FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

GENerators for Small Electrical and Thermal Systems (GENSETS)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001198
CFDA Number 81.135

FOA Issue Date:	October 16, 2014
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, November 24, 2014
Submission Deadline for Concept Papers:	5 PM ET, December 01, 2014
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.
- ARPA-E will not review or consider noncompliant or nonresponsive applications. For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 and III.C.2 of the FOA.

Questions about this FOA? Email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A.
Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: ○ Concept Summary/Overview ○ Proposed Work ○ Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, December 01, 2014
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]	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, 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 support the creation of transformational energy technologies and systems through funding and managing Research and Development (R&D) efforts. Originally chartered in 2007, the Agency was first funded through the American Recovery and Reinvestment Act of 2009.

The mission of ARPA-E is to identify and fund research to translate science into breakthrough energy technologies that are too risky for the private sector and that, if successfully developed, will create the foundation for entirely new industries.

Successful projects will address at least one of ARPA-E's two Mission Areas:

1. Enhance the economic and energy security of the United States through the development of energy technologies that result in:
   a. reductions of imports of energy from foreign sources;
   b. reductions of energy-related emissions, including greenhouse gases; and
   c. improvement in the energy efficiency of all economic sectors.
2. Ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.

ARPA-E funds applied research and development. ARPA-E exists to fund applied research and development, defined by the Office of Management and Budget as a "study (designed) to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met" and 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." ARPA-E funds technology-focused applied research to create real-world solutions to important problems in energy creation, distribution and use and, as such, will not support basic research, defined as a "systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind." While it is anticipated that in some instances some minor aspects of fundamental science will be clarified or uncovered during the conduct of the supported applied research, the major portion of activities supported by ARPA-E are directed towards applied research and development of new technologies.

While all technology-focused applied research will be considered, two instances are especially fruitful for the creation of transformational technologies:

- the first establishment of a technology based upon recently elucidated scientific principles; and
- the synthesis of scientific principles drawn from disparate fields that do not typically intersect.

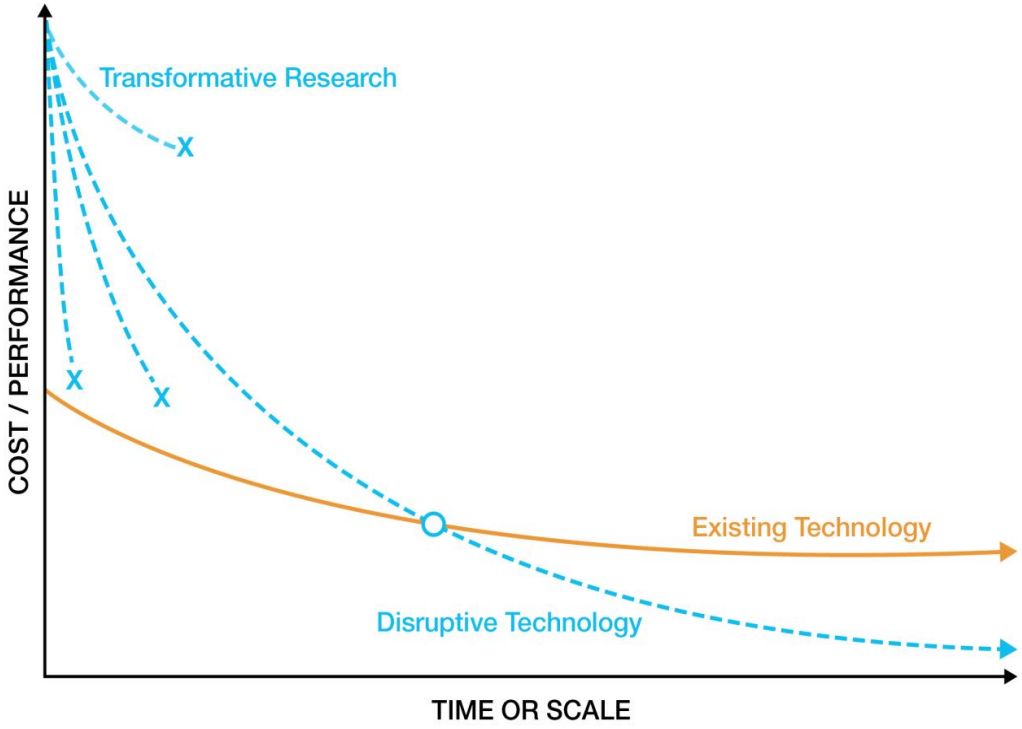

Figure 1: Description of transformational and disruptive technologies in terms of cost per unit performance versus time or scale. ARPA-E seeks to support research that establishes new learning curves that lead to disruptive technologies.

