FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

RENEWABLE ENERGY TO FUELS THROUGH UTILIZATION OF ENERGY-DENSE LIQUIDS (REFUEL)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001562
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Funding Opportunity Announcement (FOA) Issue Date:	April 26, 2016
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, May 18, 2016
Submission Deadline for Concept Papers:	5 PM ET, May 25, 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 $25 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.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 - III.C.4 of the FOA.

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

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: o Concept Summary o Innovation and Impact o Proposed Work o Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, May 25, 2016
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JULY 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 issues this Funding Opportunity Announcement (FOA) under the programmatic authorizing statute codified at 42 U.S.C. § 16538. The FOA and any awards made under this FOA are subject to 2 C.F.R. Part 200 as amended by 2 C.F.R. Part 910.

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

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector 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."[1] Applicants interested in receiving financial assistance for basic research should contact the DOE's Office of Science (http://science.energy.gov/). Office of Science national scientific user facilities (http://science.energy.gov/user-facilities/) are open to all researchers, including ARPA-E applicants and awardees. These facilities provide advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere. Projects focused on 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://www.energy.gov/ne/office-nuclear-energy) , and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. PROGRAM OVERVIEW

1. Summary

The purpose of the Renewable Energy to Fuels through Utilization of Energy-dense Liquids (**REFUEL**) program is to develop scalable technologies for conversion of electrical or thermal energy from renewable sources into chemical energy contained in energy dense Carbon-Neutral Liquid Fuels (CNLF) that can be stored, transported, and later converted into hydrogen or electricity to provide power for transportation and distributed energy generation. The overall structure of the REFUEL program is illustrated in Figure 1 below. Because CNLFs can be stored for extended periods of time and then transported to consumers using existing and inexpensive technology for liquid fuel delivery and distribution, they offer a unique opportunity to reduce both the need for energy imports and carbon emissions from the transportation sector. In meeting that need, they also have the potential to enable increased penetration of

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

intermittent renewable energy sources. The success of this program depends on developing technologies in two categories: (1) the synthesis of CNLFs using intermittent renewable energy sources and water and air (N2 and CO2) as the only chemical input streams and (2) the conversion of CNLFs delivered to the end point to another form of energy (e.g. hydrogen or electricity).

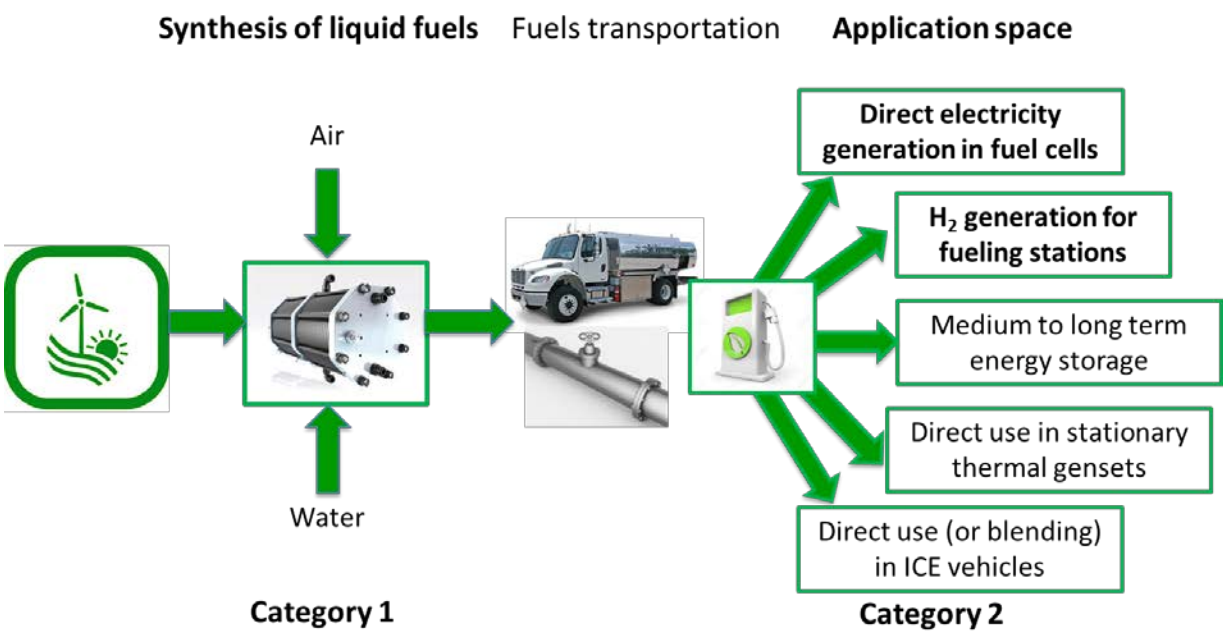

Figure 1. The production, transport and use of carbon-neutral liquid fuels for energy delivery. Areas of interest within Category 2 in this FOA are shown in bold.

The program's overall goal is a competitive total cost (including production, transportation, storage, and conversion costs) of ***delivered*** (***source-to-use***) energy (e.g. converted to motive power for transportation) as opposed to the ***primary*** energy stored in chemical form **below $0.3/kWh**, the price needed to be competitive with other carbon-free delivery methods, as will be discussed in Section B. The source-to-use energy cost (SUE) is defined here as the sum of the fuel production cost (CF), the cost of transportation or transmission from production to the user (CT), and the cost of any storage (CS), divided by the conversion efficiency (η) to account for any losses during the conversion steps:

$$SUE = \frac{CF+CT+CS}{\eta} \quad (1)$$

Representative values for several commercial approaches to providing transportation energy are given in Table 1 using gasoline burned in internal combustion engines (ICEs) as a baseline. The standard commercial process for producing H_2 (either as the final product, or as a feedstock for ammonia production) is thermochemical steam-methane reforming (SMR). The corresponding values in the table are calculated based on literature cited in the footnotes. The column titled "Electricity" is representative of moving electricity across the current grid and storing it in an electric vehicle (EV) battery. The values contained in Table 1 will be discussed further in the context of carbon-free fuels in the following sections of this document.

Table 1: Comparative costs of current different energy delivery options for transportation.

	Gasoline	Hydrogen by SMR	Ammonia by SMR/Haber-Bosch	Electricity
Specific energy density, kWh/kg	12.7	33.3	5.16	
Energy density, kWh/L	8.76	0.8	4.25	
Fuel cost, $/kg	0.54[a]	1.95[b]	0.325[c]	
Fuel cost, $/kWh	0.047	0.058	0.063	0.065[d]
Transmission cost, $/kWh[e]	0.001	0.060	0.004	0.038[d]
Storage cost, $/kWh[e]	0.001	0.030	0.007	0.160[f]
Conversion efficiency, %[f]	30	55	55	92
Source-to-use energy cost, $/kWh[g]	0.159	0.292	0.135	0.285

[a] – Average production cost for 2015 in California, http://energyalmanac.ca.gov/gasoline/margins;

[b] – $1.95/kg production cost based on SMR path: 3.1 Hydrogen Production in "DOE Multi-Year Research, Development, and Demonstration Plan" (2015) http://energy.gov/sites/prod/files/2015/06/f23/fcto_myrdd_production.pdf;

[c] – Maung, T., et al., "Economics of Using Flared vs. Conventional Natural Gas to Produce Nitrogen Fertilizer: A Feasibility Analysis", North Dakota State University (2012) http://ageconsearch.umn.edu/bitstream/133410/2/Department-APUC%20Report.pdf;

[d] – EIA Annual Energy Outlook 2015, Table titled 'Electricity Supply, Disposition, Prices, and Emissions for average 2015 electricity generation and T&D costs'; http://www.eia.gov/forecasts/aeo/data/browser/#/?id=8-AEO2015

[e] – transportation and storage costs calculated using data from: Curley, M., Pipeline and Gas Journal (2008) 235, 34; Ramsden, T., et al., "Hydrogen Pathways", NREL report TP-6A10-60528; Bartels, J. R. and Pate, M. B., "A feasibility study of implementing an Ammonia Economy", Iowa State University, 2008; Schoenung, S., "Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications", Sandia report SAND2011-4845 (2011);

[f] – Nykvist, B. and Nilsson, M., Nature Climate Change, (2015), 5, 329, assumed battery pack cost of $300/kWh, operating at one cycle per day for 8 years with a 85% round-trip efficiency (92% discharge efficiency) at 70% depth of discharge.

[g] – Conversion capital cost not included.

