FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

INTEGRATION AND OPTIMIZATION OF NOVEL ION CONDUCTING SOLIDS (IONICS)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001478
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	Friday, February 26, 2016
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, Monday, March 21, 2016
Submission Deadline for Concept Papers:	5 PM ET, Monday, March 28, 2016
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	5 PM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	TBD
Total Amount to Be Awarded	Approximately $30 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $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.G.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.

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).

- Applications found to be noncompliant or nonresponsive will not be merit reviewed or considered for award. For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 and III.C.2 of the FOA.

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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: o Concept Summary o Innovation and Impact o Proposed Work o Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, Monday, March 28, 2016
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]	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 funds research on and the development of high-potential, high-impact energy technologies that are too early for private-sector investment. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector 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 "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met" and defines "development" as the "systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."[i] 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 the improvement of existing technology platforms along defined roadmaps may be appropriate for support through the DOE offices such as: 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://nuclear.energy.gov/), and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. PROGRAM OVERVIEW

1. SUMMARY

The Integration and Optimization of Novel Ion Conducting Solids (***IONICS)*** program seeks to enable transformational electrochemical cells by creating *components* built with solid ion conductors that have a wide range of desirable properties including low ionic area-specific resistance (ASR), high chemical and electrochemical stability, high selectivity, good mechanical properties, *etc.* through innovative approaches to overcome tradeoffs among coupled properties. It also seeks to develop and apply methods for processing of solid ion conductors and their integration into electrochemical devices. Components built with solid ion conductors, especially separators, have the potential to serve as enabling platforms, as demonstrated by the wide application of Yttria-Stabilized Zirconia (YSZ) ceramics and perfluorosulfonic acid (PFSA) polymers (*e.g.*, Nafion®). The IONICS Program Categories focus on specific electrochemical cells with high impact for the energy sector whose commercial potential will be significantly enhanced with improved components built from solid ion conductors. The Program Categories include:

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[i] OMB Circular A-11 (http://www.whitehouse.gov/sites/default/files/omb/assets/a11_current_year/a11_2014.pdf), Section 84, p. 8.

1. Lithium (Li) ion conductors that enable the cycling of Li metal without shorting
2. Selective and low-cost separators for batteries with liquid reactants (*e.g.*, flow batteries)
3. Alkaline conductors with high chemical stability and conductivity
4. Other approaches that could achieve the IONICS Program Objectives.

A key requirement of the IONICS program is the creation of manufacturable components with dimensions comparable to that used in a practical device, in order to ensure that technical challenges associated with large-area processing are addressed. The required area depends on the application, but is in the range of tens to one hundred square centimeters. A second key requirement is that the cost of materials and processing is sufficiently low to allow for the broad adoption necessary for significant energy impacts. Creating low-cost components built with solid ion conductors will require pushing the boundaries of processing methods, especially for inorganic materials. ARPA-E encourages the formation of teams that include the competence to address large-area fabrication and low-cost processing.

ARPA-E expects that common technical themes will be present across the Program Categories. These themes may include, but are not limited to, polymer/inorganic composites, chemistries that realize high stability, processing methods for large-area and thin inorganic solid ion conductors, polymer and polymer composite morphology engineering, self-forming mechanisms, and others. ARPA-E expects that the realization of the aggressive targets of the IONICS program will require input from communities such as solid state ionics, polymers, ceramics, material mechanics (especially at interfaces), functional glasses, organic and inorganic chemistry, computational approaches across a range of length scales, and process engineering and scale up.

2. PROGRAM CONTEXT AND BACKGROUND

The electrochemical cell couples chemical reactions with electron flow external to the cell. It therefore provides a direct path to convert the chemical energy stored in materials such as natural gas, hydrogen, battery active materials, *etc.* into electricity. It also provides a direct path to store carbon-free intermittent renewable energy in chemical bonds, including as embodied energy in industrial products (e.g., Al) and in battery active materials that allow a return to electricity at a later time. These foundational capabilities of electrochemical cells are accompanied by two additional benefits: (1) high round-trip energy efficiency that in many cases has been realized practically (e.g., Li-ion cells can provide 90% round-trip DC-DC efficiency at relevant rates) and (2) scalability across a wide range of power levels (*i.e.*, <1 kW to >1 MW), making them suitable for both small, distributed and large, centralized installations.

Electrochemical devices have received research and development funding for many classes of batteries, transportation and stationary fuel cells, water electrolyzers, industrial electrochemical reactions, and other devices and processes. Several previous ARPA-E programs have pursued advances in electrochemical devices and processes, including Batteries for

Electrical Energy Storage in Transportation (BEEST), Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS), Robust Affordable Next Generation Energy Storage Systems (RANGE), Modern Electro/Thermochemical Advances in Light-metal Systems (METALS), Reliable Electricity Based on Electrochemical Systems (REBELS), and many projects within the OPEN portfolios.[ii] The aforementioned ARPA-E programs have principally focused on advances at the *device* or *process* level. ARPA-E funded work complements significant research and development efforts on electrochemical devices within other parts of the Department of Energy, including Basic Energy Sciences, Energy Efficiency and Renewable Energy, and the Office of Fossil Energy. Based on the observation of key challenges encountered in previous ARPA-E programs and in other research and development efforts, ARPA-E believes tremendous opportunities exist in developing a new generation of enabling components built with solid ion conductors.

There are many classes of ion conductors, including aqueous and nonaqueous salt solutions, solid ceramics, polymers and polymer gels, molten salts, and others. Electrochemical cells that operate near ambient temperatures typically use either a liquid electrolyte (*e.g.*, aqueous H_2SO_4 in the case of lead-acid batteries, or $LiPF_6$ in organocarbonates in the case of Li-ion batteries) or a polymer containing small molecules (*e.g.*, hydrated PFSA in the case of fuel cells and electrolyzers). ***While liquid electrolytes have benefits including high conductivity and excellent wetting of electrode surfaces, this program is specifically focused on electrolyte attributes unattainable with liquids, including resistance to deformation (i.e., a "solid" form), wide thermal stability, high selectivity for desired ions and neutral molecules, and other attributes detailed through this FOA.***

To provide context and background for the challenges the IONICS program will address, the remainder of this section will describe some of the tradeoffs and challenges facing solid ion conductors using specific examples for inorganic and polymeric materials. A simple way to visualize the properties required of a component built with a solid ion conductor is a radar plot with property values along the axes. Figure 1 shows such a radar plot for three exemplary Li^+-conducting inorganic materials, with the following axis labels:

- The ionic area-specific resistance (ASR) helps determine the power capability of an electrochemical device; it includes the ionic conductivity (an intrinsic property) and the thickness (an extrinsic property).
- Selectivity is the ability of a material to transport ions and neutral molecules at different rates, with a goal of high selectivity for a desired species, typically a single ion.
- (Electro)chemical stability refers to both electrochemical stability and chemical stability, the former generally referring to stability as a function of an applied potential. In the ideal case all adjacent phases in a device are thermodynamically stable against reaction; in practice, stability is frequently realized with the help of slow kinetics and the formation of passivating layers.

[ii] http://arpa-e.energy.gov/?q=arpa-e-site-page/view-programs

- The electronic ASR reflects resistance to electronic current, and includes the electronic conductivity and thickness. For a separator, the electronic ASR is ideally infinite, while for mixed conductors within electrodes a low ionic and electronic ASR is desirable.
- Thermal properties refers to the dependence of key properties like ionic and electronic ASR, (electro)chemical stability, mechanical properties, *etc.* on temperature. Ideally, a component is able to conduct current, resist degradation, and remain strong and tough across a wide range of temperatures.
- Mechanical properties are critical both during both fabrication (*e.g.*, for roll-to-roll processing the tensile strength and ability to wind around a mandrel are relevant) and during operation (*e.g.*, a high shear modulus is theorized to prevent shorting during cycling of Li metal).
- Processing refers to the method used to create components built with solid ion conductors, and cost includes both the processing cost and the bill of materials.
- Device integration refers to the ability to integrate components built with solid ion conductors with other device components, as well as the implication of the components built with solid ion conductors on other device components (*e.g.*, existing PFSA membranes require the use of costly Pt for the oxygen electrode catalyst).