ARPA-E exists to support transformational, rather than incremental research. Technologies exist on learning curves (Figure 1). Following the creation of a technology, refinements to that technology and the economies of scale that accrue as manufacturing and widespread distribution develop drive technology down that learning curve until an equilibrium cost/performance is reached. While this incremental improvement of technology is important to the ultimate success of a technology in the marketplace, ARPA-E exists to fund transformational research – i.e., research that creates fundamentally new learning curves rather than moving existing technologies down their learning curves.

ARPA-E funded technology has 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. Energy technologies typically become disruptive at maturity rather than close to inception and the maturation of nascent technologies often require significant incremental development to drives the technology down its natural learning curve to its ultimate equilibrium (see Figure 1 above). Such development might include modification of the technology itself, the means to produce and distribute that

technology, or both. Thus, while early incarnations of the automobile were transformational in the sense that they created a fundamentally new learning curve for transportation, they were not disruptive, because of the unreliability and high cost of early automobiles. Continuous, incremental refinement of the technology ultimately led to the Ford Model T: as the first affordable, reliable, mass-produced vehicle, the Model T had a disruptive effect on the transportation market.

ARPA-E will not support technology development for extended periods of time; rather, ARPA-E supports the initial creation of technology. Following initial testing of the first prototype of a device, a system, or a process, other Federal agencies and the private sector will support the incremental development necessary to bring the technology to market.

While ARPA-E does not require technologies to be disruptive at the conclusion of ARPA-E funding, ARPA-E will not support technologies that cannot be disruptive even if successful. Examples of such technologies are approaches that require elements with insufficient abundances of materials to be deployed at scale, or technologies that could not scale to levels required to be impactful because of, for example, physical limits to productivity.

ARPA-E will not support basic research aimed at discovery and fundamental knowledge generation, nor will it undertake large-scale demonstration projects of existing technologies. ARPA-E is not a substitute for existing R&D organizations within the Department of Energy, but rather complements existing organizations by supporting R&D objectives that are transformational and translational. Applicants interested in receiving basic research financial assistance should work with the Department of Energy's Office of Science (http://science.energy.gov/). Similarly, projects focused on the improvement of existing technology platforms may be appropriate for support by the applied programs – for example, the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy (http://fossil.energy.gov/), the Office of Nuclear Energy (http://nuclear.energy.gov/), and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. PROGRAM OVERVIEW

1. SUMMARY

The GENSETS Program – ***GEN****erators for* ***S****mall* ***E****lectrical and* ***T****hermal* ***S****ystems* – seeks to fund the development of potentially disruptive generator technologies that will enable widespread deployment of residential Combined Heat and Power (CHP) systems. Here, CHP is defined as the distributed generation of electricity from piped-in natural gas fuel at a residence or a commercial site complemented by use of exhaust heat for local heating and cooling. If adopted widely by U.S. residential and commercial sectors, GENSETS CHP systems could lead to annual primary energy *savings* of more than 5 quadrillion BTU (quads). GENSETS systems could also provide annual CO_2 emissions *reductions* of more than 200 million metric tons, which is roughly 10% of the CO_2 produced annually from U.S. electricity generation and 4% of total U.S. annual CO_2 emissions.

The GENSETS Program seeks transformative generators/engines with 1 kW of electrical output (kW_e) that have high efficiency (40% fuel to electricity), long life (10 years), low cost ($3,000 per system), and low emissions. Heat engines and generators capable of achieving these targets may include internal and external combustion engines, turbines, and solid state devices such as thermophotovoltaics, thermionic emitters, and thermoelectrics. It is anticipated that the same technologies developed for 1-kW_e engines in GENSETS could be adapted to build larger engines with even higher efficiencies for various commercial sectors of the U.S.

