative stack design with thin cells and effective fluid flow. A fuel cell-based ESPG sub-system would include a stack, any required balance of plant, and, if necessary, a fuel reformer and/or energy storage device. The system must operate at high altitudes (35000 ft), and therefore may require an air compressor to achieve necessary oxidant flow rates.

Examples of technical approaches include but are not limited to:

- Development of high areal energy density electrochemical fuel cells.
- Innovative design of fuel cell stack and fuel reformer and catalysts, electrocatalysts and materials to enable high power fuel cell system.
  - Areas of particular interest are approaches to novel, high power density electrode, MEA and stack architectures; oxygen- or proton-conducting solid electrolytes; direct use of liquid fuels without ex-situ reforming; using non-platinum group metal catalysts; balance of plant integration.
- Novel methods for stack manufacturing to improve performance while reducing cost.

Indirect conversion of CNLFs to electric power

Sustainable hydrocarbons (e.g. synthetic jet fuel produced by a renewable energy-powered Fischer-Tropsch process) are the most energy-dense liquid fuels. They can be used in advanced combustion engines including, but not limited to, gas turbines, turboshafts, and reciprocating internal combustion engines—coupled with an electric generator. ARPA-E is interested in supporting the development of carbon neutral liquid fueled engine technologies (up to 1 MW in scale) to deliver fuel conversion efficiencies tantamount to larger size simple-cycle aeroderivative combustion turbines, i.e. >55%, to achieve the ESPG system specific energy target. As an example, a split-power hybrid based on a gas turbine and/or a reciprocating internal combustion engine fueled by a carbon neutral liquid hydrocarbon fuel and coupled with an electric generator could be optimized to operate at the following conditions viz.: idle, take-off (peak power) and cruise (~1/3rd peak power). Additionally, a combustion engine may be integrated with a fuel cell, and operational synergies between the two components may be leveraged to reduce the overall balance of plant requirements and increase the fuel to electricity conversion efficiency (see, e.g., ARPA-E's INTEGRATE program[25]).

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[21] Sønderberg-Petersen, L., and Larsen, H., Energy solutions for sustainable development. (2007) p. 347-356
[22] Soloveichik, G.L., *Beilstein J. Nanotechnol.* (2014), 5, 1399
[23] H. Kim, et al., *J. Electrochem. Soc.* 148 (2001) A693-A695.
[24] T. Quang-Tuyen, et al, Int. J. Energy Res. 37 (2013) 609-616.
[25] https://arpa-e.energy.gov/?q=arpa-e-programs/integrate

The delivered specific power derived from a conversion technology with a lower conversion efficiency could be balanced by using a higher energy density fuel, such as a hydrocarbon. The goal of this approach is the increase of fuel conversion efficiency without reducing the engine specific power and lifetime, while also meeting or improving upon NO_X emission limits.

Examples of technical approaches include but are not limited to:

- Piston engines and turbines coupled with an electric generator
- Integrated combustion engine and fuel cell with all-electric output
- Combustion and thermal-to-electric conversion devices (e.g. thermophotovoltaic)

Hybridization of high energy density fuel conversion and high power devices

In a typical commercial flight, the relatively short takeoff and climb phases (typically up to 20 minutes) require the most power, while the longer cruise phase (25-35% power) is responsible for the bulk of the energy consumption. In a potential ESPG system approach, the takeoff power could be provided by both a high specific power energy storage device, such as a battery or supercapacitor, and by a fuel conversion device.

As an illustrative example, a possible ESPG powertrain configuration may be a power-split (or series-parallel) hybrid, as shown in Fig. 2, which features power paths from both the fuel conversion and the energy storage devices to the all-electric integrated powertrain, which is comprised of an electric motor, and its drive and thermal management system. The high-efficiency CNLF-to-electric power conversion device(s) would provide a fraction of the takeoff/climb power (supplemented by the energy storage device(s)) and all required power during cruise and descent phase. It would also recharge the energy storage device(s) with available surplus power during cruise and descent. This architecture decouples the power and energy requirements, while also providing the combined power necessary to achieve takeoff.