Technologies developed under the REFUEL program will enable long-term (i.e. multi-day capacity) energy storage and long-distance renewable energy delivery from remote, isolated, and/or stranded locations and create an affordable refueling infrastructure of clean fuels. Furthermore, all of these applications will support the goal of substantially reducing carbon emissions. Implementation of the aggressive targets of the REFUEL program will require R&D teams to be built from several communities, including: electrocatalysis, heterogeneous catalysis, materials science, electrochemical systems design, gas separation, process engineering, and systems integration.

2. Program Motivation

Chemicals, such as hydrocarbons, are effective energy carriers and return the largest fraction of their energy density when delivered via a pipeline. However, fossil fuels are major CO2 emitters and also drive energy imports. Reducing energy imports from foreign sources and energy-related emissions, including greenhouse gas (GHG) emissions, which are part of ARPA-E's mission, could be achieved by: (1) shifting to cleaner transportation fuels, e.g. hydrogen and biofuels; (2) increased use of low-carbon electricity generation forms, e.g. solar and wind; and

(3) enhancements in the efficiency and reliability of U.S. electric power distribution system. REFUEL targets areas (1) and (2) with ancillary benefits for area (3).

We define CNLFs in this FOA as: hydrogen-rich liquid fuels made by converting molecules contained in air (N2, CO2) and hydrogen from water into energy-carrying liquids at moderate temperatures and pressures using renewable energy sources. Hydrogen is the simplest chemical that can be considered for use as a CNLF (in liquid form), and stationary fuel cells and vehicles using hydrogen as a fuel are maturing technologies.[2] The standard commercial process for producing H2 is thermochemical steam-reforming of methane (SMR). H2 produced in this way is not a carbon neutral fuel, as the chemical process produces one molecule of CO2 for every four H2 molecules,[3] and the thermal energy necessary for the process is provided by CO2 emitting fossil fuel sources. Generation of carbon-neutral hydrogen is possible using electrolysis of water, if the electricity is provided from renewable sources such as wind or solar, or from nuclear energy.[4] Currently, the most advanced method for H2 production is either polymer electrolyte membrane (PEM) or alkaline water electrolysis.

Clean hydrogen is used in commercial fuel cell electric vehicles (FCEV) to achieve carbon-neutral transportation.[5,6] However, the limitations of hydrogen storage and transportation, which will be described below, have limited the growth of a hydrogen infrastructure, generating a hurdle to widespread adoption of FCEVs.[7,8] This infrastructure will not be built while the number of FCEVs using it remains low (classic “chicken and egg” problem).

Because of the inherent difficulties in achieving zero-carbon emissions with fossil fuels in the transportation sector, we must consider new options. The REFUEL program seeks to address these challenges by developing CNLFs that provide a new set of technology options for storing renewable energy in CNLFs, and delivering it economically and effectively when and where it is needed.

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[2] Fayaz, H. et al., “An overview of hydrogen as a vehicle fuel”, Renewable and Sustainable Energy Reviews (2012) 16, 5511; Cipriani, G. et al., “Perspective on hydrogen energy carrier and its automotive applications”, Int. J. Hydrogen Energy (2014) 39, 8482.

[3] “Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming”, NREL Report TP-570-27637, (2001).

[4] Hydrogen generation from biomass (reforming of bio-derived liquids, photolytic and photosynthetic biological production, and microbial-aided electrolysis) has a potential to be zero- or low-carbon but these technologies are far from commercial readiness. Tanksale, A. et al., “A review of catalytic hydrogen production processes from biomass”, Renewable and Sustainable Energy Reviews (2010) 14, 166.

[5] National Research Council. Transitions to Alternative Vehicles and Fuels. Washington, DC: National Academies Press, (2013). http://www.nap.edu/catalog.php?record_id=18264

[6] “Technology assessment: medium- and heavy-duty fuel cell electric vehicles”, California Air Resource Board (2015).

[7] Only 14 public hydrogen refueling stations exist across the U.S. today, http://www.afdc.energy.gov

[8] California proposes to build 100 additional stations by 2025 http://www.energy.ca.gov/releases/2014_releases/2014-05-01_hysdrogen_refueling_stations_funding_awards_nr.html

The following section provides examples technologies and their impact with respect to four topic areas: (1) hydrogen for energy storage and deliver; (2) opportunities for CNLFs; (3) delivery of energy services from CNLFs; and (4) ancillary benefits in integration of renewable power sources.

Hydrogen for energy storage and delivery
Chemical energy storage in hydrogen can be combined with energy transmission in the form of a compressed gas or a cryogenic liquid. Some relevant properties of hydrogen are listed in Table 2, with a comparison to gasoline, ethanol, and a potential alternative CNLF (described below). Hydrogen has extremely high specific energy (39.4 kWh/kg, HHV) but a rather low volumetric energy density (theoretical values are 2.28 kWh/L as a liquid and 1.55kWh/L as gas at 700 bar, which is reduced to 1.7 and 0.8 kWh/L in practical systems).[9] The only industrial carbon-neutral method of hydrogen production is water electrolysis, when electricity is generated by renewable sources, using commercial PEM or alkaline electrolyzers or emerging solid oxide electrolytic cells (SOEC). Hydrogen can be utilized in a variety of fuel cells, e.g. PEM fuel cells or solid oxide fuel cells (SOFC) and, with lower efficiency, in internal combustion engines or turbines for both stationary and mobile applications. One disadvantage of hydrogen is the 30 – 45% round trip efficiency (RTE) due to the less than 70% generation efficiency water electrolysis to form hydrogen and the 55 – 65% conversion efficiency in fuel cells to produce electricity.

[9] Satyapal, S., et al., *Catalysis Today* (2007), 120, 246

Table 2: Properties of current and potential transportation fuels.

	Gasoline[a]	Ethanol[b]	H_2 (SMR)[c]	H_2 (electrolysis)[c]	NH_3 (SMR/Haber-Bosch)[d]	NH_3 (electrolysis/ Haber-Bosch)[e]
Process energy, MWh/ton	1.5	2.39	50.7	55	7.8	9.5
Fuel synthesis EE, %[f]	88	70[g]	79[h]	70	66	54
CO_2 emissions, g/kWh	338[i]	104 – 273[i]	357[h]	0 – 114[j]	310	0 – 178[j]
Storage pressure, bar	1	1	700	700	10	10
Compression losses, %[k]	0	0	7 – 19	7 – 19	2 – 3	2 – 3

[a] – General Motors Corporation, Argonne National Laboratory, BP, ExxonMobil, and Shell, "Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems: A North American Analysis, Volume 3, Well-to-Tank Energy Use and Greenhouse Gas Emissions of Transportation Fuels," ANL/ES/RP-104528 (2001).

[b] – DOE Alternative Fuels Data Center, http://www.afdc.energy.gov/fuels/ethanol_fuel_basics.html

[c] – Ramsden, T. et al., "Hydrogen Pathways", NREL report TP-6A10-60528

[d] – Bartels, J.R. and Pate, M.B., "A feasibility study of implementing an Ammonia Economy", Iowa State University, 2008;

[e] – Morgan, E.R., "Techno-Economic Feasibility Study of Ammonia Plants Powered by Offshore Wind" (2013). Dissertations. Paper 697; http://scholarworks.umass.edu/open_access_dissertations/697; Matzen M, et al., *J. Adv. Chem. Eng.* (2015) 5, 128.

[f] – Energy efficiency (EE) is defined as $EE = P/(P+E)$ where P is the primary energy of extracted hydrogen and E is energy consumed for the conversion process.

[g] – Gallagher, P.W. et al., "2015 Energy Balance for the Corn-Ethanol Industry", USDA (2016) http://www.usda.gov/oce/reports/energy/2015EnergyBalanceCornEthanol.pdf

[h] – Spath, P. and Mann, M., "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming", NETL report TP-570-27637 (2001).

[i] – Wang, M. et al., "Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for U.S. use", *Environ. Res. Lett.* (2012) 7, 045905.

[j] – The value is 0 if for all energy comes from renewable electricity. Higher values are if fossil fuels are used for heating and compression.