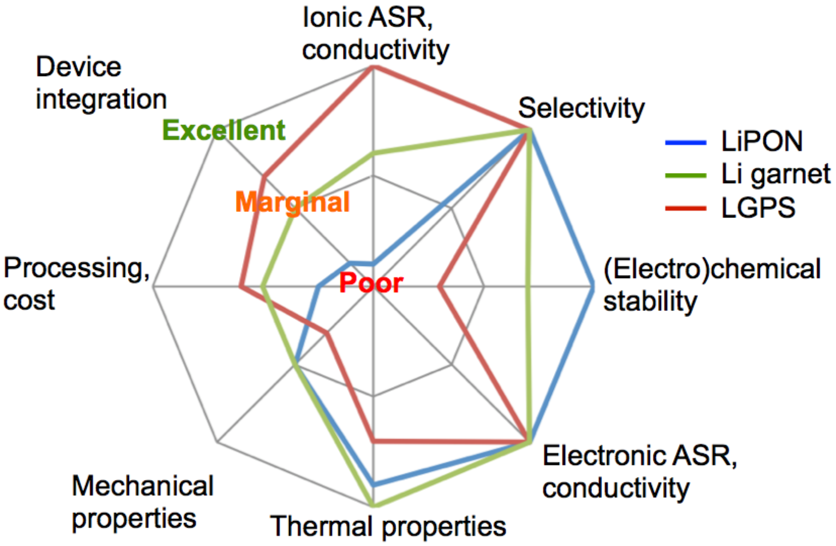

Figure 1. Radar diagram showing the qualitative attributes of three inorganic Li-conducting materials. LiPON = $Li_xPO_yN_z$, Li garnet refers to a crystal structure family (example composition: $Li_7La_3Zr_2O_{12}$), LGPS = $Li_{10}GeP_2S_{12}$.

One of the materials in Figure 1, LiPON ($Li_xPO_yN_z$ where $x = 2y+3z-5$) is an amorphous material that has a low conductivity for Li^+ (~1E-6 S/cm at 25°C, which for a typical thickness of 1 μm results in an ionic ASR of 100 Ohm-cm^2) but excellent electrochemical and (electro)chemical stability. It is deployed commercially in thin-film batteries composed of Li metal as an anode and $LiCoO_2$ as a cathode. This type of cell has definitively cycled Li metal thousands of times at 25°C while blocking Li shorting. Current densities across the interfaces between the electrodes can exceed 1 mA/cm^2 while achieving thousands of cycles.[1] Full-cell impedance[iii] is <200 Ohm-cm^2 even with the use of planar rather than porous electrodes. These results clearly show that solid-solid interfaces can be built with low impedance and sustain current densities of 1 mA/cm^2 over thousands of cycles without significant degradation for both a Li metal/LiPON interface and a LiPON/LiCoO$_2$ interface. Unfortunately, the low ionic conductivity of LiPON means that it is deployed exclusively as a thin film.[2, 3] In this cell the cathode is also vapor deposited and is also limited to only a few microns in thickness due to Li and electron transport limitations. This results in batteries with low areal capacity (~0.2 mAh/cm^2) and low energy density, and the high fraction of inactive to active material contributes to a high cost. In short, LiPON exhibits tremendous performance in some respects (in particular, it enables the use of Li metal in cells with low areal capacity), while preventing its use in devices with relevance for large-scale energy applications.

As a second example, the class of Li garnet materials (*e.g.*, $Li_7La_3Zr_2O_{12}$) have a significantly higher conductivity than LiPON (up to ~1E-3 S/cm at 25°C, which at a thickness of 10 µm results in a favorable ionic ASR of as little as 1 Ohm-cm^2), and appears to be chemically stable with Li metal.[4-6] A thickness of 10 µm can be achieved with the scalable tape-casting process; tape-casting of thin ceramic layers has been shown to offer costs of <10 \$/m^2 at high production volumes, which is the approximate cost target for a solid separator that enables the use of Li metal.[7, 8] However, a significant number of challenges remain for Li garnet materials. (1) Observations of Li penetration through its polycrystalline structure means that dendrite-free cycling is not established across the range of desired current densities and areal capacities at 25°C.[9] (2) Air exposure results in surface chemistry that can significantly increase interfacial impedance, which may have a cost implication in terms of handling.[10] (3) They are essentially refractory ceramics, which requires sintering at ~1,000°C where Li may become volatile, making precise compositional control difficult.[11]

The third example shown in Figure 1 is LGPS ($Li_{10}GeP_2S_{12}$). LGPS is a crystalline material that represents a breakthrough in terms of the Li$^+$ conductivity that can be achieved with a solid material at 25°C.[12] The conductivity of LGPS at 25°C (~1E-2 S/cm, which for a thickness of 10 µm gives an ionic ASR of just 0.1 Ohm-cm^2) exceeds that of the typical liquid electrolytes used in Li-ion batteries, and because it is a single ion conductor it will eliminate concentration polarization. Unfortunately, just as sulfides typically have higher Li$^+$ conductivity than oxides due to the more polarizable nature of sulfur than oxygen, the sulfides typically have significantly lower chemical stability, including against Li metal and common cathode materials.[4] The reduced stability also has implications for processing, as the sulfides generally have poor air and moisture stability. On the other hand, the sulfides do not require high-temperature sintering like the oxides, opening the possibility of lowering processing costs with the use of low-temperature consolidation. The shear modulus of many sulfide materials is on the order of 10 GPa, which according to theoretical predictions should be sufficient to block Li

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[iii] Full-cell impedance is the resistance to current flow between two electrodes and therefore includes both ionic and electronic resistances.

metal shorting, but as yet there is no definitive evidence that the prevention of shorting is possible.[13, 14]

These three examples of inorganic solid Li^+ conductors highlight the coupled nature of key properties, including (electro)chemical stability, conductivity, processing, mechanical properties, and implications for other device components. These tradeoffs and linkages arise from fundamental principles of chemistry and physics, and the IONICS program seeks innovative approaches that can overcome such tradeoffs *and* be translated to practice in a device context.

A second main class of solid ion conductors are polymers. One key distinction among polymer electrolytes is that some are "dry," which means they are composed only of a polymer and a salt (*e.g.*, LiTFSI in PEO), while others are "wet" and contain small molecules (*e.g.*, H_2O) that are required for the ionic conduction mechanism.[15] Both "dry" and "wet" ion-conducting polymers are within the scope of the IONICS program. Two examples of hydrated polymers, rated for their performance in a fuel cell device, are shown in Figure 2.

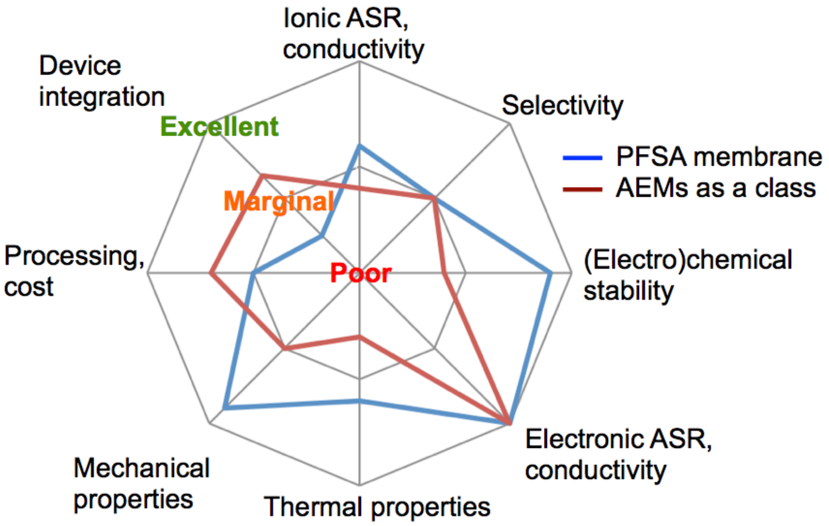

Figure 2: Radar diagram showing the qualitative attributes of two hydrated polymer ion conductors for fuel cell applications, a PFSA membrane and alkaline-exchange membranes (AEMs) taken as a class.

The first polymer example is a PFSA membrane (the word "membrane" is often used to refer to polymer and ceramic separators), discovered by Walther Grot of DuPont in the late 1960s and elaborated on by many in the years since. PFSA membranes are commercially deployed for proton-exchange membrane (PEM) fuel cells, chlor-akali production, electrolyzers, and flow batteries due to their high ionic conductivity, excellent reductive and oxidative stability and good mechanical properties. While PFSA membranes have enabled the commercial deployment of numerous electrochemical devices, some of its properties have hindered the degree of commercial uptake. In particular, the acidic nature of PFSA means that platinum group metals (PGM) are the only catalysts that can provide stable and commercially relevant rates at the oxygen and fuel electrodes at <100°C, which introduces a significant cost burden to fuel cells and electrolyzers. Efforts are underway to reduce or even eliminate the need for PGMs, but have not yet reached desired loadings while meeting other requirements such as durability.[16] Another challenge introduced by PFSA membranes is that significant hydration is required to achieve high conductivity, but is difficult to retain at high temperatures (especially above 80°C) and in direct contact with dry air or other gases. Current production of PFSA membranes for fuel cell vehicles (corresponding to sales of a few thousand vehicles per year) results in a cost of several hundred dollars per square meter.[17] In summary, PFSA membranes are the exemplar polymer solid ion conductor, with excellent chemical stability and conductivity (when hydrated), and can be easily handled and integrated in a device. However, those attributes come with a high cost (at low production volumes) and impose significant requirements for the other materials in the device (*e.g.*, the use of PGM catalysts).