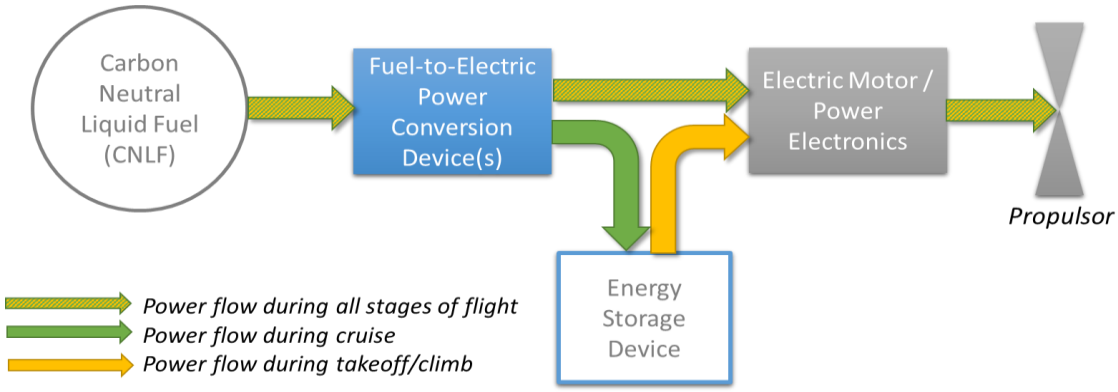

Figure 2. An example power split hybrid system for electrified aircraft propulsion. The REEACH program focuses specifically on the fuel-to-electric power conversion device (top middle blue box), though the energy storage and power generation system (ESPG), also includes the energy storage device(s), the CNLF, its tanks, and all

required balance of plant. The electric motor/power electronics and propulsor are *excluded* from the REEACH program but are the subject of the ASCEND FOAs.[2]

However, please note that due to safety requirements, the energy storage device must be fully charged at the end of the descent phase to provide maximum power if needed, such as in the case of an aborted landing (Fig. 3). Therefore, the fuel conversion device must also recharge the high-power energy storage device. *Grid electricity is not considered a viable energy source to charge the energy storage system on the ground, because the FOA concept requires that ESPG system will be ready to deploy full power at landing.*

Please note that as the development of ES devices is not the subject of this FOA, commercial or documented emerging products (TRL ≥ 7) must be used for performance/cost estimations and ESPG system testing.

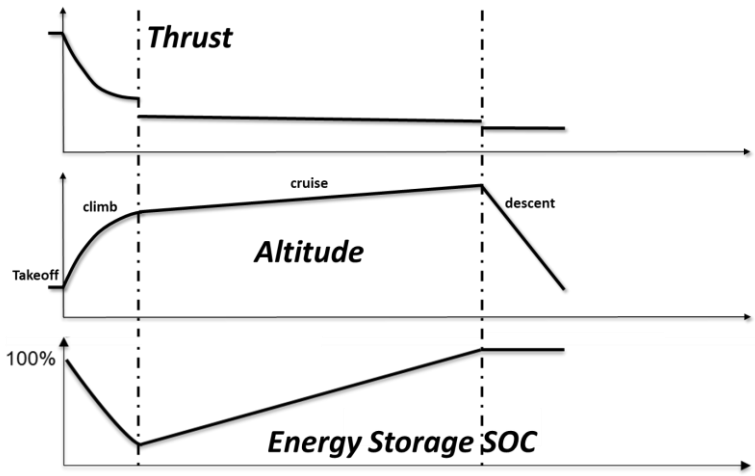

Figure 3. Exemplary aircraft mission profile (thrust, altitude, energy storage SOC). Adapted from[26]

E. PROGRAM STRUCTURE

The **REEACH** program is envisioned in two separate, sequential phases:

Phase I focuses on the development and validation of an ESPG sub-system detailed design that meets the ESPG sub-system technical targets, along with proof-of-concept development and testing of key enabling technologies and/or sub-components. The demonstration of a breadboard fuel-to-electric power conversion device is highly desirable. Phase I can be proposed for a maximum of 24 months.