2. BACKGROUND AND MOTIVATION

2.1 Opportunity and Impact of CHP

In 2013, U.S. central-station power plants consumed 38.2 quads of primary energy to generate 12.4 quads of electricity with an average electricity generation efficiency of 33% when aggregated over all primary energy sources, including coal, natural gas, nuclear, hydro, and wind[1]. In the process, 67% of the primary energy was wasted as heat (25.8 quads) and about 2 billion metric tons of CO_2 were emitted to the environment, which is about 38% of the total annual U.S. CO_2 emissions[2]. Distributed CHP systems are an alternative to central-station power plants. In these systems, an electrical generation system located in a residence or at a commercial site consumes natural gas to generate electricity locally and then the exhaust heat is utilized for local heating needs (in contrast to being wasted at central-stations). The combined efficiency of primary energy usage in CHP can be higher than 80%. Since about 75% of the electricity generated from all central-station power plants is consumed by the residential and commercial sectors, CHP in these sectors can have a huge impact on both energy savings

[1] https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2013/2013USEnergy.png
[2] www.eia.gov

and CO_2 emissions reduction. In addition, CHP can bring power resilience to households and commercial entities to counter weather-related outages that cause billions of dollars of losses to the U.S. economy annually.[3]

The current best-performing engines for CHP at small-scale (<2-kW_e) have a fuel-to-electricity efficiency of about 26% and a Capital Expenditure (CAPEX) of more than $6,000 per kW_e. The combination of low efficiency and high cost has significantly limited CHP deployment in the U.S. residential sector, resulting in fewer than 1,000 total installed units[4], or a deployment rate of less than 0.002%. In order to fundamentally change this dynamic, ARPA-E believes that an efficiency of at least 40% and a system cost of less than $3,000 per kW_e is needed. The ARPA-E GENSETS program seeks new engine (generator) technologies to enable widespread deployment of CHP, primarily for the residential sector. However, if successful, it is anticipated that the same technologies could be readily scaled up to enable extensive CHP implementation in the commercial sector. Roughly 70 million U.S. residential homes[2] currently have access to natural gas, critical for widespread CHP deployment. To enable residential CHP adoption, ARPA-E believes that inexpensive, efficient, small-scale generators are the key enabler.

2.2 The Optimal CHP System

Optimal Size and Efficiency

A single size engine/generator will not satisfy every application in a diverse residential CHP market. However, ARPA-E's analysis, presented below, indicates that a 1-kW_e output is optimal for most residential applications.

In order to define an optimal engine/generator size that could be deployed across the entire U.S. residential sector, ARPA-E analyzed the energy consumption profile using the National Renewable Energy Laboratory (NREL) BEopt tool[5] for twelve representative cities in the seven Building America Climate Regions[6]. For example, Figure 2 shows the hourly energy consumption/load profile for Chicago (in the cold climate zone) during representative summer and winter days. The green solid line represents the output from a theoretical 1-kW_e generator running at a steady-state all day. In both the January and July cases, a 1-kW_e system would send a small amount of electricity to the grid during the early morning hours and the household would extract electricity from the grid during evening hours to supplement their electricity needs. For most days, the electricity from the 1-kW_e system is slightly below the household needs and hence the household would need to extract a small amount of electricity from the grid.

[3] Arghandeh et al. IEEE Power & Energy Magazine, September/October, 2014, p. 76.
[4] http://arpa-e.energy.gov/sites/default/files/Mike%20Cocking_Marathon.pdf
[5] https://beopt.nrel.gov/
[6] http://www.eia.gov/consumption/residential/maps.cfm

A 1-kW_e 40% electrical efficiency system would generate 1.5 kW per hour of exhaust heat, represented by the light-blue areas enveloped by thin dashed red lines in Figure 2. For Chicago, the exhaust heat would be able to satisfy all the domestic hot water needs and also contribute to space heating requirements during the cold-weather months. Additional space heating could be provided by a natural gas fired furnace, which is likely >80% efficient. In the summer months, the exhaust heat produced from the CHP system is beyond the domestic hot water requirements. However, air conditioning energy saving opportunities could be realized through use of advanced adsorption chillers.