The second example shown in Figure 2 is alkaline-exchange membranes (AEMs) as a class (*i.e.*, the performance values shown are typical of leading AEM membranes). A wide range of chemistries has been explored; an example composition includes a polysulfone backbone with a quaternary ammonium head group.[18-20] The main benefit of an alkaline- rather than proton-exchange membrane is that alkaline creates a path for the use of non-PGM (and hence less expensive) catalysts and uncoated, inexpensive stainless steel bipolar plates. However, AEMs generally have much lower chemical stability and moderately lower conductivity than PFSA membranes such as Nafion®. The chemical stability is lower than PFSA membranes because the high chemical stability imparted by the use of strongly electron-withdrawing fluorine in acid has not been matched by structures resistant to attack by strongly nucleophilic hydroxide anion, especially in partially hydrated states when the hydroxide anion may not be fully solvated. The need to achieve high chemical stability in a material that includes cations and is subjected to strong base is a challenge for AEMs that needs to be overcome. At the same time, an AEM also needs to resist other modes of degradation, such as that caused by radicals generated by electrode reactions. AEMs often have more swelling than PFSA membranes because the high ion exchange capacity needed to boost ionic conductivity also results in more water uptake. However, recent results have shown that AEMs, on an ion-exchange-capacity normalized basis, can reach the same conductivity as PFSA membranes under certain conditions.[21] In short, AEMs offer a path to lower cost currently inaccessible for PFSA membranes, but have performance that needs significant improvement.

From the point of view of processing and handling, polymers as a class of materials are nearly ideal because of their mechanical flexibility and ease of manufacture. Unfortunately, the engineering of polymers across all the length scales necessary to achieve low ionic resistance in a component is generally more difficult than with inorganic materials, as the >100x higher Li^+ conductivity at 25°C of the best inorganic materials compared to dry polymers shows.[12] While the inclusion of small molecules that facilitate conduction in polymers can dramatically improve conductivity, managing the balance of those small molecules imposes significant burdens on the overall device. Inorganic ion-conductors as a class of materials are generally more difficult to process (often requiring high temperatures where key components – such as Li

– may be volatilized) and generally have mechanical properties far inferior to polymers, especially in terms of the critical property of fracture toughness. Unlike polymers (consider the ubiquitous plastic bag!), there are no widely available, free-standing, sub-50 micron inorganic layers, let alone any that can be produced for <1 $/m^2.

The examples discussed in this section were chosen to illustrate the challenges associated with the full and simultaneous realization of eight key properties required to significantly advance solid ion conductor use in electrochemical devices. There are numerous classes of materials under development as solid ion conductors not mentioned above, including metal-organic frameworks,[22, 23] covalent organic frameworks,[24] 2D materials,[25] plastic crystals,[26] and others. The IONICS program is open to any and all solid materials classes that can achieve the pertinent technical targets provided in Section I.E of the FOA.

C. PROGRAM OBJECTIVES

The overall objective of the IONICS program is to enable widespread deployment of transformational electrochemical cells with energy applications through the development of separators and porous electrodes built with solid ion conductors. To meet this objective, the IONICS program seeks to overcome difficult technical challenges associated with simultaneously achieving a wide set of property attributes, cost-effective and scalable processing of solid ion conductors, and the integration of component with solid ion conductors into devices. Building on the discussion of Figure 1 and Figure 2, Figure 3 shows a radar plot of numerous attributes of interest and the IONICS program goal of transforming components and materials from a state of limited attributes (shown in red) to a state of complete attributes (shown in green).

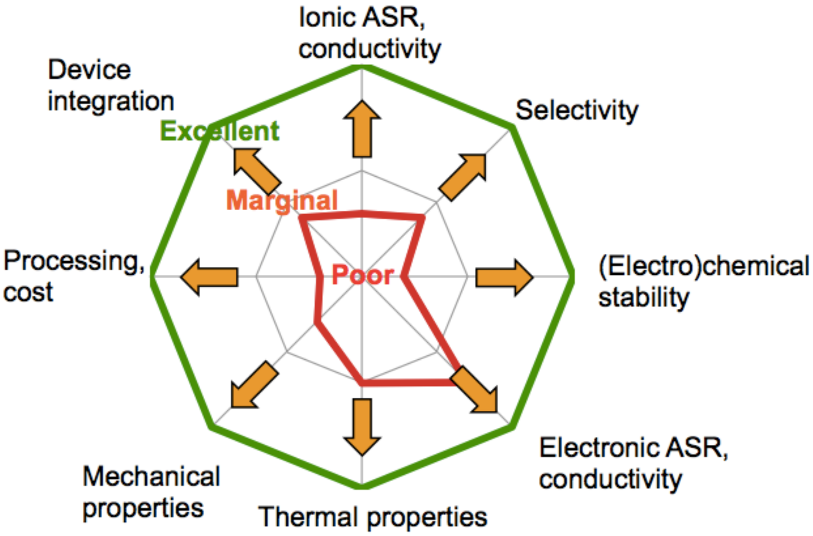

Figure 3: Radar diagram showing the overall objective of the IONICS program: replace today's components based on solid ion conductors that have limited and uneven attributes (red) with new components optimized along all the required axes (green).

As discussed in Section I.B of the FOA, the motivation behind Categories 1, 2 and 3 of the IONICS program is to develop components that can significantly accelerate the commercial potential of specific types of electrochemical cells. The motivation behind Category 4 is to allow for the development of components that will accelerate the commercial potential of electrochemical cells not specified in Categories 1, 2, or 3 and further the Program Objectives. An additional goal of the IONICS program is to establish a research paradigm in which subject matter experts from numerous backgrounds and disciplines are united by the common theme of overcoming the difficult technical challenges associated with ion-conducting solid material properties, the processing of ion-conducting solids, and the integration of ion-conducting solids into devices. Research on solid ion conductors is often conducted with a focus on only one or two properties, with ionic conductivity being the most prominent. Fully and simultaneously achieving desired property values in *every one* of the desired property values is a tremendous challenge, and in practice the device context and other constraints result in prioritization. The IONICS program seeks to confront this challenge directly, with the expectation that pursuing all desired properties simultaneously will yield new approaches that enhance performance and accelerate commercialization. While the projects in the IONICS program will work on a diverse set of materials and devices, ARPA-E anticipates productive technical exchanges among program participants along common technical themes that may include, but are not limited to, polymer/inorganic composites, chemistries that realize high stability, processing methods for large-area and thin inorganic solid ion conductors, polymer and polymer composite morphology engineering, self-forming mechanisms, and others. Specific research and development communities that ARPA-E anticipates could contribute to the IONICS program include solid state ionics, polymers, ceramics, material mechanics (especially at interfaces), functional glasses, organic and inorganic chemistry, computational approaches across a range of length scales (including approaches consistent with the Materials Genome Initiative), and process engineering and scale up.

An additional program-level objective is the creation of components with dimensions comparable to that used in a practical device. Creating components with an area matching that of relevant devices will ensure that IONICS projects will address technical challenges in moving beyond coin or button cells (with areas <10 cm^2) to areas of tens to one hundred square centimeters.

D. TECHNICAL CATEGORIES OF INTEREST

The IONICS program contains four Categories. These Categories were chosen based on an analysis of potential impact on the overall US energy sector, variety and significance of technical opportunities, and overall funding context. Each submission to the IONICS FOA must address only one of the four Technical Categories of Interest.

Category 1: Li ion conductors that enable the cycling of Li metal without shorting

Motivation and Impact

Li-ion batteries are currently in a phase of massive commercial adoption and manufacturing scale-up that will lower costs and catalyze the growth of electrical energy storage in both vehicle and stationary applications. However, the Li-ion technology being scaled up today has a trifecta of performance limitations that incremental progress cannot address: (1) the energy density is limited by the amount of charge that can be practically stored *via* the intercalation mechanism, (2) thermally-activated degradation modes limit the upper operating temperature to ~ 50 °C and require cooling systems, and (3) the use of organic carbonates in the electrolyte results in cells with intrinsic flammability concerns. These performance limitations have a high potential to be addressed by replacing the negative electrode with Li metal, and the liquid electrolytes in the separator and the porous positive electrode with solid ion conductors. Overcoming this trifecta of performance limitations opens a path to cell costs below 100 $/kWh and pack costs below 175 $/kWh, which would surpass the approximate limits of present Li-ion technology at large scale.[27, 28] Cost reductions at the cell level will come primarily through increasing energy density and thereby reducing the bill of materials per unit of energy stored, while improvements in thermal stability and safety will have significant benefits at the system level by reducing packaging and controls and creating design flexibility.

In the US today, about 4% of new light-duty vehicles contain a partially or fully electrified powertrain. Further improvements to batteries are widely recognized as a key barrier to wider adoption. A 10% increase in electrified powertrains will reduce US oil consumption by 3%, total US energy use by 1%, and total US CO_2 emissions by 1% (as well as reduce emissions of NO_x and other combustion products).[iv] In addition to impacts on vehicles, cell technology that is energy dense, thermally stable, and non-flammable will be of interest for grid storage, particularly in dense urban environments.