[26] Chati, Y. S., & Balakrishnan, H. (2013). Aircraft engine performance study using flight data recorder archives. In 2013 Aviation Technology, Integration, and Operations Conference (p. 4414)

Subject to the availability of appropriated funds, projects that achieve technical success under Phase I and that are selected by ARPA-E to proceed to Phase II will develop a sub-scale fuel-conversion-to-electric-power developmental prototype with peak power output of at least 5kW and steady-state power output of at least 1.75 kW, which will be subsequently tested with the selected CNLF using a simulated mission profile, as shown in Table 2. This final deliverable must be designed for reliable operation at high altitude (35,000 to 40,000 ft), though testing of the unit under the conditions of pressure and temperature representative of cruise altitude is not required. The fuel conversion device must include the CNLF tank and any necessary balance of plan components. Phase II can be proposed for a maximum of 24 months.

While only Phase I will be funded at the time of award, ARPA-E requires that Applicants include proposed task descriptions and budgets for both Phase I and II, culminating in a sub-scale developmental **prototype.** If successful in Phase I, and subject to the availability of appropriated funds, a subset of Phase I awardees may proceed to Phase II, at ARPA-E's sole discretion.

F. TECHNICAL PERFORMANCE TARGETS

The following metrics (Table 1) apply to all proposals submitted to this FOA:

Table 1: Technical targets for the all-electric, end of the program ESPG systems.

ID	Description	Target
1.1	Energy storage and power generation (ESPG) system specific energy for narrow body aircraft	> 3000 Wh/kg
1.2	Powertrain system specific power for target narrow body aircraft	> 0.75 kW/kg
1.3	Cost of fuel for delivered electrical energy at 100 MWh scale	< $0.15/kWh
1.4	Initial capital cost of ESPG system including all required balance of plant components	< $1000/kw

The configuration adopted to estimate the various figures of merit is loosely based on the existing Boeing 737-800 platform. A fixed maximum takeoff weight (MTOW) of 79,016 kg with peak power of 26 MW, the fuel tank capacity of 26,022 L and a maximum payload of 20,540 kg must be used for the ESPG system parameters calculation. All applicants must use the following mission profile for modeling and testing (Fig. 3, Table 2):

Table 2. Exemplary mission profile to be used for calculations of program-level targets.

Time, hours	Power, % of peak**
1/12	100
1/6	70
1/4	50
1/3	35
5	35
1/2	30
1/12*	100
1/6*	70
1/2*	35
1/2*	30

* Emergency procedure (must meet the requirements specified in FAR 121.639[27])

** Peak delivered power of 26 MW is expected for narrow body aircraft modeling. For the chosen developmental prototype, the peak power is defined by the applicant (but not less than 5 kW).

Supplemental Explanation of Performance Targets:

1.1 For this FOA, the ESPG system includes fuel energy conversion device including balance of plant and electric generator if applicable, an optional energy storage device including thermal and battery management systems and the fuel tank with the selected CNLF. The amount of fuel is limited by the tank size. The system specific delivered energy must apply with the mission profile defined below.

$$ESPG\ Specific\ Energy\left(\frac{Wh}{kg}\right) = \frac{Total\ ESPG\ system\ delivered\ energy\ (Wh)}{Total\ Mass\ of\ ESPG\ System\ (kg)}$$

[27] https://www.govinfo.gov/app/details/CFR-2012-title14-vol3/CFR-2012-title14-vol3-sec121-639

$$= \frac{(Primary\ fuel\ energy) * (Conversion\ efficiency)}{Total\ mass\ of\ ESPG\ System}$$

where the total mass of the ESPG system includes the mass of the fuel conversion, energy storage, balance of plant, and fuel tank components, as well as the mass of fuel.