[k] – Percentage of energy contained in a fuel

Hydrogen compression and, especially, liquefaction incur additional energy losses (up to 10 and 35%, respectively). In contrast to liquid H_2, which boils-off with a rate of 1 – 4% per day depending on the tank,[10] hydrogen storage and transportation as a compressed gas has very low losses. Therefore, the latter is a more attractive option for long-term storage (from days to seasonal). Average cost of hydrogen transportation via a 750 mile long pipeline is estimated to be $1 – 2/kg H_2 or $0.03 – 0.06/kWh,[11] which is substantially more expensive than pipeline transportation of gasoline (about $0.025/gal or $0.001/kWh)[12] or ammonia ($34/ton per 1000 miles or $0.004/kWh for 750 miles).[13]

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[10] Zhang, J., et al., *J. Heat Transfer* (2005) 127, 1391.

[11] Amos, W., "Costs of Storing and Transporting Hydrogen", NREL report TP-570-25106 (1998); Ramsden, T. et al., "Hydrogen Pathways", NREL report TP-6A10-60528 (2013).

[12] Curley, M. *Pipeline and Gas Journal* (2008) 235, 34.

[13] J. R. Bartels, M. B. Pate, A feasibility study of implementing an Ammonia Economy (2008) Iowa State University, https://nh3fuel.files.wordpress.com/2013/07/bartels-dec2008-implementinganammoniaeconomy.pdf

Opportunities for CNLFs

The use of energy-dense liquids, e.g. liquid ammonia or renewable hydrocarbons, with a similar RTE may be an attractive alternative to H_2, due to the absence of or low compression losses. Storage and transportation costs can be even lower if the carbon-neutral production cost is higher than that of H_2. Such CNLFs could be used in appropriately designed fuel cells. Alternatively, the costs of compression and storage, which is the major cost of the H_2 refueling station,[14] can be reduced by using with CNLFs as hydrogen carriers and the existing liquid fuel infrastructure technologies. An ANL/TIAX analysis of hydrogen delivery. using liquid hydrogen carriers with a hydrogen content of 6 – 7 wt.%, showed that the carrier hydrogen delivery cost will be lower than liquid or compressed (700 bar) hydrogen.[15] CNLFs with higher hydrogen content will be even less costly. Some examples of potential CNLFs are presented in the following section.

The fuels discussed in this section are representative examples of the types of fuels that would be deemed responsive to this FOA, but this are not intended to be an exhaustive list.

Some promising CNLFs are already manufactured thermochemically at a large commercial scale (at least several thousand tons per year). The second most manufactured chemical in the world, ammonia (NH_3), is produced at large-scale Haber-Bosch plants. Production volume is 160 million tons per year with 9.6 million tons produced in the U.S..[16] Hydrogen is combined with nitrogen over a catalyst at temperatures ranging from 380 to 520 °C and pressures ranging from 150 to 250 bar, Equation (2).[17,18] Optimization of process temperatures and pressures, as well as catalyst material developments over the years have resulted in 30% efficiency improvements, but the process still accounts for 1 – 2% of global energy consumption.[19]

$$N_2 + 3H_2 \rightarrow 2NH_3 \qquad (2)$$

Modern Haber-Bosch plants, using hydrogen generation by SMR, release about 1.6 – 1.8 ton CO_2 per ton of NH_3 of which only 0.95 ton comes from the SMR process and the rest from heating and pressurization needs.[20] Energy consumption for NH_3 production using SMR varies from 7.8 to 10.5 MWh per ton of NH_3 (including feedstock, which accounts for 80% of

[14] Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs. NREL report BK-6A10-58564 (2014).

[15] Ahluwalia, R. K., et al., "Technical Assessment of Organic Liquid Carrier Hydrogen Storage Systems for Automotive Applications" ANL/TIAX report, (2011).

[16] http://minerals.usgs.gov/minerals/pubs/commodity/nitrogen/mcs-2011-nitro.pdf

[17] Smil, V., Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production, MIT Press (2004). ISBN 9780262693134.

[18] Himstedt, H. H., et al., U.S. Patent Application 20150125377.

[19] Smil, V., Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production, MIT Press (2004). ISBN 9780262693134.

[20] EIA data: http://www.iea.org/publications/freepublications/publication/tracking_emissions.pdf; EPA data: https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Chapter-4-Industrial-Processes.pdf

energy).[21] A potentially greener technology option of using hydrogen from water electrolysis requires 9.5 MWh to make 1 metric ton NH_3[22] (of which 8.9 MWh comes from hydrogen production, assuming 50.2 kWh/kg H_2).[23] Solid-state electrochemical ammonia synthesis, a possible alternative to the Haber-Bosch process, has potentially lower energy input and operational pressure and temperature[24] thus simplifying the balance of plant, and could be cost competitive as long as the reaction rate is significantly increased.

Ammonia is in the liquid state below -33 °C or under 15 bar at ambient temperature and has an energy density of 4.25 kWh/L. This value is 35% higher than the energy density of liquid hydrogen (in reality the difference is even larger due to large energy requirements for H_2 liquefaction) and 2.5 times higher than that of hydrogen compressed to 700 bar. It is widely used as a fertilizer, a refrigerant, and a feedstock for the chemical industry The use of ammonia as a fuel, energy carrier and hydrogen storage material has also been widely discussed.[25,26,27]

Another example of a nitrogen-based energy-dense fuel is hydrazine hydrate ($N_2H_4{\cdot}H_2O$). It is currently produced by oxidation of ammonia at a large scale (80,000 ton/year globally) and is therefore more expensive than ammonia. However, it has a high energy density (3.56 kWh/L), is easy to handle (freezing point -51.7 °C, flash point 74 °C) and, if low-cost synthetic methods are developed, it may fit the technical targets of this FOA. To accomplish wide-scale implementation of CNLFs, technological advances in both the production and conversion of this fuel would need to be achieved. An example of a non-toxic substitute for hydrazine with low carbon footprint is carbohydrazide (CH_6N_4O). Carbohydrazide has been used as a fuel in a fuel cell with an OCV 1.65V.[28]

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[21] Rafiqul, I., et al, "Energy efficiency improvements in ammonia production—perspectives and uncertainties *Energy* (2005) 30, 2487; http://ietd.iipnetwork.org/content/ammonia#benchmark.

[22] Bartels, J. R., Pate, M. B. "A feasibility study of implementing an Ammonia Economy", Iowa State University, 2008.

[23] Grundt, T., and K. Christiansen. *Int. J. Hydrogen Energy* (1982) 7.3, 247.

[24] Giddey, S., el al, *Int. J. Hydrogen Energy* (2013) 38, 14576; Garagounis, I., et al, *Front. Energy Res.* (2014) 2, 1; http://dx.doi.org/10.3389/fenrg.2014.00001; Renner, J. N., *Electrochem. Soc. Interface* (Summer 2015) 51-57

[25] Thomas, G. and Parks, G., U.S. Department of Energy Report (2006) http://www.hydrogen.energy.gov/pdfs/nh3_paper.pdf; Olson, N., and Holbrook, J. (2007) http://www.powershow.com/view/5b55a-MWZjZ/NH3_The_Other_Hydrogen_TM_powerpoint_ppt_presentation; Klerke, A., et al, *J. Mater. Chem.* (2008) 18, 2304; Bartels, J.R., Graduate Theses and Dissertations. Iowa State University, Paper 11132 (2008); Lan, R., et al, *Int. J. Hydrogen Energy* (2012) 37, 1482; Lan, R. and Tao, S. *Front. Energy Res.*, (2014) 2:35 http://dx.doi.org/10.3389/fenrg.2014.00035

[26] Ammonia is considered non-flammable by DOT classification (Class 2.2: Non-flammable compressed gas) and quickly dissipates into atmosphere if a leak does occur. It can be detected by a strong pungent smell by most people in concentrations of about 1 ppm, which is well below its harmful limits (300 ppm). See "Comparative Quantitative Risk Analysis of Motor Gasoline, LPG, and Anhydrous Ammonia as an Automotive Fuel", Quest Consultants Inc., Norman, Oklahoma, June, 2009

[27] Independent studies concluded that the hazards and risks associated with the truck transport, storage, and dispensing of refrigerated anhydrous ammonia are similar to those of gasoline and LPG Duijm, .N. J., et al, "Safety assessment of ammonia as a transport fuel" (Denmark. Forskningscenter Risoe) (2005)

[28] J. Qi et al, *ChemSusChem*, (2015) 8, 1147.