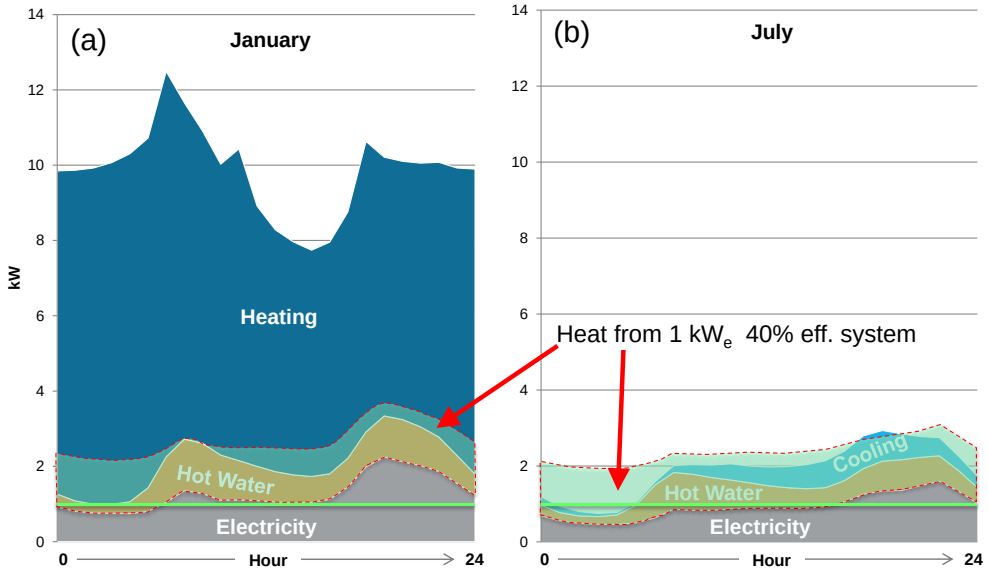

Figure 2. Hourly residential energy consumption profile for Chicago during (a) January and (b) July. The turquoise-colored areas enveloped by the red dashed lines represent the heat output from a 1-kW_e system at 40% electrical efficiency.

Larger CHP systems are unnecessary for ordinary homes in the residential sector and would lead to reduced overall efficiency. First, excess electricity generated by a larger system would need to be delivered to the grid, which may or may not pay retail or even wholesale electricity price depending on the local and the electricity utility policies. Second, systems above 1 kW_e would produce a significant amount of unused exhaust heat during the warm-weather months. This would necessitate the system to operate at a reduced load (which lowers the efficiency) or to operate only in cold weather months (which reduces the capacity factor). Similar conclusions are drawn from ARPA-E's examination of load data for the 11 other cities located across different climate zones[7]. Based on this analysis, ARPA-E has determined that 1-kW_e is an appropriate scale in terms of electrical and thermal output for application across the U.S. and focuses this FOA on developing a generator to provide that output with 40% electrical efficiency.

[7] http://arpa-e.energy.gov/sites/default/files/JC%20Zhao_Small%20engines%20for%20CHP%20workshop%20Introduction_final.pdf

Minimum System Lifetime and Maximum Viable CAPEX

Reducing total cost of ownership will be a key enabler to CHP system adoption. This FOA focuses primarily on the CAPEX associated with the gas to electrical generation part of the system. The CAPEX defined here includes the system cost but excludes the installation and balance of plant costs. (The balance of plant includes a smart meter and heat exchangers to dissipate excess heat not being used).

ARPA-E performed a techno-economic analysis for a hypothetical residence with an hourly 1 kW electric and 1.5 kW thermal load (both assumed constant for simplicity). The 2013 national average retail price of electricity ($0.11 per kWh) and natural gas ($10.85 per thousand cubic feet) were used in the analysis. In this case, a customer would pay about $1,700 a year to obtain electricity from the grid and natural gas through a pipeline, which serves as the baseline scenario. Replacing this with CHP would require the homeowner to pay the initial labor costs at installation and balance of system costs of ~$1,400, and an Operation and Maintenance (O&M) cost of roughly $0.005 per kWh. ARPA-E analysis shows breakeven for the homeowner in 7 years if the 40%-efficient generator system costs about $3,000 in CAPEX. The homeowner would pay about $1,240 per year, and would be able to use savings in electricity and natural gas costs to recover the cost of the CHP system and pay ongoing O&M costs.