Technical opportunities

The minimum requirement for Category 1 is to definitively show the cycling of Li metal at conditions defined in Section I.D of the FOA. Cycling of Li metal without shorting at 25°C has been a goal in the battery community for decades, however it has been successfully proven only in thin-film cells based on LiPON solid electrolyte with low areal capacity, which creates serious limitations as discussed in the context of Figure 1. While an understanding of the fundamental ingredients required to cycle Li metal continues to mature, an important

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[iv] Electric drivetrains includes hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and full battery electric vehicles (BEV). Calculation assumes electric drivetrain vehicles will be sold in a 2:1:1 ratio (HEV:PHEV:BEV).[29] Reductions are based on a "well-to-wheels" analysis which evaluates feedstock production, processing, fuel production, fuel delivery, as well as vehicle energy use.[30]

theoretical paradigm (with some empirical support) is that a separator material with a shear modulus approximately twice that of Li metal itself is sufficient to block dendrites.[14, 31] LiPON far exceeds this threshold, although it should be noted that some solid electrolytes (*e.g.*, the Garnet material discussed in the context of Figure 1) do allow Li penetration through grain boundaries even though they have a sufficient shear modulus.[9, 13, 32] Recent years have seen tremendous developments in the area of Li-conducting solid phases; especially noteworthy is the 2011 report of $Li_{10}GeP_2S_{12}$ (LGPS) that has an ionic conductivity greater than typical commercial Li-ion electrolytes.[12] Sn and Si versions of that material have also been prepared that have roughly equivalent conductivity to the Ge version.[33, 34] There have also been significant advances in Li-conducting ceramic oxides, glasses, and polymers. Although no single material today has all of the desired properties shown in Figure 1, each desired property can be found among the entire set of Li^+-conducting materials. This naturally leads to the idea that the desired set of properties may be achieved with composites of existing materials. Engineering the interfaces among the various phases to ensure that low ionic resistance, mechanical properties sufficient to block Li metal shorting, thermal stability, *etc.*, are realized *at the component level* is a critical technical path for the composite approach. Recent results by IBM research for a Li-conducting ceramic in a polymer matrix is an example of this approach.[35] While the minimum requirement of Category 1 is to cycle Li metal according to the metrics defined in Section I.E of the FOA, proposals may also include the construction of porous electrodes built from solid Li^+-conducting materials. The emphasis of work on porous electrodes should be on approaches that can successfully integrate solid Li^+ conductors with solid active materials and other components to impart thermal stability and safety characteristics unattainable with Li-ion technology.

Examples of technical approaches of interest for Category 1 include, but are not limited to:

- Composites of existing Li^+ conducting materials, especially polymer/ceramic composites with a high potential to achieve both a full set of desired properties and an ability to use existing roll-to-roll processing lines.[35]
- Composites of existing Li^+ conducting materials inspired by successful composites of other ion-conducting materials.[36]
- Low-cost, continuous, scalable processing techniques for inorganic solid ion conductors. As one example, a process is under development to make thin (down to 20 microns), flexible, polycrystalline, ceramic layers.[37]
- New materials that offer significantly improved properties compared with existing materials. As one example, a dry Li^+-conducting polymer that achieves a conductivity exceeding 5E-4 S/cm at 25°C and other desired properties would be a significant advance.
- The use of self-forming mechanisms to create passivating interfacial layers, or even the active materials or the separator itself, as a way to reduce processing steps.[38, 39]
- Supported films, which allow ion conductor thickness significantly less than 20 microns.

Note: All technology examples provided in this FOA are only meant to illustrate principles, and they are not meant to prescribe or limit the technical approaches proposed under the IONICS program.

Areas specifically NOT of interest in Category 1 are described in Section III.C.3 of the FOA.

Category 2: Selective and low-cost separators for batteries with liquid reactants (*e.g.*, flow batteries)

Motivation and Impact

The cost of electricity from wind and solar is increasingly favorable for mass deployment. Unfortunately, the limitations of the present electric power grid can prevent integration of abundant, but intermittent, wind and solar resources to as little as ~20% (the number varies with location and other factors) of the energy on the grid without significant curtailment.[40] More secure, reliable, and flexible operation of the grid can be accomplished through grid expansion (averaging over larger areas to reduce variability), responsive load, energy storage, or ramping of assets such as gas turbines (the current practice). Category 2 of the IONICS program is focused on energy storage, where ARPA-E's goal is to develop a transformative approach that allows the delivery of wind and solar energy with "firm" capacity near US wholesale prices. This requires adding only a few cents per kWh to wind and solar prices, which roughly corresponds to a *fully installed capital cost* (on an AC/AC basis) of 150 $/kWh, assuming at least 5,000 cycles and 80% round-trip efficiency. A system with these attributes would profoundly transform electricity systems around the world and pave the way for significantly more integration of wind and solar, especially at deep penetration levels (>50%). Past efforts funded by ARPA-E (including the GRIDS program and many projects in the OPEN portfolios) have developed advanced technologies in pursuit of this goal. The IONICS program is aimed at key issues identified in previous research and development efforts on energy storage for the grid, with a specific focus on separators for batteries with liquid reactants.

Batteries that use liquid reactants have a high potential to achieve extremely long cycle life because they avoid the numerous degradation modes associated with solid reactants, including those present in Li-ion batteries that often limit cycle life to 1,000 cycles or less. Cost modeling for aqueous liquid reactant batteries has established a challenging, but plausible, path to *fully installed systems* at 150 $/kWh for a five hour discharge time, a cost point that Li-ion batteries are not expected to reach.[41] These liquid reactants are typically embodied in a flow cell design, in which liquid reactants are stored in tanks and pumped to a stack of cells in which power is produced and accepted.[42] A significant advantage of flow batteries is the ability to decouple the energy and power portions of the battery, allowing the power portion to be specifically designed for highest performance and lowest cost. Flow batteries are particularly advantageous for long discharge times (*i.e.*, ≥5 hours). Other liquid reactants also have potential for extremely long cycle life and low cost; the most prominent examples make use of liquid sodium metal (or a sodium alloy) and a solid Na^+-conducting separator in a non-flow arrangement.[43-45]

The fundamental challenge with the use of liquid reactants is that realizing their promise of high cycle life can be accomplished in only two ways: (1) use a separator with essentially perfect selectivity for a common ion that passes between the electrodes (*e.g.*, a solid Na^+-conducting solid electrolytes such as β''-Al_2O_3), or (2) find a liquid reactant for which crossover does not lead to permanent cell degradation but only a loss in efficiency. The challenge in case (1) is that a "perfectly" selective separator has not yet enabled a low-cost system (*c.f.*, the Na/S battery, with reactants costing <1 $/kWh, nevertheless costs far more than 150 $/kWh at the system level), in part because of the cost of such a "perfect" separator. The challenge in case (2) is that there is only one practical example, to date, of a reactant that can be renewed when it crosses through the separator. That case is vanadium, which is cycled in its 2/3 and 4/5 oxidation states (at the negative and positive electrodes, respectively); these oxidation states have an adequate potential difference (a 1.25 V standard cell potential) and are suitability located relative to the stability window of aqueous electrolytes. Unfortunately, the vanadium itself costs between 35 and 85 $/kWh (the price in the past fifteen years has largely depended on demand in the steel industry), preventing flow cells built with vanadium reactants from reaching ≤150 $/kWh for fully installed systems.[41] Further, even the vanadium system requires the use of an ion-exchange membrane to limit crossover, and available PFSA membranes add 25 $/kWh or more (for a 5 hour discharge time) to the system cost.

Technical opportunities

There are two basic directions to drive advances in separators for batteries with liquid reactants: (1) Develop a high-performance separator with essentially perfect selectivity that creates two separate compartments coupled only by the exchange of a desired ion or ions. This approach offers tremendous design flexibility because it can fundamentally decouple the conditions at the two electrodes. (2) Develop separators for liquid reactants that do not require "perfect" selectivity and decoupling of the electrodes, but where achieving a lower cost than PFSA membranes *at near-term production volumes* would significantly hasten market adoption.[v] Crossover that leads to irreversible degradation (Case (1)) requires a per-cycle selectivity[vi] in excess of 99.995% to achieve 5,000 cycles while retaining 80% of the initial capacity. Inorganic materials have the potential to reach such a high selectivity because of their highly selective ion-conducting channels, but ion-conducting inorganic materials are typically expensive and require high operating temperatures to achieve high-efficiency cell operation. For case (2), there are a number of engineered liquid reactants under development that often make use of PFSA membranes because of their ready availability, but would greatly benefit

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[v] Section I.D of the FOA defines cost targets and production volumes.