In terms of carbon containing CNLFs, there are numerous examples that would fit the definition, such as hydrocarbon fuels such as synthetic gasoline or diesel fuel, alcohols, and dimethyl ether., The requirements are that the carbon is directly taken from the atmosphere or another sustainable CO_2 source and that the fuel is produced in a one-pot chemical or electrochemical process. Current processes for production of synthetic fuels such as Fischer-Tropsch process are multi-step, very capital intensive and eventually not economical. Reducing the process complexity may allow increased efficiency and lower costs. A viable pathway to generate power (e.g. in fuel cells or ICEs as a drop-in fuel) or hydrogen should be demonstrated or adopted from literature. In addition, carbon containing CNLFs must have the potential to meet the source-to-use energy cost targets.

Delivery of Energy Services from CNLFs

For the REFUEL program, the primary end use for a CNLF is either direct conversion to electricity in a fuel cell, or cracking to release hydrogen for subsequent use in a fuel cell to delivery carbon-free power for transportation.

Conversion of CNLFs to electricity

CNLFs may be converted into useful work after transportation and/or storage either directly or indirectly. In this FOA, direct conversion is defined as delivering the fuel to a fuel cell anode without any prior chemical conversion to generate electricity directly. Indirect conversion includes fuel that is reformed (cracked) such that hydrogen is stored/delivered at the endpoint of the transportation and distribution system for further use in fuel cells.

CNLFs can be converted to electricity using fuel cells, which are electrochemical devices in which the fuel is separated from an oxygen source by an electrolyte. The CNLF can be fed to the fuel cell anode; there it is either electrochemically oxidized directly, or converted to hydrogen which is then oxidized. Existing DOE programs in the Office of Energy Efficiency and Renewable Energy (EERE)[29] and the Office of Fossil Energy[30] have focused on low temperature PEM fuel cells and high temperature SOFCs for transportation and stationary power applications, respectively. Over the past ten years, these programs have advanced PEM and SOFC technologies in both performance and cost. In 2014, ARPA-E started the Reliable Electricity Based on ELectrochemical Systems (REBELS)[31] program, focusing on fuel cells operating in an intermediate temperature range of 200 – 500 °C.

One CNLF that has received significant attention for electrochemical conversion is ammonia. Alkaline fuel cells containing Pt[32] or Ni[33] anode electrocatalyst and operating from 40 to 450 °C

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[29] http://energy.gov/eere/office-energy-efficiency-renewable-energy
[30] http://energy.gov/fe/office-fossil-energy
[31] http://arpa-e.energy.gov/?q=arpa-e-site-page/view-programs
[32] Silva, J., et al, *Applied Catalysis A: General* (2015), 490, 133 ; Yang, J., et al, *Journal of Power Sources*, (2014), 245, 277
[33] Ganley, J., *Journal of Power Sources,* (2008), 178, 44

have been powered with ammonia. In these studies, the peak power density ranged from 2 to 40 mW/cm^2, which are modest values compared to PEM and SOFC devices. To increase the power density it is necessary to minimize ammonia crossover through the electrolyte. Another approach to ammonia fuel cells is with SOFCs operating around 550 – 800 °C. In this temperature range, ammonia is first decomposed, followed by electrochemical oxidation of hydrogen. The demonstrated peak power density on ammonia fuel was 1028 mW/cm^2 at 800 °C.[34] The decrease in power when switching from hydrogen to ammonia was approximately 10%. These impressive power densities show the promise of direct ammonia fuel cells.

Other liquid fuels including hydrazine have been used in direct fuel cells.[35] Ethanol, a product of biomass anaerobic digestion has been used in SOFCs with the performance similar to ammonia.[36] Liquid fuels such as toluene, n-decane, and synthetic diesel[37] as well as palm-derived biodiesel[38] have been shown to operate stably at 700 – 800 °C. However, the long-term stable performance of such systems will likely be a challenge, due in part to increases in ohmic resistance from coke formation.

Generating H_2 from CNLFs

Generation of hydrogen from CNLFs can provide a viable path to affordable hydrogen refueling stations. Currently, about 75% of the refueling station capital cost is compression and storage.[39] Compressor cost sharply increases with the size, which is required for fast transfer of daily hydrogen delivery. In addition, large hydrogen compressors have so far demonstrated inadequate reliability. Continuous cracking of a CNLF to supply smaller size compressors for smaller high pressure tanks will allow modular capability and increase the station reliability. The use of liquid fuels to generate hydrogen on demand may allow dramatically reduced size and footprint of the storage and compressors. Storage of 300 kg compressed hydrogen occupies 450 sq. ft.[40] while the energy equivalent amount of liquid ammonia takes 10 times less space and can be placed underground in a standard 1000 gallon tank.

Cracking of ammonia is well known and is already a commercial process. In spite of high cracking temperature and expensive catalysts it is considered as viable option for hydrogen delivery.[41] Recently, it has been reported that inexpensive alkali metal amides may replace or reduce loading of platinum group metal (PGM)-based catalysts and substantially reduce the

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[34] Liu, L., et al, *International Journal of Hydrogen Energy*, (2012), 37, 10857

[35] Soloveichik, G.L., *Beilstein J. Nanotechnol.* (2014), 5, 1399

[36] Sønderberg-Petersen, L., and Larsen, H., Energy solutions for sustainable development. (2007) p. 347-356

[37] H. Kim, et al., *J. Electrochem. Soc.* 148 (2001) A693-A695.

[38] T. Quang-Tuyen, et al, Int. J. Energy Res. 37 (2013) 609-616.

[39] Parks, G., "Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs", NREL report BK-6A10-58564 (2014).

[40] National Petroleum Council Report, Chapter 15 – Hydrogen, www.npc.org/reports/FTF-report-080112/Chapter_15-Hydrogen.pdf

[41] Cheddie D., "Ammonia as a Hydrogen Source for Fuel Cells: A Review", in "Hydrogen Energy - Challenges and Perspectives", Chapter 13 (2012), DOI: 10.5772/47759.

cracking temperature.[42] Another potential approach to H_2 generation from CNLFs is electrolysis. For example, ammonia oxidation to H_2 has a low potential (0.06V) and therefore has much lower energy requirements (1.55 kWh/kg H_2) compared to water electrolysis.[43] Several approaches to liquid NH_3 electrolysis have been demonstrated[44] but the development of more effective electrocatalysts and cell designs is necessary.

CNLFs, especially hydrocarbons and ammonia, can potentially be used directly or as a blend in internal combustion engines or turbines. Such applications, including fuel blending or engine modifications that allows the direct use of non-traditional fuels are outside the scope of this FOA.

Ancillary benefits in integration of renewable power sources

Penetration of renewables (solar, wind, biomass) has been limited by restricted power flow control options for the grid, grid resilience, intermittency, poor long-term predictability, and poor geographic matching of supply and demand. These problems can lead to curtailment of renewable production, and the use of less cost effective alternatives such as fast-ramping natural gas turbines ("peaker plants"). If the present grid structure continues, it is estimated that from 5.5%[45] to 21%[46] of variable generation (100 – 400 TWh) will be curtailed in 2050 at 50% renewables penetration. Further increasing the renewables penetration to 80% would require 95 – 115 GW of storage capacity.[47]

With a variety of grid modernization approaches, such as demand response, under way, it is likely that the amount of storage needed to integrate high renewable penetration will be reduced, but will still be very significant. The production of CNLFs from renewable power can potentially serve as an alternative form of energy storage, if the scale and production capacity can be matched to regional variabilities in electric power supply. Previously, it was shown that stationary fuel cells integrated with energy storage and demand control techniques can reduce grid instability.[48] Due to the significant costs of creating new electrical transmission capability, and losses in transmission, CNLF production plants would likely be placed near to sources of renewable power, and the fuels would be shipped to consumers at lower cost by truck, rail or pipeline. While the primary goal of this program is the production and conversion of CNLFs for

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[42] David, W. et al, *J. Am. Chem. Soc.*, (2014) 136, 13082; Guo, J., et al, *ACS Catal*. (2015) 5, 2708.
[43] Vitse, F., et al, *J. Power Sources* (2005) 142, 18–26.
[44] Hanada, N., et al, *Chem. Commun.*, (2010) 46, 7775; Little, D., et al, *Energy Environ. Sci.* (2015) 8, 2775.
[45] Lopez, A., et al, "U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis", NREL report TP-6A20-51946 (2012)
[46] GE Energy Consulting, J. Bebic et al., "Grid of the Future: Quantification of Benefits from Flexible Energy Resources in Scenarios With Extra-High Penetration of Renewable Energy", Nov. 2014
[47] Augustine, et al. Renewable Electricity Generation and Storage Technologies. Vol 2. of Renewable Electricity Futures Study. NREL Report TP-6A20-52409-2 (2012).
[48] Meacham, J.R. et al., J. Power Sources (2006) 156, 472; Auld, A.E. et al., *IEEE Transactions on Energy Conversion* (2009) 24, 617.

transportation, future applications in long term storage for support of the electric power system can also be envisioned.[49]

Summary

The technical approach of the **REFUEL** program is to develop novel cost- and energy-efficient technologies for generation of energy-dense liquid fuels from renewable energy, water, and air, and their subsequent conversion to deliverable power for transportation and distributed generation.