More analysis was performed by varying the values of CAPEX, lifetime/durability of the system, electricity price, and capacity factor. The results clearly show that even with 40% electrical efficiency, if the system lifetime is below 10 years, it is very hard to compete with today's baseline. A lower CAPEX of $1,000 would provide a payback period of three years, but ARPA-E recognizes that it is unlikely that a 40%-efficient generator could be produced at such low cost.

ARPA-E recognizes that installing and maintaining the electricity grid requires high fixed-cost investment in wires, transformers, etc. Currently, residential customers pay for these costs predominantly through their $/kWh retail electricity rates. As the penetration of distributed generation continues to grow, traditional utility rate structures that recover fixed costs through variable rates can cause problems such as utility revenue inadequacy and cross-subsidization between customers. Projecting the actual cost of grid electricity into a future with widespread CHP penetration is highly uncertain, since customers who install CHP systems would continue to rely on a connection from the electrical grid and they will continue to pay a portion of the cost of grid installation and maintenance. A lower bound for comparison would be to use the current wholesale electricity price in the analysis ($0.06 to $0.10 per kWh), which with a 7-year payback indicates that the CAPEX would likely need to be below $2,000 for the 40% generator.

In light of the considerations above, the GENSETS FOA sets a CAPEX target of $3,000 and a system lifetime of 10 years. These targets provide a fair balance between payback time for the consumer in light of uncertainty in future electricity prices associated with high CHP penetration.

Emissions and Noise Requirements

In order to be widely deployable across the country over time, ARPA-E expects CHP systems to meet the 2007 California Air Resources Board (CARB) emissions regulations for natural gas powered electrical generation technologies in distributed generation applications[8]. The GENSETS targets for emission of nitrogen oxide (NOx), carbon monoxide (CO) and volatile organic compounds (VOCs) are 0.07, 0.10, and 0.02 lb/MW-hr, respectively.

The GENSETS Program also utilized the Environmental Protection Agency (EPA) New Source Performance Standards (NSPS) on Particulate Materials (PM) to set the limit at 0.4 g/kW-hr[9]. The GENSETS Program also aims at regulating both CO_2 and CH_4 greenhouse gas (GHG) emissions using a CO_2 equivalent (CO_2eq) number that is calculated based on the 100 year global warming potential (GWP) value of 28 [10] for CH_4; and the system-out CO_2eq limit is 1100 CO_2eq lb/MW-hr. The acceptable target noise level for customers, who likely would install the CHP systems in their basement, is 55 dB (A-weighting) measured at a 3-foot distance.

2.3 Technical Opportunities, Challenges and State-of-the-Art

Various systems have been commercialized or are in development for CHP applications requiring <5-kW_e, including internal combustion engines (ICEs), external combustion engines such as Stirling engines and Rankine engines, fuel-cells, micro-turbines, and solid state devices such as thermionic generators, thermoelectrics, and thermophotovoltaics (TPV)[11].

Table 1 shows best-in-class electrical conversion efficiencies for small-scale CHP applications[12,13,14]. The heat recovery efficiency is for domestic heating and hot-water. The total CHP efficiency is the sum of the electrical conversion and heat recovery efficiencies.

For a combustion engine, the final electrical efficiency η_e can be written as:

$$\eta_e = \eta_{comb} \cdot \eta_{ind} \cdot \eta_m \cdot \eta_{alt} \qquad \text{(Eq. 1)}$$

The combustion efficiency η_{comb} represents the portion of the fuel's energy that is converted into useful heat. The indicated cycle efficiency η_{ind} refers to the fraction of the useful heat energy that is converted into closed-cycle work after losses. The mechanical efficiency η_m is the percent of useful closed cycle work that is available at the shaft taking into account friction and parasitic losses. Finally, the alternator efficiency η_{alt} represents the portion of shaft work that is converted into useful electrical power. To reach the 40% η_e target, improvements in the contributing efficiencies in Eq. (1) are sought.