1.2 Takeoff (peak) power defined by the mission profile above must be used for this calculation. The system description for 1.1 applies here.

$$ESPG\ Specific\ Power\ \left(\frac{kW}{kg}\right) = \frac{Peak\ Electric\ Power\ Output\ of\ ESPG\ system\ (kW)}{Total\ Mass\ of\ ESPG\ System\ (kg)}$$

where the total mass of the ESPG system includes the mass of the fuel conversion, energy storage, balance of plant, and fuel tank components, as well as the mass of fuel.

1.3 Only fuel cost is considered for this metric. The delivered specific electric energy (in kWh/kg) is defined as the product of primary energy content and conversion efficiency:
$E_d = E_p * \eta$.
The total cost of delivered energy must be calculated using documented market costs or cost based on life cycle analysis for the carbon-neutral liquid fuel, and target conversion efficiency must be based on a performance estimate. Approximate costs are noted in Table 3 based upon references 27-33. However, ARPA-E will accept other cost estimates from Applicants if supported by credible references and/or independent cost models

1.4. See system description in 1.1 for items that must be included in the initial capital cost

Representative examples of several commercial (manufactured at the scale of at least one thousand metric tons per year) or soon-to-be-commercial renewable CNLFs are given in Table 3 along with liquid hydrogen conventional jet fuel for comparison. The applicant should use market, manufacturer's quotation or literature values for the cost of the proposed fuel. The same approach should be used for estimation of the equipment cost. A more detailed cost calculation with references and stated assumptions will be required in the Full Application

phase. Any proposed fuels must have a scalable path to nearly zero-carbon, and, therefore, the carbon intensity of **delivered** energy (in g CO_2/kWh) must be calculated using the fuel carbon intensity confirmed by documented life cycle analysis (LCA) data or calculated using GREET model[28] and the following formula:

$$Carbon\ Intensity\ of\ Delivered\ Electrical\ Energy\left(\frac{gCO2}{kWh}\right) = \frac{Carbon\ Intensity\ of\ Fuel\ Production\ \left(\frac{gCO2}{kWh}\right)}{Conversion\ Efficiency\ \eta}$$

Table 3: Energy density and cost of promising renewable liquid fuels for all-electric powertrain.

Fuel	Primary specific energy, kWh/kg	Primary energy density, kWh/L	Cost, $/kWh ($/unit)
Jet fuel*	12.04	9.68	0.052 (626/ton)[29]*
Bio LNG	14.0	6.3	0.071 (2.68/DGE)[30]*
Synfuel	12.0	9.68	0.076 (181/bbl)[31]
Biojet fuel	10.6	8.37	0.130 (6.6/gal)[32]
n-BuOH	9.17	7.43	0.087 (3.8/gal)[33]
Ethanol	8.33	6.57	0.062 (1.56/gal)[34]
Dimethyl ether	7.9	5.28	0.063 (443/ton)[35]
LH2	33.3	2.55	0.120 (4/kg)

* - Fossil based, included for comparison

[28] https://greet.es.anl.gov/
[29] https://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx
[30] https://afdc.energy.gov/fuels/prices.html

[31] https://www.eprg.group.cam.uk
[32] Review of Biojet Fuel Conversion Technologies, NREL report TP-5100-66291, 2016.
[33] https://onlinelibrary.wiley.com/doi/full/10.1002/bbb.1431
[34] https://markets.businessinsider.com/commodities/historical-prices/ethanol-price/usd
[35] https://www.ceicdata.com/en/china/china-petroleum--chemical-industry-association-petrochemical-price-organic-chemical-material/cn-market-price-monthly-avg-organic-chemical-material-dimethyl-ether-990-or-above

The fuel conversion efficiency target depends on selection of CNLF and ESPG system configuration and should be calculated by the applicant to meet the specific energy target. It is highly desirable that specific power of the fuel-to-electric power conversion device developmental **prototype be at least 2.5 kW/kg to be able to meet the overall ESPG system specific power target. A startup time of less than 30 minutes is also highly desirable.**

A submission to this FOA must present a well-justified, realistic case that the proposed technologies will meet or exceed the performance and cost targets for the entire ESPG sub-system. While a conceptual layout of the ESPG system with approximate calculations is acceptable for the concept paper (CP) phase, a more detailed system design and cost calculation with references and stated assumptions will be required in the Full Application phase.