This approach will allow use of existing liquid fuel transportation technologies for transferring renewable energy from remote or stranded locations to the end-use customer instead of using electricity or hydrogen (schematically represented in Figure 1). Renewable energy such as electricity from solar and wind farms, will be converted to a CNLF (technologies of interest in Category 1), transported by existing methods, and converted via direct (electrochemical in a fuel cell) or indirect (via intermediate hydrogen extraction) oxidation at the point of use (technologies of interest in Category 2). Conceptually this program aims to minimize system level carbon emissions, and electrical transmission and storage losses, while remaining cost competitive.

The target CNLFs can be indefinitely stored in the liquid state under moderate pressure (up to 20 bar) or moderate cooling (down to -40 °C), can be transported using existing or easily expanded and modified infrastructure, and converted back into electricity and/or heat. The conversion products (primarily N_2, H_2O, and CO_2) are not captured and are released to the atmosphere. Fuels containing carbon are acceptable as long as the carbon is taken directly from air or other sustainable sources such as biomass fermentation and not from fossil fuels.

Generation of liquid fuels and their conversion to energy is currently not efficient and is economical only at large scale. To fully exploit the advantages of liquid fuels, it is therefore necessary to: (1) minimize production and conversion losses and make these processes scalable to small or medium sizes that match the scale of renewable generation; and (2) to use the existing infrastructure technologies, which is comprised of pipelines, railroads, tanker trucks, ships, terminals, as well as above- and below-ground storage. Developing technologies that work at a scale matching renewables generation and minimizing transportation/transmission and delivery costs creates opportunities for increased renewables deployment.

C. Program Objectives

The overall objective of the ***REFUEL*** program is to develop novel, cost-effective technologies to create carbon-neutral liquid fuels (CNLFs) from water and air, using renewable electricity, and subsequently convert the CNLFs to power for transportation. If successful, the program

[49] Melaina, M. and Eichman, J., "Hydrogen Energy Storage: Grid and Transportation Services", NREL report NREL/TP-5400-62518 (2015).

outcomes will transform the way renewable electricity is stored and transported from remote generation sites to the end point customer. These changes will increase utilization of intermittent renewable energy and reduce carbon emissions.

The first specific objective of this FOA is to seek cost-effective and energy-efficient technologies for generation of energy-dense liquid fuels from renewable energy, water and air. These technologies should be scalable and match the scale of renewable energy generation, such as wind farms or solar arrays, and be tolerant to the uncertain and variable nature of renewable energy sources. For the purpose of this FOA, the appropriate scale for CNLF production is 150 MW of renewable energy, which matches a single mid-size solar/wind farm or combination of several renewable sources to increase the capacity factor. This size represents both scalability and compatibility with renewable resources. The resulting fuels should be transportable using liquid fuel infrastructure (already built or which can be built with known and already deployed technologies), and stored and dispensed as a liquid.

The second specific objective of this FOA is to develop efficient methods for the conversion of CNLFs to electricity or hydrogen (as an energy carrier for zero-emission vehicles). The only products of such conversion should be water and N_2 thus creating a net zero-carbon process; in the case of carbon containing fuels, CO_2 emissions are allowed as long as equal amounts are captured from air or other sustainable sources during the synthesis process.

The cost analysis needs to consider the entire value chain from generation through distribution to use. The cost targets for this FOA are selected in order to be disruptive with current state-of-the-art and be competitive with projected methods of electricity and hydrogen transmission, distribution, storage and delivery. The cost metric includes costs of fuel production, transportation, storage, and conversion to electricity or hydrogen. A 750 mile transportation scenario is used in this FOA, which is similar to a TransWest Express, LLC project to deliver the wind power from Wyoming to California.[50] The proposed technologies should demonstrate the potential to achieve the cost of ***source-to-use delivered*** **energy of below $0.3/kWh** to the end-user at target production volumes. This value is based on the analysis of cost structure for projected large scale fuel manufacturing processes using renewable energy and known conversion processes, such as ICE or fuel cell power generation. The parameters for the analysis are presented in Table 3. An illustrative example of the cost structure of ***source-to-use delivered*** energy (including production, transmission, storage and conversion costs) for carbon- and nitrogen-based CNLFs compared to *projected* hydrogen vehicles and battery-electric vehicles (BEV)pathways is given in Figure 2 (cost assumptions are based on Table 3). If successful, the CNLF route will be more economical compared to other methods. The cost reduction potential for CNLFs and hydrogen comes from improving the production and conversion efficiencies (Figure 2), while for BEVs the battery cost is critical.

[50] http://www.powercompanyofwyoming.com/about/docs/The-Anschutz-Corporation-Overview.pdf

Only approximate calculations of the source-to-use delivered energy cost is required for the concept paper (CP) phase. Meeting or exceeding this target for small to medium scale processes is a great challenge, and can be addressed by improvements in fuel production or conversion or both. The ideal program outcome would be a suite of technology solutions that enable significantly reduced CO_2 emissions for transportation and increased penetration of renewables.

Table 3: Parameters for evaluation of the full costs of delivering transportation power using carbon-free energy sources.

Scenario	Synthetic (carbon-neutral) Gasoline	Carbon free H_2	Carbon free NH_3	Renewable electricity
Fuel production cost, $/kWh	0.090[a]	0.090[b]	0.128[c]	0.056[d]
Transportation or transmission cost, $/kWh[e] ,	0.001	0.060	0.004	0.038
Storage cost, $/kWh[e]	0.001	0.030	0.008	0.106[f]
Conversion efficiency, %[e]	30	55	55	92
Source-to-use energy cost, $/kWh	0.303	0.327	0.256	0.236

[a] – Target $3/gge set by EERE Office of Biotechnology and this FOA: http://energy.gov/sites/prod/files/2016/03/f30/At_A_GLANCE%20(BETO).pdf

[b] – Target $3/gge set by EERE Fuel Cell Technology Office; FCTO Multi-Year Research, Development, and Demonstration Plan, 3.1 Hydrogen Production (2015) http://energy.gov/sites/prod/files/2015/06/f23/fcto_myrdd_production.pdf

[c] – Target of this FOA.

[d] – Production cost for the solar:wind=60:40 mix from International Renewable Energy Agency (IRENA) (2015). “Renewable Power Generation Costs in 2014”, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

[e] – See Table 1 footnotes for assumptions.

[f] – Assumed battery pack cost $200/kWh

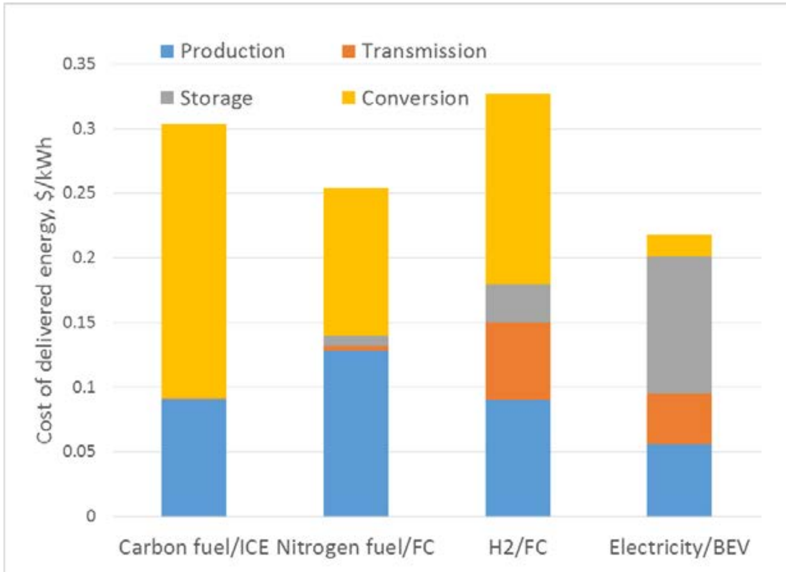

Figure 2. An example of the cost structure of source-to-use delivered energy for different pathways of renewable energy delivery.[51]

Beyond the specific objectives of the individual program categories, an additional objective of the **REFUEL** program is to create a research community, from various backgrounds and disciplines, united by the common theme of enabling widespread integration of renewable energy via the use of energy-dense liquid fuels. The fuels research is often conducted with a focus on either production or conversion. ARPA-E seeks to advance a research and development agenda in which *both* sides are considered and optimized to enable innovation in this area.