[8] 17 CCR §94203(b) (California Code of Regulations)
[9] 40 C.F.R. § 1039.101
[10] http://www.ipcc.ch/report/ar5/wg1/
[11] http:/www.microchap.info/micro_chp_products.htm
[12] Barbieri et al., Applied Energy, V.97, 2012, pp.723-733
[13] De Paepe et al., Energy Conversion and Management, V.47, 2006, pp. 3435-3446
[14] http://world.honda.com/news/2011/p110523Gas-Engine-Cogeneration/

Table 1: State-of-the-art efficiencies of engines for small-scale CHP applications[12,13,14]

Device/Parameter	ICE	Stirling engine	Micro-turbine	Thermophotovoltaic
Electrical power (kW_e)	1.0	2.0	3.0	1.5
Thermal power (kW)	2.5	8.0	15.0	9.4
Fuel Power (kW)	3.8	10.0	18.8	12.2
Electrical conv. eff. (%)	26.3	20.0	16.0	12.3
Heat recovery eff. (%)	65.7	80.0	80.0	79.8

ARPA-E recognizes there is a significant technology gap between the current state-of-the-art engine fuel to electricity efficiency (~26%) and the 40% target, especially while meeting demands on CAPEX/cost ($3,000) and system lifetime/durability (10 years). A fundamental challenge in devising small-scale heat engines with high efficiency is minimizing heat losses. With the exception of incomplete combustion, the main losses suffered when converting one form of energy to another are attributable to heat transfer losses. The challenge is significant for 1 kW_e engines where the high surface area to volume ratio leads to increased heat transfer loss. Figure 3 shows a typical small-scale mechanical heat engine efficiency loss breakdown. This figure suggests many methods that will likely be needed to increase the engine efficiency: 1) effective recuperation of the exhaust heat using bottoming cycles; 2) reduced heat transfer through the engine wall using thermal barriers or reduced combustion temperature to reduce the gradient across the wall; 3) effective recuperation of heat transferred to the engine coolant; and 4) reduced frictional loss through better lubrication and other techniques. Additional efficiency gains could also be obtained by reducing the parasitic losses in converters and electronics. Finally, coupling a mechanical engine with a solid state device such as a thermoelectric generator may be necessary to achieve 40% electrical efficiency. Therefore, successful systems may require topping or bottoming cycles as well as potential use of emissions reduction sub-systems. Innovative approaches together with cost-effective manufacturing technologies are needed to achieve the CAPEX target.

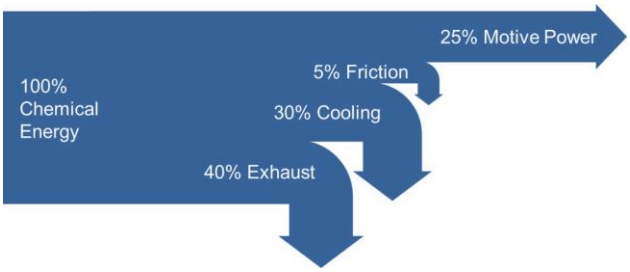

Figure 3. Typical small-scale heat engine efficiency losses.

The subsequent technical examples are meant only to illustrate principles; they are not meant to prescribe or limit the technical approaches that might receive an award through the GENSETS Program. ARPA-E will consider making an award to any application that effectively addresses the technical challenges and leads to the development of technology that can meet or exceed the associated Technical Performance Targets specified in Section I.E. ARPA-E will make awards only to transformational solutions that go well beyond the state-of-the-art.

Internal Combustion Engines (ICEs)

For generations, ICEs have been the predominant engine for a range of applications and have also penetrated the CHP market. However, ICE efficiencies remain far below the target of this FOA. Nonetheless, there are many potential opportunities for increasing efficiency. For example, the natural gas powered ICE, noted in the second column in Table 1, achieves high efficiency by employing an over-expanded Atkinson cycle and a unique geometric design.[14]

Novel strategies for reducing in-cylinder heat transfer[15] and friction[16] and/or novel methodologies for tapping coolant and exhaust heat need to be devised for ICEs to deliver 40% electrical efficiency at the 1-kW_e size. New understanding of combustion science such as boosted homogeneous charge compression ignition (HCCI) [17] and novel implementation of more effective thermodynamic cycles such as Miller cycle and Humphrey cycle may also enable significantly higher efficiencies. Some of the current technologies in this direction are Miller cycle using variable valve timing (VVT) [18], boosted HCCI, advanced Corona ignition system (ACIS) [19], lean natural gas combustion[20], low temperature combustion using high exhaust gas recirculation (EGR) [20], opposed two-stroke piston engine[21], free piston linear generator [22,23,24], and employment of five-stroke cycle[25]. It should be noted that above examples do not entail ARPA-E's endorsement of a specific technology but they are listed here to stimulate more ideas/concepts for efficiency enhancements.