The research objectives for Phase I projects are: (1) a detailed design for the ESPG sub-system showing a path to achieving the target specific energy and specific power and the cost metrics, and (2) the de-risking of the fuel conversion component(s) through development and testing. A submission **must** include the efficiency and power density targets for the proposed conversion device(s) within the ESPG, and those targets will define the milestones for the Phase I work. The demonstration of a sub-scale fuel conversion device is highly encouraged.

If successful in Phase I, and subject to the availability of appropriated funds, a subset of Phase I awardees may proceed to Phase II, at ARPA-E's sole discretion. The final research objective for Phase II projects is envisioned as a fully functional bench-scale developmental prototype of the fuel conversion to electric power device, tested under conditions imitating the exemplary flight, per the mission profile presented in Table 2. The developmental prototype would be designed to operate at International Standard Atmosphere (ISA) conditions in temperature and pressure at altitudes ranging from 35,000 to 40,000 ft., though testing at the temperatures and pressures experienced at cruise is not required. The applicant would measure the specific power and fuel conversion efficiency of the developed fuel conversion device and calculate the delivered specific power and energy for both the Phase II project developmental prototype and a narrow body aircraft. The minimum developmental prototype size chosen by ARPA-E would allow the results from the performance tests, as defined below, to be readily used to predict the performance, life-time, and cost of the proposed system for a narrow-body aircraft. The final Phase II developmental prototype would demonstrate power of at least **5 kW (peak)/1.75 kW (steady)**. The developmental prototype testing should be done with CNLFs either purchased or prepared by the project team. At least 10 duty cycles, and not less than 600 hours of operation, would be demonstrated without visible reduction in the system power and energy efficiency. **Please note that all submissions to this FOA must include a work plan and budget for BOTH Phase I and Phase II.**

Lastly, all projects must deliver a detailed techno-economic analysis for the ESPG system based on a comprehensive performance model. The measured fuel conversion device specific power and energy efficiency should fit the predicted values from the model for the selected developmental prototype size, CNLF, and system configuration.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $20 million available for new awards, to be shared between FOAs DE-FOA-0002240 and DE-FOA-0002241, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 5-10 awards under FOAs DE-FOA-0002240 and DE-FOA-0002241. ARPA-E may, at its discretion, issue one, multiple, or no awards.

Individual awards may vary between $500,000 and $10 million.

The period of performance for funding agreements may not exceed 48 months for Phase 1 and Phase 2 combined. ARPA-E expects the start date for funding agreements to be November 2020, or as negotiated.

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

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

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

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

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

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

B. RENEWAL AWARDS

At ARPA-E's sole discretion, awards resulting from this FOA may be renewed by adding one or more budget periods, extending the period of performance of the initial award, or issuing new award. Renewal funding is contingent on: (1) availability of funds appropriated by Congress for the purpose of this program; (2) substantial progress towards meeting the objectives of the approved application; (3) submittal of required reports; (4) compliance with the terms and conditions of the award; (5) ARPA-E approval of a renewal application; and (6) other factors identified by the Agency at the time it solicits a renewal application.

C. ARPA-E FUNDING AGREEMENTS

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

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[36] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.D below.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[37]

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

ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement, which is available at http://arpa-e.energy.gov/arpa-e-site-page/award-guidance.

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

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

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

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

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

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

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

3. OTHER TRANSACTIONS AUTHORITY

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

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

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

D. STATEMENT OF SUBSTANTIAL INVOLVEMENT

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

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- ARPA-E may, at its sole discretion, modify or terminate projects that fail to achieve predetermined Go/No Go decision points or technical milestones and deliverables.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.338 and 200.339.
- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

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

1. INDIVIDUALS

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,38 as the lead for a Project Team,39 or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. DOMESTIC ENTITIES

For-profit entities, educational institutions, and nonprofits[40] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

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

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

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

3. FOREIGN ENTITIES

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or

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

[39] 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.