D. TECHNICAL CATEGORIES OF INTEREST

This program is focused on supporting chemistry and system concepts in energy transmission using CNLFs in one or both of the following categories:

- **CATEGORY 1: Small- and medium-scale synthesis of energy-dense carbon-neutral liquid fuels using water, air, and renewable energy source**

- **CATEGORY 2: Electrochemical processes for generation of hydrogen or electricity from energy-dense carbon-neutral liquid fuels**

The full impact of the **REFUEL** program will only be realized by linking these two categories and therefore *ARPA-E strongly encourages applications that address both categories.* For example, if proposing electrochemical production of a fuel, it is encouraged to also propose the electrochemical conversion of that fuel to electricity or hydrogen. Importantly, applications in

[51] The parameters used for the source-to-use cost calculation are presented in Table 3.

Category 1 proposing the synthesis of a novel fuel for which there is no commercially accepted method for manufacturing and conversion to electricity or hydrogen are strongly encouraged to also propose an approach for the conversion of that fuel to electricity or hydrogen, i.e. must address both Category 1 and Category 2. If only Category 1 is proposed in this case, the applicant must provide a reasonable explanation of how a conversion process for the fuel could be developed.

Category 1:

The final deliverable for Category 1 is a laboratory prototype that can be scaled to a cost-competitive small- to medium-scale synthesis of energy-dense CNLFs using air, water, and renewable power such as wind and solar. Some possible CNLFs are commercially available (e.g. ammonia) and are produced over thousands of tons per year using thermochemical methods. In this program, production using new approaches based on the use of renewable energy as well as novel fuels or fuel compositions may be developed. All CNLFs have to be responsive to this FOA in the terms of physical properties, energy density, handling, and conversion to electricity and fuels as defined in the technical targets section and metrics tables below. For example, a proposed fuel should be liquid over a practical range of temperatures, stable for an indefinite period of time, and compatible with existing methods and infrastructure for liquid storage and transportation. The required purity of fuels depends on the fuel type as well as on the application and this metric has to be defined by an applicant and expressed in terms of content of the main component and the maximum concentration of individual impurities that have or may have a deleterious effect on the fuel use. A proposed fuel must have a high autoignition point (>200 °C) to ensure its safe use.

The synthesis of energy-dense CNLFs must be economical at small- to medium-scales to match the deployment of renewable power generation. This scale will require new methods to synthesize energy-dense fuels and innovative designs of chemical (***Subcategory 1A***) or electrochemical (***Subcategory 1B***) reactors. The current thermochemical production scale, e.g. Haber-Bosch synthesis of ammonia, is too large for the deployable scale of renewables (from 1 – 2 MW to 100 – 150 MW). The conventional process scales down poorly: the production cost increases from $325/ton NH_3 (at the natural gas price $5/MMBtu) for the production scale of 516,000 ton/year to $545 to $983 with decreasing the scale to 50,000 to 3,400 tons per year.[52] To match the capacity of the majority of new renewable energy installations (ca. 80 – 350 MW with average size of 90 MW (in 2009) for wind farms and 150 MW for solar PV plants),[53] fuel production plants should be a capable of generating around 10 – 25 ton NH_3/hr at peak power with demonstrated energy consumption (Table 1). This scale is substantially smaller than a

[52]Maung, T. et al., "Economics of Using Flared vs. Conventional Natural Gas to Produce Nitrogen Fertilizer: A Feasibility Analysis", North Dakota State University (2012): http://purl.umn.edu/133410

[53] Wiser, R., Bolinger, M., "Wind Technologies Market Report", LBNL (2015), https://ilsr.org/us-wind-projects-get-bigger-building-not-adding-turbines

typical Haber-Bosch plant, which generates 50 – 125 ton NH_3/hr in steady state,[54] and therefore represents a substantial challenge.

The production method should also be tolerant to intermittent energy supply, i.e. it should effectively operate at variable rates of production. For both existing commercial and newly-proposed fuels, both new synthetic methods and improvements to existing synthetic methods will be considered. Proposed synthetic methods must lead to a reduction of energy consumption and/or production cost. The proposed manufacturing methods may include known processes, e.g. intermediate hydrogen production by water electrolysis, though direct, one-pot synthetic methods are preferable. Only direct electrochemical conversion of CO_2 to CNLFs that can be directly used in fuel cells or in ICEs will be considered (*Subcategory 1B*).

The production cost for the proposed technology should be calculated using the input electricity price of $0.05/kWh. For applicants solely addressing Category 1, the total cost of delivered energy should be calculated using documented costs for fuel storage, transportation, and proposed use. For the concept paper, reasonable approximate values, as provided in Table 3, may be used. Input and output energy values should be used to calculate overall efficiency.

Examples of technical approaches include but are not limited to:

- High energy density fuels – Areas of particular interest are nitrogen-based fuels, e.g. ammonia, hydrazine hydrate and its derivatives including scaling down an air separation process; carbon containing fuels based on CO_2 capture from air or other sustainable sources thus enabling zero-carbon cycle, e.g. hydrocarbons or stable, non-corrosive oxygenates that can be used as a fuel for ICEs or fuel cells and be produced by direct electrochemical or thermochemical (one-pot) reaction.
- Novel methods for synthesis of known energy-dense liquid fuels – Areas of particular interests are direct electrochemical and thermochemical methods for synthesizing CNLFs that use water as a hydrogen sources instead of molecular hydrogen, and effective catalytic methods for hydrogen generation that allow for substantial decrease of operating pressures and temperatures.
- Innovative design of electrochemical and catalytic reactors operating at moderate pressure and temperatures and providing high yield per pass/volume and selectivity; membrane reactors that allow removal or supply of reactants thus shifting the equilibrium.
- Catalysts, electrocatalysts and materials to enable fuel synthesis.

Category 2:

The final deliverable for Category 2 is a prototype that demonstrates efficient and cost-effective technologies for conversion of CNLFs to hydrogen to be used in H_2 refueling stations (*Subcategory 2A*) or directly to electricity for mobile applications (*Subcategory 2B*). The

[54] Giddey, S., et al, *Int. J. Hydrogen Energy* (2013) 38, 14576.

prototype must be scalable to an economically viable conversion for use in light, medium and heavy duty vehicles.

In ***Subcategory 2A***, to enable hydrogen refueling stations, it is necessary to generate hydrogen from a CNLF on demand with high yield and sufficient purity for use in commercial PEM fuel cells. Storing hydrogen in the form of a liquid fuel with hydrogen density greater than liquid hydrogen will reduce the cost and footprint of current hydrogen storage. CNLF decomposition that occurs at lower temperatures could decrease energy requirements for decomposition and enable smaller heat exchangers, leading to lower system costs. To achieve this goal, it is necessary to develop more active and less expensive catalysts. Delivery of H_2 at an elevated pressure will reduce the energy spent on compression. Development of modular system designs, e.g. several modules comprising smaller cracking reactors and compressors, could potentially greatly improve reliability of the refueling stations.

Direct conversion of CNLFs to electricity is the subject of ***Subcategory 2B***. Liquid fuels (e.g. methanol, NH_3) can be used in low temperature (PEM, alkaline exchange membrane (AEM)) and high temperature (SOFC) fuel cells. Although the use of such fuels in fuel cells is well known, current technologies have low conversion and selectivity and are expensive. One of the major problems is the lack of active, selective and inexpensive electrocatalyst for anode reactions that limits current density and efficiency, and increases the stack cost. One possible solution is reforming (internal fuel cracking) to hydrogen, which is easier to oxidize. Another problem to be addressed is insufficient membrane conductivity leading to low power and therefore oversized stack cost, and, for low temperature fuel cells, low selectivity causing fuel crossover and reducing the fuel cell efficiency. Crossover is less pronounced for AEMs but they have the additional issue of low thermal stability. All types of fuel cells have the shared problem of sluggish kinetics for the oxygen reduction reaction (ORR) at the cathode, which is more pronounced for PEM FCs with acidic membranes and is less problematic for AEM fuel cells. In addition to development of more effective anode electrocatalysts and membranes, substantial improvements may be reached via novel electrode and cell design and better system integration. A separate ARPA-E program, Integration and Optimization of Novel Ion Conducting Solids (IONICS), has one Technical Category focusing exclusively on ex-situ testing of AEMs. . In the IONICS program full cells will not be made and tested. In **REFUEL**, however, submissions to *Subcategory 2B* must propose full cells that meet the metrics defined below.