[15] Chan and Kohr, Journal of Materials Engineering and Performance, V.9, 2000, pp.103-109
[16] http://energy.gov/sites/prod/files/2014/03/f8/deer12_gangopadhyay.pdf
[17] Kobayashi et al., Journal of Natural Gas Science and Engineering, V.3, 2011, pp.651-656
[18] Fontana and Galloni, Applied Energy, V.86, 2009, pp.96-105
[19] Burrows, J., et al., MTZ, V.74, No. 6, 2013, pp.38-41
[20] Caton, J.A., Energy Conversion and Management, V.79, 2014, pp.146-160
[21] http://www.achatespower.com/pdf/light-duty_engine_study.pdf
[22] Kosaka, H., Akita, T., Moriya, K., Goto, S. et al. (2014) SAE Technical Paper 2014-01-1203 doi: 10.4271/2014-01-1203
[23] Goto, S., Moriya, K., Kosaka, H., Akita, T. et al. (2014) SAE Technical Paper 2014-01-1193 doi: 10.4271/2014-01-1193
[24] Van Blarigan et al. SANDIA Report SAND99-8206, 1998
[25] Kéromnès et al., Energy Conversion and Management, V.82, 2014, pp.259-267

Benchmarking experiments by Thomas[26] show that, with a three-way catalyst, a 4.7 kW_e ICE CHP system with a fuel to electricity conversion efficiency of 24.7% produces about 0.1 mg/Nm^3 of CO and 8.4 mg/Nm^3 of NOx emissions. Boosted HCCI or lean natural gas combustion can increase the electrical efficiency, but that may lead to higher CO and hydrocarbon (HC) emissions as well as higher combustion noise due to increased rates of in-cylinder peak pressure rise. Mitigation of HC and CO emissions can potentially be achieved by using a high-efficiency oxidation catalyst or a catalytic afterburner. HCCI and lean combustion can reduce system-out NOx, and additional NOx reduction can be achieved with the use of EGR, lean NOx trap (LNT), or selective catalytic reduction (SCR) to meet the emissions standards of the FOA. While the emissions challenge can be overcome, the cost of mitigation needs to be minimized to meet GENSETS targets.

Stirling Engines

Although Stirling engines may be the most mature external combustion engines that have penetrated the CHP market, considerable innovation would be needed to meet the targets of this FOA. As shown in Table 1, the current state-of-the-art small-scale Stirling engines have roughly 20% electrical efficiency.

Realizing 40% electrical efficiency will likely require significant improvements in combustion efficiency and indicated efficiency by lowering the heat losses. Significant improvements in mechanical efficiency will also be needed to achieve the FOA target. Much higher efficiency may be achieved by: 1) increasing the maximum working fluid temperature to 1000 °C or even 1100 °C using state-of-the-art high-temperature alloys[27,28] and additive manufacturing technology[29] – leading to much higher thermodynamic cycle Carnot efficiencies, 2) augmenting the recuperation effectiveness, and 3) reducing the parasitic losses in converters and electronics. ARPA-E strongly encourages innovative concepts that couple a combustion engine such a Stirling engine with a solid state device such as a thermoelectric generator and/or a thermionic emitter to achieve 40% electrical efficiency.

Thomas[26] also shows that a 9 kW_e Stirling engine CHP system with a fuel to electricity conversion efficiency of 26.8% produced about 191 mg/Nm^3 of CO and 105 mg/Nm^3 of NOx emissions. The system incorporated a flameless oxidation burner[30] and a catalyst for emissions reduction. When higher combustion temperatures are to be used to achieve higher Carnot efficiency, both HC and CO emissions can be reduced but the NOx emissions would increase and may require further exhaust after-treatment such as EGR, combustion gas recirculation (CGR)[31], SCR, or LNT.