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

otherwise formed or to be formed) under the laws of a State or territory of the United States to receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. All work under the ARPA-E award must be performed in the United States. The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application and can be found at https://arpa-e-foa.energy.gov/. Refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. CONSORTIUM ENTITIES

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

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

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

B. COST SHARING[41]

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

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

1. BASE COST SHARE REQUIREMENT

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.C.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime Recipient must provide at least 20% of the Total Project Cost[42] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[43]

2. INCREASED COST SHARE REQUIREMENT

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

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

3. REDUCED COST SHARE REQUIREMENT

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

- A domestic educational institution or domestic nonprofit applying as a Standalone Applicant is not required to provide cost share.
- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs/DOE Labs/Federal agencies and instrumentalities (other than DOE) are not required to provide cost share.
- Small businesses – or consortia of small businesses – may provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[44] If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the costs incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.

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[42] The Total Project Cost is the sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs and FFRDCs.
[43] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.
[44] Small businesses are generally defined as 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). Applicants that are small businesses will be required to certify in the Business Assurances & Disclosures Form that their organization meets the SBA's definition of a small business under at least one NAICS code.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.[45]
- Project Teams where domestic educational institutions, domestic nonprofits, small businesses, and/or FFRDCs perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.
- Projects that do not meet any of the above criteria are subject to the base cost share requirements described in Sections III.B.1 and III.B.2 of the FOA.

4. LEGAL RESPONSIBILITY

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

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

5. COST SHARE ALLOCATION

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

6. COST SHARE TYPES AND ALLOWABILITY

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

[45] See the information provided in previous footnote.

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

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

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

In addition, Project Teams may not use independent research and development (IR&D) funds[46] to meet their cost share obligations under Cooperative Agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under "other transaction" agreements.

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

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

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

7. COST SHARE CONTRIBUTIONS BY FFRDCS AND GOGOS

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

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

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

8. COST SHARE VERIFICATION

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

C. OTHER

1. COMPLIANT CRITERIA

Concept Papers are deemed compliant if:

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

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

Full Applications are deemed compliant if:

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

Full Applications found to be noncompliant may not be merit reviewed or considered for award. ARPA-E may not review or consider noncompliant Full Applications, including Full

Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Replies to Reviewer Comments are deemed compliant if:

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

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

2. RESPONSIVENESS CRITERIA

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

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

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

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- Fuels not produced on commercial scale (< 1000 metric tons per year)
- Fuels that do not meet the carbon neutral liquid fuel (CNLF) criteria established in section 1.C.
- Compressed gaseous fuels (H_2, CH_4)
- Liquid hydrogen fuel
- Fuels in the form of a slurry
- Development of novel energy storage devices and/ or the use of energy storage devices that are not currently commercially available (i.e. Technology Readiness Level ≥ 7)
- Metal-air batteries
- Improvements in hydrogen/air fuel cells
- System architectures that are battery-only, and/or parallel hybrids in which any fraction of fuel is converted directly into shaft power that is supplied directly to the propulsor

4. LIMITATION ON NUMBER OF SUBMISSIONS

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

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E eXCHANGE

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

2. CONCEPT PAPERS

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

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

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

3. FULL APPLICATIONS

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

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

4. REPLY TO REVIEWER COMMENTS

Once ARPA-E has completed its review of Full Applications, reviewer comments on compliant and responsive Full Applications are made available to Applicants via ARPA-E eXCHANGE. Applicants may submit an optional Reply to Reviewer Comments, which must be submitted by the deadline stated in the FOA. Section IV.E of the FOA provides instructions on submitting a Reply to Reviewer Comments.