For applicants solely addressing Category 2, the total cost of delivered energy should be calculated using documented costs for the carbon-neutral generation (using renewable energy), storage, and transportation of the fuels to be used. Input and output energy values should be used to calculate overall efficiency.

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

- High and intermediate temperature fuel cells for electricity generation directly from CNLF's – Areas of particular interest are approaches to novel, high power density electrode architectures; oxygen- or proton-conducting solid electrolytes; direct use of liquid fuels without ex-situ reforming; using non-platinum group metal catalysts; materials and device designs for long life fuel-air systems; integrated systems for combined heat and power generation.

- Ambient temperature fuel cells for electricity generation directly from CNLF's – Areas of particular interest are approaches to novel high power density membrane-electrode assemblies using anion exchange membranes; direct use of liquid fuels without reforming; using non-platinum group metal catalysts; system integration.
- Hydrogen generation systems for hydrogen refueling stations – Areas of particular interest are approaches to low temperature thermal catalytic cracking; electrochemical decomposition; high pressure delivery, electrochemical hydrogen compression.

The ideal project team will have engineering and scientific expertise in every aspect of the fuel production and/or conversion system design and a good understanding of catalysis, electrochemistry, material properties, energy storage systems, and catalytic or electrochemical reactor design. This teaming arrangement is especially important for projects focused on novel fuels because any claim of potential benefit requires a thorough understanding of their possible use for electricity or hydrogen generation and system design requirements. The team needs to have the necessary expertise in fuel and fuel cell manufacturing, though ARPA-E does not require the participation of the established industrial manufacturers.

E. TECHNICAL PERFORMANCE TARGETS

Proposed technical plans must show a well-justified, realistic potential for the technology to meet or exceed the **REFUEL** cost targets for source-to-use energy or hydrogen. To achieve this goal, the detailed Technical Performance Targets described below should be met. If an applicant applies for both Categories 1 and 2, then some trade-offs between Category Technical Performance Targets for different process efficiencies may be considered. The final research objective for projects funded under this FOA is a fully functional prototype, specific for each subcategory (see Tables below), that credibly demonstrates all technical targets. The minimum prototype size, which is different for each subcategory, has been chosen by ARPA-E so that the results from the performance tests, as defined below, can be readily used to predict the performance, life-time, and cost of the proposed systems.

The cost of *source-to-use* electrical energy (in $/kWh) is defined as the sum of CNLF production (technologies described in Category 1), transportation, storage, and conversion to electricity (technologies described in Category 2). *A clear justification of the potential to deliver a total cost of source-to-use energy below $0.3/kWh must be provided for the application to be considered*. The scale of fuel production plant for this cost estimation should be 150MW. It is anticipated that several technical approaches are capable of meeting this target, and preference will be given to submissions that have demonstrated a potential to be substantially lower in the cost. Specific technical targets presented below are set to ensure that the overall vision may be realized and should be addressed in the application.

Concept Papers must include evaluation of the source-to-use delivered energy cost. If applying only to Category 1 then the applicant should use literature values for cost of conversion technologies appropriate to the proposed fuel. If applying only to Category 2, then the applicant should use literature values for the carbon-free production cost of the input fuel. *For simplicity, in the Concept Paper phase, transmission and storage costs for the calculation should be assumed to be $0.02/kWh for any CNLF*. A more detailed cost calculation with references and stated assumptions will be required in the Full Application phase, at which point additional guidance will be provided. All proposed technologies have to be nearly zero-carbon, e.g. release no more than 50 g CO_2 from auxiliary processes per kWh produced energy.

Category 1:
The following metrics apply to all projects in Category 1 (see subcategory targets for additional metrics):

ID	Description	Target
1.1	Fuel cost on primary energy basis at 150MW scale	< $0.13/kWh
1.2	Fuel energy density	> 3.5 kWh/L
1.3	Storage temperature	above -40°C[1]
1.4	Storage pressure	below 20 bar[2]
1.5	Autoignition point	> 200 °C
1.6	Liquid fuel viscosity	< 100 Centipoise
1.7	CO_2 released in fuel production	< 50g CO_2/kWh of fuel energy content

[1] – at ambient pressure
[2] – at ambient temperature

Subcategory 1A is comprised of chemical (catalytic) synthesis of energy-dense CNLFs based on hydrogen produced from water splitting and innovative designs of chemical reactors. The following metrics apply to projects in subcategory 1A:

Specific to subcategory 1A: Chemical production		
ID	**Description**	**Target**
1A.1	Reaction rate	> $7x10^{-7}$ mol cm^{-2} s^{-1}
1A.2	Final prototype productivity	> 1 kg CNLF/day
1A.3	Total production energy efficiency	> 60%
1A.5	Fuel synthesis efficiency	> 86%
1A.6	Fuel purity	> 99%

Subcategory 1B is comprised of electrochemical and thermochemical synthesis of energy-dense CNLFs using water and innovative designs of electrochemical reactors and thermochemical systems. The following metrics apply to projects in subcategory 1B:

Specific to subcategory 1B: Electrochemical production		
ID	**Description**	**Target**
1B.1	Current density for electrochemical production	> 300 mA/cm^2
1B.2	Final prototype productivity	> 100 g CNLF/day
1B.3	Coulombic efficiency	> 90%
1B.4	Production energy efficiency	> 60%
1B.5	Degradation rate	0.3%/1000 hrs
1B.6	Fuel purity	> 99%

End-of-project deliverables:

Both subcategories have to deliver a detailed techno-economic analysis based on a comprehensive model meeting all of the technical targets and demonstrate a pathway to the CNLF cost target at a scale of 150 MW input energy.

Subcategory 1A: Demonstration of a bench scale reactor producing a CNLF at >1 kilogram per day.

Subcategory 1B: Demonstration of a short stack prototype producing a CNLF at >100 gram per day.

Any application proposing the synthesis of a novel fuel for which there is no commercially accepted method for manufacturing should indicate a technical path and use reasonable conversion cost for conversion to electricity or hydrogen. In this case applicants are strongly encouraged to submit to Categories 1 and 2 and to meet all relevant metrics.

Supplemental Explanation of Category 1 Performance Targets:

1.1 See the full explanation in the overview of this Section.
1A.1 Proposed manufacturing process of a CNLF should be tolerant to intermittent nature of renewables. The process should be demonstrated with a prototype reactor at a kg/day scale in a continuous (500 hours) operation with at least 5 interruptions designed to test the effect of intermittency in power supply.
1A.3 Total production energy efficiency is defined as the ratio of CNLF primary energy to total consumed energy when water is used as hydrogen source.
1A.4 Fuel synthesis efficiency is defined as the ratio of primary energy to consumed energy when a CNLF is synthesized using hydrogen.

1B.1 Proposed manufacturing process of a CNLF should be tolerant to intermittent nature of renewables. The process should be demonstrated with a prototype reactor at a kg/day scale that operates for 500 hours continuously with at least 5 on/off cycles.

1B.4 Production efficiency is defined as the ratio of theoretical process energy to consumed energy.

1B.5 Degradation is defined as the increase in cell voltage at the target current density.