[vi] The definition of selectivity for the purpose of Category 2 is the following: (number of moles of desired ion passed over a full charge/discharge cycle) / (number of moles of desired ion passed *plus* the number of moles of reactant or other species that lead to degradation or a loss of current efficiency per charge/discharge cycle).

from the development of membranes with superior performance-to-cost ratios, especially at the low production volumes facing flow battery manufacturers in the emerging grid storage market. PFSA membranes have anion-lined conducting channels with a characteristic size of 2-3 nm, sufficient for many reactants such as vanadium to achieve >97% selectivity during cycling, an adequate value for overall system operation.[41, 46-48] The design of ion-conducting channels in separators that are specifically tailored to the conditions present with emerging reactants based on Fe, Cr, S, quinones, *etc.*, is a key goal for Category 2. [49-51] Although the primary focus of Category 2 is the creation of selective membranes that further the development of low-cost batteries with liquid reactants, membrane design is often inextricably connected with the nature of the liquid reactants and so Category 2 is open to funding the co-development of membranes *and* liquid reactants. Several recent ideas show promise for creating separators with high selectivity and other performance attributes, and constitute examples of technical approaches of interest in Category 2.

Examples of technical approaches of interest for Category 2 include, but are not limited to:

- Inorganic nanoparticles blended into a porous polymer membrane that can fill pores and help block large active ions. [52]
- Both anion exchange membranes and amphoteric (possessing both acid and base character) polymers have shown promise in reducing the crossover of positively charged active species without significantly affecting conductivity.[53-55]
- Designing active species to have physically large cross sections and then combining them with a nanoporous membrane that may be infiltrated with an ionomer[50, 56] potentially allows for both high selectivity (*via* a combination of size and charge exclusion) and low resistance (*via* the small thickness of the supported membrane).
- Thin layers of inorganic materials may offer extremely high selectivities and low resistance even at 25°C, especially with the use of very thin, supported inorganic layers. Such an approach would need to meet the challenge to devise a fabrication technique with sufficiently low cost necessary for widespread implementation.[37, 57, 58]
- Separators enabling the use of molten sodium or sodium alloys at temperatures near 100°C and below.[44, 45]

Note: All technology examples provided in this FOA are only meant to illustrate principles, and they are not meant to prescribe or limit the technical approaches proposed under the IONICS program.

Areas specifically NOT of interest in Category 2 are described in Section III.C.3 of the FOA.

Category 3: Alkaline conductors with high chemical stability and conductivity

Motivation and Impact

Despite a number of drawbacks, hydrogen remains a compelling energy carrier because of its abundance, ease of synthesis, point-of-use emission of only water, usefulness as a fuel or in chemical processes, and other benefits. Vehicles that use proton-exchange membrane fuel cells (PEMFCs) are available for sale (*e.g.*, the Toyota Mirai), and numerous applications for hydrogen fuel cells and electrolyzers have been identified.[59, 60] A particular advantage for hydrogen as fuel carrier, compared with batteries, is the ability to fully charge a vehicle with a 300-mile range in minutes, similar to existing gasoline vehicles. A future with hydrogen as a significant energy carrier depends, to a significant degree, on advances in the oxygen electrode. The oxygen electrode has been explored in many reaction media (*e.g.*, aqueous media across a broad range of pH values, as well as nonaqueous and solid ceramic), but has been most heavily developed at acidic pH for automotive hydrogen fuel cells. The reason for the pursuit of the acid pathway is the existence of PFSA membranes, discussed earlier in the context of Figure 2. A consequence of the operation of the oxygen electrode in acid media is the need to use PGMs as a catalyst, as well as carbon-based or coated metal bipolar plates. Significant efforts are underway to reduce the amount of PGMs required, including efforts to develop viable non-PGM catalysts.[61, 62] While state-of-the-art Pt loadings of 0.15 mg/cm^2 have been achieved for automotive applications, commercial loadings (*e.g.*, as estimated for the Toyota Mirai) are typically ~0.3 mg/cm^2 or higher due to reliability concerns, translating into ~30 g of Pt per vehicle.[63] At this loading an annual production of ~7 million vehicles would require doubling of the current annual production of Pt. At a Pt price of 1500 $/troy ounce, at high production volumes (500k vehicles/y) the cost of Pt accounts for 49% of the total stack cost.[17] In addition, an acid system requires the use of a coating on the surface of stainless steel bipolar plates, resulting in plates that account for 22% of total stack costs.[17] Taken together, the cost of these two components significantly hinders the ability of PEMFC systems to achieve their ultimate cost targets.[16]

As an alternative, the oxygen electrode can operate in basic media with non-noble catalysts such as Ni and uncoated stainless steel bipolar plates.[19] Indeed, alkaline electrolyzers and fuel cells have been deployed for terrestrial and space applications with liquid alkaline electrolytes. But there are major drawbacks for both fuel cells and electrolyzers with a porous separator running on liquid alkaline electrolytes: for fuel cells, strongly basic liquid electrolytes react with CO_2 in air and form carbonate precipitates that degrade performance, requiring the use of pure O_2. For electrolyzers, compressed hydrogen is typically desired, but a porous separator with a liquid electrolyte cannot sustain the pressure differentials of a solid polymer (*cf.*, PFSA membranes can be designed to withstand pressure differentials of hundreds of bar).[64] The use of an AEM with cationic head groups bonded to a backbone can potentially resolve both of these challenges and enable the promise of operating the oxygen electrode in base in a practical system. In particular, an AEM can prevent carbonate precipitation upon air exposure (although AEM conductivity is reduced in the carbonate form compared to the hydroxide form) and sustain a pressure gradient to grant the benefits of electrochemical hydrogen compression. Overall, cost estimates of an AEM stack show a potential for ~25% lower system cost than using a PEM stack, and this CapEx benefit is roughly the same for automotive and combined heat and power (CHP) fuel cells.[vii]

In short, the development of a high-performance alkaline-exchange membrane has a high potential to put the oxygen electrode, as embodied in fuel cells for automotive or stationary applications as well as electrolyzers, on a fundamentally lower cost trajectory.

Technical Opportunities

No alkaline-exchange membrane is currently available with properties comparable to PFSA membranes. The biggest challenge for AEMs at present is achieving a high chemical stability at desired operating temperatures of ≥80°C, and ideally ≥95°C. Achieving these temperatures is critically important because they allow for cost-effective and compact heat rejection.[viii] For fuel cell applications where air is a reactant, good conductivity must be achieved with bicarbonate and carbonate from CO_2, and operation in a partially hydrated state is also necessary. A wide range of chemistries is being pursued, with backbones typically drawn from among the set of polymers that are stable in strong alkaline solutions at high temperatures, such as poly(arylene ethers), poly(ether ether ketone), poly(ether-imide), and various fluoropolymers.[19, 66, 67] Numerous tethers and cation head groups are also under exploration; benzyl- and alkyl-substituted quaternary ammonium groups are the most common cation head groups. In general, the resulting membranes exhibit stability for up to thousands of hours at ≤60°C and have conductivity moderately lower than PFSA membranes.[20]

There are a number of promising new chemistries emerging as well as a set of approaches to engineer the morphology of AEMs that have not yet been thoroughly explored.[68-70] Among the promising new chemistries, AEMS with high conductivity (>100 mS/cm at 80°C), stability in strong base at 80°C for several weeks, and good mechanical properties have been established, although achieving all of these property values in a single material, and showing they can be retained across a range of hydration levels and with an acceptable degree of swelling for device integration, has not been proven.[71-76] In terms of morphology engineering, the idea is to create segregated regions of hydrophobic and hydrophilic channels. Such a structure decreases the interaction between the hydroxide groups and the polymer backbone and has shown the potential to dramatically reduce degradation.[21, 77, 78] Morphology engineering may also

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[vii] For proton exchange membrane (PEM) fuel cells, the platinum-based catalyst and bipolar plates constitute over 70% of the fuel cell stack costs at high volumes.[17] By moving to an alkaline environment stack costs can potentially be reduced by 50%, resulting in vehicle fuel cell system cost reductions of up to 25%. Assumptions: use of non-PGM based catalysts and enablement of uncoated steel bipolar plates due to the reduced corrosion in the alkaline environment. Stack costs constitute 50% of system level costs for high volume PEM fuel cell production models.[17]

[viii] For example, the Department of Energy has set a target for $Q/\Delta T$, the heat rejection rate (Q) over the available temperature difference (ΔT) between a fuel cell temperature and a defined ambient temperature.[65]

help overcome classic tradeoffs among, for example, ionic conductivity and mechanical strength due to competing dependencies on swelling of ionic sites.[21, 79] Inorganic/organic composite membranes are another approach that shows promise for creating conductive and stable AEMs.[80]

Examples of technical approaches of interest for Category 3 include, but are not limited to:

- Approaches that retain the compelling performance that has been shown for a subset of properties while realizing significantly improved performance in all other properties.
- Morphology engineering to create phase-segregated structures that simultaneously address chemical stability, conductivity, mechanical properties, and other attributes relevant to AEM performance.
- Inorganic/organic composite membranes.
- AEMs capable of operation at temperatures significantly above 80°C, which is beneficial for heat transfer out of fuel cell systems.
- Material compositions and processing techniques that enable low cost at low production volumes.