ARPA-E performs a preliminary review of Replies to determine whether they are compliant, as described in Section III.C.1 of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

5. PRE-SELECTION CLARIFICATIONS AND "DOWN-SELECT" PROCESS

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

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

6. SELECTION FOR AWARD NEGOTIATIONS

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

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

B. APPLICATION FORMS

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

C. CONTENT AND FORM OF CONCEPT PAPERS

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

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

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

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

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

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

1. CONCEPT PAPER

a. CONCEPT SUMMARY

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

b. INNOVATION AND IMPACT

- Clearly identify the problem to be solved with the proposed technology concept.
- 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.F of the FOA.

c. PROPOSED WORK

- Describe the deliverable(s) for Phase I and 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 for Phases I and II; total project cost including cost sharing.

d. TEAM ORGANIZATION AND CAPABILITIES

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

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

F. INTERGOVERNMENTAL REVIEW

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

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

H. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

To apply to this FOA, Applicants must register with ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). Concept Papers, Full Applications, and Replies to Reviewer Comments must be submitted through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx). ARPA-E will not review or consider applications submitted through other means (e.g., fax, hand delivery, email, postal mail). For detailed guidance on using ARPA-E eXCHANGE, please refer to the "ARPA-E eXCHANGE Applicant Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

Upon creating an application submission in ARPA-E eXCHANGE, Applicants will be assigned a Control Number. If the Applicant creates more than one application submission, a different Control Number will be assigned for each application.

Once logged in to ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx), Applicants may access their submissions by clicking the "My Submissions" link in the navigation on the left side of the page. Every application that the Applicant has submitted to ARPA-E and the corresponding Control Number is displayed on that page. If the Applicant submits more than one application to a particular FOA, a different Control Number is shown for each application.

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Concept Paper, or Full Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

Applicants should not wait until the last minute to begin the submission process. During the final hours before the submission deadline, Applicants may experience server/connection congestion that prevents them from completing the necessary steps in ARPA-E eXCHANGE to submit their applications. **ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.**

ARPA-E may not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications may be deemed noncompliant (see Section III.C.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

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

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

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

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

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

1. CRITERIA FOR CONCEPT PAPERS

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

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

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

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

Submissions will not be evaluated against each other since they are not submitted in accordance with a common work statement. The above criteria will be weighted as follows:

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

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

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

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

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

III. **Synergy of Public and Private Efforts**.
   a. Avoids duplication and overlap with other publicly or privately funded projects;

b. Promotes increased coordination with nongovernmental entities for demonstration of technologies and research applications to facilitate technology transfer; or
c. Increases unique research collaborations.

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

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

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

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 MARCH 2020]

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

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

2. CONCEPT PAPER NOTIFICATIONS

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

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

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

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2020]

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

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

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

- ARPA-E will post responses on a weekly basis to any questions that are received that have not already been addressed at the link above. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- ARPA-E will cease to accept questions approximately 10 business days in advance of each submission deadline. Responses to questions received before the cutoff will be posted approximately one business day in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- Responses are published in a document specific to this FOA under "CURRENT FUNDING OPPORTUNITIES – FAQS" on ARPA-E's website (http://arpa-e.energy.gov/faq).

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

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

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

B. DEBRIEFINGS

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

VIII. OTHER INFORMATION

A. TITLE TO SUBJECT INVENTIONS

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

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

B. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

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

1. GOVERNMENT USE LICENSE

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

2. MARCH-IN RIGHTS

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

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

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

C. RIGHTS IN TECHNICAL DATA

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

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to five years in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be

protected from public disclosure for a reasonable time in order to allow for filing a patent application.

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

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

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

E. FOAS AND FOA MODIFICATIONS

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

F. OBLIGATION OF PUBLIC FUNDS

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

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

G. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

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

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

H. RETENTION OF SUBMISSIONS

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

I. MARKING OF CONFIDENTIAL INFORMATION

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

Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions containing confidential, proprietary, or privileged information must be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S.

Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

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

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

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

J. COMPLIANCE AUDIT REQUIREMENT

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

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

IX. GLOSSARY

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

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

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

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

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

DOE: U.S. Department of Energy.

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

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

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

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

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

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

PI: Principal Investigator.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing any of the research and development work under an ARPA-E funding agreement, whether or not costs of performing the research and development work are being reimbursed under any agreement.

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

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

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

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

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