Category 2:

Subcategory 2A is comprised of hydrogen generation from CNLFs using thermal or electrochemical pathways and innovative reactor design. The following metrics apply to projects in subcategory 2A:

Subcategory 2A: Hydrogen generation		
ID	**Description**	**Target**
2A.1	Hydrogen delivered cost at target pressure	< $4.5/kg
2A.2	Final prototype size	10 L H_2/min
2A.3	Hydrogen generation rate	> 0.15 g H_2/h/cm^3
2A.4	Conversion to hydrogen	> 99%
2A.5	Energy efficiency	> 80%
2A.6	Maximum cracking reactor temperature	450 °C
2A.7	Hydrogen delivered pressure	30 bar
2A.8	Life time (projected)	10 yrs
2A.9	Concentration of catalyst poisoning impurities	< 100 ppb

Subcategory 2B is comprised of electricity generation from CNLFs using electrochemical fuel cells and innovative cell design. The following metrics apply to projects in subcategory 2B:

Subcategory 2B: Direct use of fuel		
ID	**Description**	**Target[a]**
2B.1	Delivered source-to-use energy cost target	< $0.3/kWh
2B.2	Final prototype size	50 W
2B.3	Maximum operating temperature	650 °C
2B.4	Current density at 0.75 V	> 300 mA/cm^2
2B.5	Electrical efficiency@ 25% of rated power	> 55%
2B.6	Minimum continuous stack testing time	500 hours
2B.7	Power degradation rate	< 0.3% per 1,000 hours

[a] – For more guidance on system requirements see DOE Fuel Cell Technical Team Roadmap (2013), http://energy.gov/sites/prod/files/2014/02/f8/fctt_roadmap_june2013.pdf (mobile applications) and DOE Solid State Energy Conversion Alliance (SECA) program, http://www.netl.doe.gov/research/on-site-research/research-portfolio/coal-research/seca-index (stationary applications)

End-of-project deliverables:

Both subcategories have to deliver a detailed techno-economic analysis based on a comprehensive model meeting all of the targets.

Subcategory 2A: Demonstration of a bench scale cracking reactor or electrochemical cell stack producing H_2 from a CNLF at greater than 100 grams per day.

Subcategory 2B: Demonstration of a short stack prototype of at least 50 W and consisting of at least 3 cells with a total working area greater than 250 cm^2. The fuel must be fed directly to the anode; concepts that propose an external fuel processing unit will not be considered for selection.

Supplemental Explanation of Category 2 Performance Targets:

2A.1 See the full explanation in the overview of the Technical Targets section.
2A.3 Conversion to hydrogen is defined as the percentage of extracted hydrogen from containing in a CNLF.
2A.4 Energy efficiency (EE) is defined as *EE = P/(P+E)* where *P* is the primary energy of extracted hydrogen and *E* is energy consumed for the conversion process.
2A.7 Testing time for the projects will be 500 hours.
2A.8 Concentration of ammonia or other fuel cell catalyst poisoning gases in generated hydrogen should be less than 100 ppb for its direct use in a PEM fuel cell.
2B.1 See the full explanation in the overview of the Technical Targets section.
2B.5 Electrical efficiency is defined as the ratio of produced electrical energy to primary energy of a CNLF.
2B.7 Degradation is defined as the decrease in fuel cell voltage at the target current density

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $25 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 April 1, 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 submissions 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."[55] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.C below.

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

1. Cooperative Agreements

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[56]

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 Lab Authorization" and "Field Work Proposal" section of the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

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

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

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

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

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 in accordance with 2 C.F.R. §§ 200.338 and 200.339.

- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

III. Eligibility Information

A. Eligible Applicants

1. Individuals

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[57] as the lead for a Project Team,[58] or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. Domestic Entities

For-profit entities, educational institutions, and nonprofits[59] 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.

[57] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[58] 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.
[59]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.

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

3. Foreign Entities

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or otherwise formed or to be formed) under the laws of a State or territory of the United States to receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. 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.4 of the FOA. Each consortium must have an internal governance structure and a written set of internal rules. Upon request, the consortium entity must provide a written description of its internal governance structure and its internal rules to the Contracting Officer (ARPA-E-CO@hq.doe.gov).

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

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

B. COST SHARING[60]

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[61] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[62]

2. INCREASED COST SHARE REQUIREMENT

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

Under 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").[63] If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the costs

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

[61] 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.

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

[63] Small businesses are generally defined as domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards). Applicants that are small businesses will be required to certify in the Business Assurances & Disclosures Form that their organization meets the SBA's definition of a small business under at least one NAICS code.

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.[64]

- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs 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 perform greater than or equal to 80%, of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.

- Projects that do not meet any of the above criteria are subject to the minimum cost share requirements described in Sections III.B.1 and III.B.2 of the FOA.

4. Legal Responsibility

Although the cost share requirement applies to the Project Team as a whole, the funding agreement makes the Prime Recipient legally responsible for paying 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.

[64] See the information provided in previous footnote.

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[65] 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.

[65] As defined in Federal Acquisition Regulation Subsection 31.205-18.

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

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

7. Cost Share Contributions by FFRDCs and GOGOs

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

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

8. Cost Share Verification

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

C. Other

1. Compliant Criteria

Concept Papers are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Concept Paper complies with the content and form requirements in Section IV.C of the FOA; and

- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Concept Papers found to be noncompliant may not be merit reviewed or considered for award. ARPA-E 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.

Full Applications found to be noncompliant may 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 Replies to Reviewer Comments comply with the content and form requirements of Section IV.E of the FOA.

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

2. Responsiveness Criteria

ARPA-E performs a preliminary technical review of Concept Papers and Full Applications. The following types of submissions, and those identified below in Section III.C.3, may be deemed nonresponsive and may not be reviewed or considered:

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

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

- Reversible liquid fuel generation (hydrogenation/dehydrogenation)
- Liquid hydrogen
- Fuels by conversion of fossil fuels (e.g. methane to liquid)
- Fuels by conversion of CO_2 generated from fossil fuels
- Fuels in the form of a slurry
- Carbon positive processes that exceed the Technical Performance Target

- Generation of fuels by biological or enzymatic methods
- Photochemical water splitting
- Fuels generating solid residues
- Systems with onboard fuel reforming
- Optimization and modification of combustion engines
- The use of fuels in microbial and enzymatic fuel cells
- Technologies for transportation and storage of liquid fuels
- Oxygen cathode improvements in fuel cells
- Blending of fuels
- Improvements in hydrogen/air fuel cells

4. Limitation on Number of Applications

Small businesses that qualify as "Small Business Concerns" are strongly encouraged to apply under ARPA-E FOA DE-FOA-0001563, Renewable Energy to Fuels through Utilization of Energy-dense Liquids (REFUEL SBIR/STTR)). To determine eligibility as a "Small Business Concern" under DE-FOA-0001563, please review the eligibility requirements in Sections III.A-III.D of DE-FOA-0001563 (SBIR/STTR), available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov).

Small businesses that qualify as a "Small Business Concern" may apply to only one of the REFUEL FOAs.

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.H.1 of the FOA and the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

2. Concept Papers

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

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria 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 application submission that is unlikely to be selected for award negotiations. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

3. Full Applications

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 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. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria in Section V.A.2 of the FOA.

4. Reply to Reviewer Comments

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

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

5. Pre-Selection Clarifications and "Down-Select" Process

Once ARPA-E completes its review of Full Applications and Replies to Reviewer Comments, it may, at the Contracting Officer's discretion, conduct a pre-selection clarification process and/or perform a "down-select" of Full Applications. Through the pre-selection clarification process or down-select process, ARPA-E may obtain additional information from select Applicants through pre-selection meetings, webinars, videoconferences, conference calls, written correspondence, or site visits that can be used to make a final selection determination. ARPA-E will not reimburse Applicants for travel and other expenses relating to pre-selection meetings 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.

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

Each Concept Paper 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.
- Include an estimated value of the source-to-use energy cost (SUE) for a CNLF as determined by the following formula, where η is conversion efficiency, CF is the fuel production cost, CT is the transportation or transmission cost and CS is the storage cost:

$$SUE = (CF+CT+CS)/\eta$$

- If only applying to Category 1 then the applicant should use literature values for cost of conversion technologies appropriate to the proposed fuel. If applying only to Category 2, then the applicant should use literature values for cost of the input carbon-neutral fuel.
- For simplicity, in the CP phase, transmission and storage costs for the calculation should be assumed to be $0.02/kWh for any CNLF.

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 JULY 2016]

E. Content and Form of Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JULY 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 JULY 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;
- Failing to click the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

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

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

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

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

1. Criteria for Concept Papers

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

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- Achievement of the Technical Performance Targets defined in Section 1.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and
- Demonstration of awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

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

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;
- Sufficiency of technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;
- Clearly defined project outcomes and final deliverables;
- Identification of 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 JULY 2016]

3. Criteria for Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JULY 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 JULY 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 merit reviewed or considered for award. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Concept Paper or Full Application was rejected.

2. Concept Paper Notifications

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

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

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

3. Full Application Notifications

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

B. Administrative and National Policy Requirements

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

C. Reporting

[TO BE INSERTED BY FOA MODIFICATION IN JULY 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).

J. COMPLIANCE AUDIT REQUIREMENT

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

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

IX. GLOSSARY

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

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

ARPA-E: is the Advanced Research Projects Agency – Energy, an agency 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).