Note: All technology examples provided in this FOA are only meant to illustrate principles, and they are not meant to prescribe or limit the technical approaches proposed under the IONICS program.

Areas specifically NOT of interest in Category 3 are described in Section III.C.3 of the FOA.

Category 4: Other approaches that could achieve the IONICS Program Objectives

This Category supports the development of components built with solid ion conductors that fall within the overall vision of the IONICS program but do not fit within Categories 1 to 3. In particular, Category 4 targets transformative electrochemical cells for the energy sector that are limited by a component that could be significantly improved with a solid ion conductor. The goal for this Category, as for the other Categories, is to achieve a technical breakthrough and a practical demonstration at the component level. While the purpose of this Category is to be open to high-impact innovations outside of Categories 1 to 3, applicants should be aware that there is a higher burden to quantify the potential impact of innovations.

Examples of technical approaches of interest for Category 4 include, but are not limited to:

- Solid ion conductors that enable the production of light metals such as Al and Mg in electrolytic cells. Highly stable metal oxide conductors are of interest, as are materials that directly conduct Mg^{2+} or Al^{3+} to allow the direct production of purified metal at the cathode.
- Low-cost separation of the components of air, especially at scales smaller than cryogenic processes, is important for applications such as oxy-combustion and the

production of ammonia. Solid ion conductors that create new learning curves for the separation of the components of air are of interest.

Note: All technology examples provided in this FOA are only meant to illustrate principles, and they are not meant to prescribe or limit the technical approaches proposed under the IONICS program.

Areas specifically NOT of interest in Category 4 are described in Section III.C.3 of the FOA.

E. TECHNICAL PERFORMANCE TARGETS

The IONICS program is focused on transformative components built from solid ion conductors, and the technical performance targets in this section are focused at the component level. Component testing in devices to verify component performance is required for particular Categories, as further described below.

Proposed technical plans must show a well-justified potential to meet or exceed the quantitative Technical Performance Targets described below.

Category 1: Li ion conductors that enable the cycling of Li metal without shorting

Technical metrics

The following metrics apply to solid Li^+-conducting separators, the minimum requirement of Category 1:

ID	Metric	Value
1.1	Separator that enables the cycling of Li metal without shorting at 25°C[A]	Modulus, surface, and microstructural properties that prevent Li metal shorting
1.2	Thermal properties[B]	Suitable for cell operation from −20 to 70°C
1.3	Component area over which property values are achieved to within ≥90% uniformity[C]	≥ 30 cm^2
1.4	Cost[D]	$\leq \$10/m^2$
1.5	Ionic ASR at 25°C	≤ 5 Ohm-cm^2
1.6	Capacity of Li metal moved per cycle	≥ 3 mAh/cm^2

1.7	Current density	$\geq$3 mA/cm^2
1.8	Number of cycles without Li metal shorting, or $\geq$20% degradation of other performance metrics	$\geq$500
1.9	Electrochemical stability[E]	0-4.5 V *vs.* Li/Li$^+$ is desired; sufficient to meet metric 1.14 is required
1.10	Thickness	$\leq$20 μm
1.11	Depth of discharge of the Li electrode (*i.e.,* fraction of the Li metal present that is cycled)	$\geq$80%
1.12	Electronic ASR at 25°C	$\geq$1E5 Ohm-cm^2
1.13	Mechanical properties for handling and operation	Suitable for handling components with an area at least that defined in metric 1.3, and for operation
1.14	Device Integration	Suitable for integration into a cell that achieves $\geq$1000 Wh/L and $\geq$400 Wh/kg for the cell repeat unit (current collectors, electrodes, and separator)

[A] At present, theoretical and empirical results suggest that a shear modulus approximately twice that of Li metal itself is required to prevent Li shorting.[14, 31] Proposals for solid separators with a significantly lower modulus should provide theoretical and/or empirical rationale for why they will be able to block Li metal shorting.

[B] Thermal properties need to be sufficient such that a cell built with this separator can operate without external heating or cooling across a wide range of ambient temperatures relevant for automotive or outdoor use. At low temperatures this means the conductivity is sufficiently high that the cell can self-heat, and the mechanical properties are such that Li metal shorting is still avoided, albeit at a lower current density than higher temperatures. At high temperatures this means the cell can operate without unacceptable degradation.

[C] Component development and testing work, including *in situ* device testing, may be done on areas smaller than that defined in metric 1.3, but a scientifically principled approach to scale-up must be developed and components with the area in metric 1.3 must be made and tested by the end of the program.

[D] At a battery production capacity of 10 GWh per year. This cost target is estimated with the following assumptions: a separator cost to energy of <20 $/kWh, a discharge time of 3h, and a power density of 10 mW/cm^2. See reference [8] for a relevant cost discussion.

[E] Accurate measurements of electrochemical stability are not simple. Two comments: (1) Measurements of electrochemical stability with cyclic voltammetry are generally inadequate for device-relevant stability. An important objective of the IONICS program is to significantly raise the bar on measurements of the electrochemical stability of solid Li$^+$ conductors. (2) A true thermodynamic stability window of 4.5V is not expected; rather, kinetic stability imparted through the formation of stabilizing, interfacial layers is expected to provide stabilization.

As stated previously, proposals to Category 1, in addition to the minimum requirement of enabling the cycling of Li metal with metrics 1.1 to 1.14, may also propose the construction of porous electrodes built from solid Li^+-conducting materials, in which case metrics 1.15 to 1.23 also apply.

ID	Metric	Value
1.15	Component area over which property values are achieved to within ≥90% uniformity[F]	≥30 cm^2
1.16	Thermal properties[G]	Suitable for cell operation from −20 to 70°C
1.17	Ionic conductivity of conducting phase	≥5E-4 S/cm
1.18	Electrode-level ASR measured at 50% SOC under practical compression conditions[H]	≤50 Ohm-cm^2
1.19	Electrode capacity	≥3 mAh/cm^2
1.20	Number of cycles with 80% capacity retention in a full-cell format at ≥1 mA/cm^2	≥500
1.21	Electrochemical stability	Suitable for use with positive electrode materials that enable metric 1.14
1.22	Mechanical properties of composite electrode	Suitable for cell manufacturing process that enables cells at 100 $/kWh (*i.e.*, suitable for roll to roll processing is preferred)
1.23	Device integration	The creation of a solid-state cathode based on existing metal-oxide electrode materials is preferred; other electrode materials will be considered on a case-by-case basis

[F] Component development and testing work, including *in situ* device testing, may be done on areas smaller than that defined in metric 1.15, but a scientifically principled approach to scale-up must be developed and components with the area in metric 1.15 must be made and tested by the end of the project.

[G] See note for metric 1.2 above.

[H] A common method to maintain interfacial contact in solid state electrodes is to apply high pressures. Metric 1.16 must be measured at pressures that can be practically achieved in a battery pack.

Project deliverables

The final project deliverables for Category 1 are:

- For projects exclusively addressing metrics 1.1 to 1.14, both symmetric cell (Li metal *vs.* Li metal) testing and full cell (Li metal *vs.* a cathode) testing are required. Full cell testing may be done with a conventional Li-ion cathode and liquid electrolyte to reduce complexity. Cell testing may be done at area smaller than that in metric 1.3, but cell testing at the area of metric 1.3 is required by the end of the project.
- For projects also addressing metrics 1.15 to 1.23, cells with Li metal as the negative electrode and the proposed solid porous positive electrode must be tested. Cell testing may be done at area smaller than that in metric 1.15, but cell testing at the area of metric 1.15 is required by the end of the project.

Category 2: Selective and low-cost separators for batteries with liquid reactants (*e.g.*, flow batteries)

Technical metrics

ID	Metric	Value
2.1	Production cost for a battery system with liquid reactants, a 5 hour charge and discharge time, and 80% round-trip DC-DC efficiency[A,B,C]	≤100 $/kWh
2.2	Expected cycle life to 80% of initial capacity given separator selectivity	≥5,000
2.3	Component area over which property values are achieved to within ≥90% uniformity[D]	≥100 cm^2
2.4	Per-cycle selectivity when reactant crossover leads to irreversible capacity loss[E]	>99.995%
2.5	Separator cost to energy at production volume of 100 MW/y for a separator that achieves >97% selectivity [F]	≤10 $/kWh
2.6	Ionic ASR	Sufficient to provide power density to meet metric 2.1; for aqueous flow batteries, <0.3 Ohm-cm^2 as described in reference [81]
2.7	Electronic ASR	≥1E4 Ohm-cm^2
2.8	Separator electrochemical and chemical stability	≤0.4% performance degradation per 1,000 hours of cycling over potential window and

		electrode compositions
2.9	Mechanical properties	Sufficient for handling during device fabrication, and for stable operation over ≥5,000 cycles

[A] At a production capacity of 2 GW / 10 GWh per year (a 5 hour system).
[B] For this metric a battery system is defined to include all of the items required to provide and receive DC power, but excludes costs such as inverters, project development and siting costs, utility interconnections, *etc.* The energy basis for this calculation should be the usable energy of the system. ARPA-E refers readers to reference [41] for an excellent cost analysis and set of specific component cost targets, especially for flow batteries.
[C] Note the specification of a battery system cost target provides applicants flexibility to balance the costs of individual components. However, ARPA-E is generally looking for separator costs to energy of <10 \$/kWh for the system specifications in metric 2.1.
[D] Component development and testing work, including *in situ* device testing, may be done on areas smaller than that defined in metric 2.3, but a scientifically principled approach to scale-up must be developed and components with the area in metric 2.3 must be made and tested by the end of the project.
[E] The definition of selectivity for the purpose of Category 2 is the following: (number of moles of desired ion passed over a full charge/discharge cycle) / (number of moles of desired ion passed *plus* the number of moles of reactant or other species that can lead to degradation or a loss of current efficiency per charge/discharge cycle)
[F] For separators that do not offer the enabling and extremely high selectivity required when crossover leads to irreversible degradation, the separator should still achieve >97% selectivity *and* provide a significantly lower cost at near-term production volumes (100 MW/y) than PFSA separators, while providing equivalent or superior performance. See Figure 57 of reference [17] for the expected cost/volume curve of a supported PFSA membrane.

Project deliverables

The final project deliverables for Category 2 are:

- Both *ex situ* (*e.g.*, measurements of chemical stability as defined in metric 2.8 may be at least partially accomplished with an extended soak) and *in situ* (*e.g.*, measurements of expected cycle life as defined in metric 2.2) measurements are expected. Both *ex situ* and *in situ* measurements may be done with component areas smaller than that defined in metric 2.3, but a scientifically principled approach to scale-up must be developed and components with the area in metric 2.3 need to be made and tested by the end of the project. Cell testing at an area smaller than that defined in metric 2.3 is acceptable throughout the project.
- As stated in the discussion of Category 2 in Section I.C of the FOA, membrane development is often inextricably connected to the development of reactants, so projects in Category 2 may also propose to deliver reactants co-developed with selective separators.

Category 3: Alkaline conductors with high chemical stability and conductivity

Technical metrics

ID	Metric	Value
3.1	Membrane chemical stability (at ≥80°C immersed in a pH≥14 solution)[A]	≥1000 hours with ≤2% loss in ion exchange capacity, ionic ASR, spectroscopic measures of membrane state, and mechanical properties
3.2	Component area over which property values are achieved to within ≥90% uniformity[B]	≥100 cm^2
3.3	Ionic ASR (hydroxide form, 80°C, liquid equilibrated)	≤0.04 Ohm-cm^2
3.4	Ionic ASR (80°C, ≤50% RH, under air exposure, *i.e.*, in presence of 400 ppm CO_2)	≤0.08 Ohm-cm^2
3.5	Mechanical durability during humidity cycling[C]	≥20,000 RH cycles
3.6	Electronic ASR	≥1000 Ohm-cm^2
3.7	Humidity Stability Factor[D]	>5
3.8	Swelling in liquid water at 25°C	<50%
3.9	Pressure differential (bar)	≥1
3.10	H_2 crossover and O_2 crossover	≤25 nmol/cm^2-s
3.11	Cost for membrane that can be practically integrated in a device[E]	≤20 $/$m^2$

[A] For a discussion of spectroscopic and mechanical tests that may be done to characterize degradation see [19] or [82]

[B] Component development and testing work may be done on areas smaller than that defined in metric 3.2, but a scientifically principled approach to scale-up must be developed and components with the area in metric 3.2 must be made and tested by the end of the project.

[C] The RH testing procedure is described in reference [83]. Membrane mechanical properties must be sufficiently retained during RH cycling; the most important metric for this is the membrane's ability to maintain low levels of gas crossover, as defined in metric 3.10.

[D] Definition: (Strain at breaking point at 25°C and 50% RH) / (Linear swelling at 100°C in liquid water). This metric is a rough check to ensure that a membrane can stretch more at 25°C than it naturally swells when fully hydrated at 100°C, and has been found to correlate with RH cycles to failure. See references [84] and [85] for further discussion.

[E] At a production capacity to supply 100,000 fuel cell vehicles per year. “Practically integrated” refers to the mechanical properties required for handling and device manufacturing.

Project deliverables

Membrane testing in Category 3 will be exclusively *ex situ* because *ex situ* testing facilitates the ability to test new ideas without the significant complexity of full cell fabrication and instrumentation, especially given the Category 3 focus on AEMs stable at high temperatures.. ARPA-E understands the value of *in situ* testing, as well as the high importance of the development of ionomers for the electrodes, and may consider funding such work, subject to the availability of appropriated funds. Further, while there are significant differences in the requirements around hydration and applied pressure for fuel cells and electrolyzers, the single set of metrics for Category 3 is oriented towards the fuel cell application. Significant progress towards these metrics should result in membranes that can be transferred to electrolyzers for testing and further development, another potential topic for additional work under a later funding mechanism. Hence, the end-of-project deliverable for Category 3 is a set of components with an area defined by metric 3.2 that meets the other metrics in the Category 3 table above.

Category 4: Other approaches that could achieve the IONICS Program Objectives

Technical metrics

This Category may encompass a range of approaches and applications. Applicants must present the technical metrics they plan to achieve during the course of their project following the format presented in the Table below. Applications proposing solid ion conductors that could be used in multiple types of electrochemical cells should clearly state the expected impact of at least one electrochemical cell containing proposed innovations, so ARPA-E can be sure that the impacts are sufficient to warrant support.

The suggested format for presentation of technical metrics for applications in Category 4 is:

ID	Metric	Value
4.1	Component area over which property values are achieved to within ≥90% uniformity	Comparable to that in relevant electrochemical device (cm^2)
4.2	Ionic area-specific resistance	Provide expected thickness in microns and ASR in units of Ohm-cm^2
4.3	Selectivity	Describe what ions and neutral species the solid ion conductor is selective towards and method to measure selectivity. Provide selectivity with units as appropriate (*e.g.*, a per-pass current efficiency, or a side reaction

		current density at steady state)
4.4	Electrochemical and chemical stability	Measurement technique and duration of chemical stability, with units of hours, volts, *etc.*, as appropriate
4.5	Electronic area-specific resistance	Provide expected thickness in microns and ASR in units of Ohm-cm^2
4.6	Thermal properties	Describe relevant thermal characteristics, including ASR as a function of temperature, the presence of phase changes, the temperature at which irreversible degradation mechanisms begin, *etc.* Provide thermal characteristics with relevant units, such as ASR in Ohm-cm^2 as a function of temperature, the temperature at which a degradation rate exceeds the target for the desired operating life of the device, *etc.*
4.7	Mechanical properties	Mechanical properties relevant to both function in the device and to the processing and handling steps. Examples: fracture toughness, shear modulus, tensile strength, hydration cycling, *etc.*
4.8	Processing and cost	Description of processing method and the assumed attributes and production volume in cost target. Provide cost as \$/m^2 as a function of volume in m^2/year.
4.9	Device integration	Describe implications of solid ion conductors properties on other parts of the device
4.10	Impact	Components built from solid ion conductors for electrochemical devices that have a clear potential to impact at least 1% of US energy-related emissions, imports, or overall energy use.

Project deliverables

A set of components with an area defined by metric 4.1 that meets the other metrics in the Category 4 table above. Applicants should propose a level of testing appropriate for their component.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $30 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 12-15 awards under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

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

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects the start date for funding agreements to be January 2017, or as negotiated.

ARPA-E encourages applications 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.

Applications 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 applications should 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, applications 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 applications with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

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

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

B. ARPA-E FUNDING AGREEMENTS

Through Cooperative Agreements, Technology Investment Agreements, 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."[ix] Accordingly, ARPA-E has substantial involvement in the direction of every project, as described in Section II.C of the FOA below.

1. COOPERATIVE AGREEMENTS

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

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.

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 Authorization" and "Field Work Proposal" sections 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

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

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

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 (http://arpa-e.energy.gov/arpa-e-site-page/award-guidance).

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. TECHNOLOGY INVESTMENT AGREEMENTS

ARPA-E may use its "other transactions" authority under the America COMPETES Reauthorization Act of 2010 or DOE's "other transactions" authority under the Energy Policy Act of 2005 to enter into Technology Investment Agreements (TIAs) with Prime Recipients. ARPA-E may negotiate a TIA when it determines that the use of a standard cooperative agreement, grant, or contract is not feasible or appropriate for a project.

A TIA is more flexible than a traditional financial assistance agreement. In using a TIA, ARPA-E may modify standard Government terms and conditions. See 10 C.F.R. § 603.105 for a description of a TIA.

In general, TIAs require a cost share of 50%. See Section III.B.2 of the FOA.

C. STATEMENT OF SUBSTANTIAL INVOLVEMENT

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

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an

award.

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

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

1. INDIVIDUALS

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[xi] as the lead for a Project Team,[xii] 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

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

[xii] The term "Project Team" is used to mean any entity with multiple players working collaboratively and could encompass anything from an existing organization to an ad hoc teaming arrangement. A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.

For-profit entities, educational institutions, and nonprofits[xiii] 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. All foreign entities must be incorporated (or otherwise formed) under the laws of a State or territory of the United States. Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or otherwise 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. 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/. Please 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

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[xiii] 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.

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[xiv]

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

1. BASE COST SHARE REQUIREMENT

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

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).

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

[xv] 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.

[xvi] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.

Under a Technology Investment Agreement, the Prime Recipient must provide at least 50% of the Total Project Cost as cost share. ARPA-E may reduce this minimum cost share requirement, as appropriate.

3. REDUCED COST SHARE REQUIREMENT

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

- A domestic educational institution or domestic nonprofit applying as a Standalone Applicant is required to provide at least 5% of the Total Project Cost as cost share.

- Small businesses – or consortia of small businesses - will provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[xvii] 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.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80%, but less than 100%, of the total work under the funding agreement (as measured by the Total Project Cost) the Project Team 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.[xviii]

- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs/DOE Labs are required to provide at least 5% of the Total Project Cost as cost share.

- Project Teams where domestic educational institutions, domestic nonprofits, small businesses, and/or FFRDCs/DOE Labs 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

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[xvii] 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 that their organization meets the SBA's definition of a small business under at least one NAICS code. This certification must be provided with the other information requested in the Business Assurances & Disclosures Form.

[xviii] See the information provided in previous footnote.

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 minimum cost share requirements described in Section III.B 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 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.1 of the FOA.

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

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

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

In addition, Project Teams may not use independent research and development (IR&D) funds[xix] to meet their cost share obligations under cooperative agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under Technology investment 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 and GOGOs are funded by the Federal Government, costs incurred by FFRDCs and GOGOs 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.

[xix] 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.

Applications found to be noncompliant will not be merit reviewed or considered for award. ARPA-E will 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.

Applications found to be noncompliant will not be merit reviewed or considered for award. ARPA-E will 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.
- The 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 will be deemed nonresponsive and will not be reviewed or considered:

- Applications that fall outside the technical parameters specified in Section I.E of the FOA
- Applications that have been submitted in response to other currently issued ARPA-E FOAs.
- Applications that are not scientifically distinct from applications submitted in response to other currently issued ARPA-E FOAs.
- Applications for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Applications for large-scale demonstration projects of existing technologies.
- Applications for proposed technologies that represent incremental improvements to existing technologies.

- Applications for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Applications for proposed technologies that are not transformational, as described in Section I.A of the FOA.
- Applications 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.
- Applications that are not scientifically distinct from existing funded activities supported elsewhere, including within the Department of Energy.
- Applications that describe a technology but 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. AREAS SPECIFICALLY NOT OF INTEREST

- Applications that propose the following:
    - Within any Category:
        - Liquid-based approaches to achieving technical metrics.
    - Category 2: Any of the following
        - The development and/or optimization of flow battery or other liquid reactant battery systems with multi-cell stacks or arrangements.
        - Proposals without specific reactants to be enabled with the proposed membrane solutions, or proposals to develop membranes for reactants that do not have a clear path to reach the cost targets in Section I.D of the FOA.
        - Incremental improvements to PFSA membranes.
        - The exclusive development of liquid reactants for use with existing membranes.
    - Category 3: Any of the following
        - Work on electrode design, catalysis, stack design and development, *etc.*, are not of interest for Category 3.
        - Proposals that focus on the use of alkaline conductors for applications other than for fuel cells or electrolyzers are not of interest in Category 3. (But for the application of alkaline conductors, or anion conductors more generally, to flow batteries, the submission should be made to Category 2, and for other electrochemical cells the submission should be made to Category 4.)
    - Category 4: Any of the following
        - Metal oxide conductors for separators or electrodes for solid-oxide fuel cells.
        - The development of existing classes of proton conductors for vehicle fuel cells (e.g., PFSA membranes or polybenzimidazole (PBI) membranes).

Ion-transport membranes (ITMs) based on YSZ for separation of the components of air.

4. LIMITATION ON NUMBER OF APPLICATIONS

ARPA-E is not limiting the number of applications that may be submitted by 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.G.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. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria in Section V.A.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 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 30 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. Applications found to be noncompliant or nonresponsive will not be merit reviewed or considered for award.

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 and site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for funding 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.

7. MANDATORY WEBINAR

All selected Applicants, including the Principal Investigator and the financial manager for the project, are required to participate in a webinar that is held within approximately one week of the selection notification. During the webinar, ARPA-E officials present important information on the award negotiation process, including deadlines for the completion of certain actions.

B. APPLICATION FORMS

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

C. CONTENT AND FORM OF CONCEPT PAPERS

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

- The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables.

- The Concept Paper must be submitted in Adobe PDF format.

- The Concept Paper must be written in English.

- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).

- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator’s Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.

- The first paragraph must include the Lead Organization's Name and Location, Principal Investigator's Name, Technical Category, Proposed Funding Requested (Federal and Cost Share), and Project Duration.

ARPA-E will not review or consider noncompliant and/or nonresponsive Concept Papers (see Section III.C of the FOA).

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

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

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

1. CONCEPT PAPER

a. CONCEPT SUMMARY

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

b. INNOVATION AND IMPACT

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

c. PROPOSED WORK

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

- Discuss alternative approaches considered, if any, and why the proposed approach is most appropriate for the project objectives.

- Describe the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach. Provide specific examples of supporting data and/or appropriate citations to the scientific and technical literature.

- Describe why the proposed effort is a significant technical challenge and the key technical risks to the project. Does the approach require one or more entirely new technical developments to succeed? How will technical risk be mitigated?

- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.

- Estimated federal funds requested; total project cost including cost 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 MAY 2016]

E. CONTENT AND FORM OF REPLY TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]

F. INTERGOVERNMENTAL REVIEW

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

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]

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 User 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 will not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications will 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;
- 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 extent to which the proposed quantitative material and/or technology metrics demonstrate the potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- The extent to which the proposed concept is innovative and will achieve the technical performance targets defined in Section 1.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and
- The extent to which the Applicant demonstrates 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;
- The extent to which the Applicant proposes a sound 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;
- The extent to which project outcomes and final deliverables are clearly defined;
- The extent to which the Applicant identifies techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; 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 MAY 2016]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]

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 (including gender) of technical personnel in the proposed Project Team;
   b. Technological diversity;
   c. Organizational diversity;
   d. Geographic diversity;
   e. Technical or commercialization risk; or
   f. Stage of technology development.

II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
   a. Reduction of US dependence on foreign energy sources;
   b. Stimulation of domestic manufacturing;
   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 MAY 2016]

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 reviewed or considered. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Concept Paper or Full Application was rejected.

2. CONCEPT PAPER NOTIFICATIONS

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

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

A notification letter encouraging the submission of a Full Application does not authorize the Applicant to commence performance of the project. Please refer to Section IV.G.2 of the FOA for guidance on pre-award costs.

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2016]

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. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- ARPA-E will cease to accept questions approximately 5 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 posted to "Questions and Answers" 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. 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.

B. 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.

C. 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.

D. 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.

E. 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.

F. TITLE TO SUBJECT INVENTIONS

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and

Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions. If they elect to retain title, they must file a patent application in a timely fashion.

- All other parties: The Federal Non Nuclear Energy 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 CFR Part 501.

G. 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.

3. U.S. MANUFACTURING REQUIREMENT

ARPA-E requires that awards address whether products embodying or produced through the use of subject inventions (i.e., inventions conceived or first actually reduced to practice under ARPA-E funding agreements) are to be substantially manufactured in the United States by Project Teams and their licensees. The requirement varies depending upon whether an awardee is a small business, University or other type of awardee. The Applicant may request a modification or waiver of the U.S. Manufacturing Requirement.

H. 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.

I. 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).

IX. REFERENCES

TABLE OF ABBREVIATIONS

AEM	Alkaline-exchange membrane. This abbreviation may also refer to an Anion-exchange membrane, which does not require an anion to be an alkaline anion (*i.e.*, OH^-, HCO_3^-, CO_3^{2-})[19]
ASR	Area-specific resistance
BEV	Battery electric vehicle
FOA	Funding opportunity announcement
IONICS	Integration and Optimization of Novel Ion-Conducting Solids
LGPS	$Li_{10}GeP_2S_{12}$
LiPON	$Li_xPO_yN_z$ where $x = 2y+3z-5$
PEM	Proton-exchange membrane
PFSA	Perflourosulfonic acid
PHEV	Plug-in hybrid electric vehicle
RH	Relative humidity
YSZ	Yttria-Stabilized Zirconia

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X. GLOSSARY

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

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

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

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

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

DOE: U.S. Department of Energy.

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

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

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

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

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

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

PI: Principal Investigator.

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

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).