[26] Thomas, B., Applied Thermal Engineering, V.28, 2008, pp.2049-2054
[27] Harada, H. Proceedings of the International Gas Turbine Congress 2003 Tokyo, IGTC2003Tokyo KS-2, pp. 1-9.
[28] Pollock, T; Tin, S. J. Prop Power, vol. 22, 2006, pp. 361-374.
[29] Gibson, et al. Additive Manufacturing Technologies, Springer, 2010.
[30] Wünning, J.G.,Thermprocess Symposium, Düsseldorf, 2003 (http://www.flox.com/documents/03_TP.pdf)
[31] http://www.sgc.se/ckfinder/userfiles/files/SGC144.pdf

Micro-Turbines

Micro-turbines are essentially low-powered versions of gas-turbines used in Brayton cycle power plants. Micro-turbine technologies are more mature for applications over 20 kW_e than for the 1-kW_e regime. For applications less than 5 kW_e there are no major commercial products available; however, a prototype 3 kW_e (15 kW thermal output) system for small-scale CHP achieving 16% electrical efficiency and 80% thermal efficiency has been reported and is being commercialized.[32] A rig testing by Visser et al.[33] of another 3 kW_e micro-turbine system shows that much of the fuel energy goes into exhaust (47%), and heat, friction and parasitic losses (39.4%). Higher efficiency micro-turbines may be developed by reducing viscous losses (loss due to low Reynold's number flow) in the turbine passages, lower heat losses (loss due to high surface-to-volume ratios), and lower mechanical and parasitic losses. A suite of technologies may be required to achieve this FOA's targets such as new turbine design concepts, high efficiency intake-air recuperation, reduced heat and frictional losses, use of newer materials such as SiC and Si_3N_4 [34,35] to increase the material temperature limit to 1200 °C or higher for enabling higher thermodynamic cycle Carnot efficiencies[36], and incorporation of solid state devices and other topping or bottoming cycles such as organic Rankine cycle[37].

Only large-capacity turbines have demonstrated CARB 2007 distributed generation emissions compliance[38]. Micro-turbines may produce higher HC and CO due to inefficient combustion. Higher combustion/gas temperatures will be needed to increase the fuel to electrical conversion efficiency, which will likely result in higher NOx emissions and thus require further exhaust after-treatment such as EGR, SCR, or LNT. Mitigation of HC and CO can potentially be achieved by using a high-efficiency oxidation catalyst or a catalytic afterburner. Other low NOx technologies could include the flameless oxidation burner or ultra-low NOx burner[39].

Solid-State Devices

Several solid-state devices are applicable to power generation and CHP systems, and could be used as topping or bottoming cycles on combustion/mechanical engines. Most prominent among these are thermoelectric generators, thermionic emitters, Na/H/O ion expansion electrochemical devices, thermophotovoltaics (TPVs), and pyroelectrics. There are only a handful of demonstrated technologies in engineered systems. Data on one particular TPV system indicates an electrical efficiency of 12.3% for a 1.5 kW_e system with component efficiency of over 15% [40] as shown in Table 1. Current state-of-the-art efficiencies of solid state

[32] http://www.mtt-eu.com/applications/micro-chp
[33] Visser et al., ASME Journal of Engineering for Gas Turbines and Power, V.133, 2011, pp.042301-1-042301-8
[34] http://infohouse.p2ric.org/ref/20/19293.pdf.
[35] Singh, M. et al. DOI: 10.1002/9781118144091.ch26 (2011).
[36] McDonald and Rogers, Applied Thermal Engineering, V.28, 2008, pp.60-74
[37] Mago and Luck, Applied Energy, V.102, 2013, pp.1324-1333
[38] http://www.arb.ca.gov/energy/dg/eo/dg018.pdf
[39] http://www.energy.ca.gov/2013publications/CEC-500-2013-043/CEC-500-2013-043.pdf
[40] http://www.jxcrystals.com/old_TPV/RomeCHP.pdf

devices have not exceeded 20%, however they possess significant potential for achieving higher efficiencies with newer materials, architectures, and manufacturing processes[41,42,43]. As mentioned before, they can also play a significant role in reaching high overall system efficiency by serving as either a topping or a bottoming cycle to another device/engine.

The emissions and noise challenges for solid state devices are essentially the same as the Stirling engines where natural gas combustion is used to generate heat to be converted to electricity in these devices.

C. PROGRAM OBJECTIVES

As seen in Section I.B of this FOA, all the current state-of-the-art engines for CHP suffer from low efficiency and high cost. The ARPA-E GENSETS program is seeking fundamentally disruptive technologies that can markedly improve the fuel to electricity efficiency to 40% while delivering 1 kW_e electrical power at low cost. The total system cost should not exceed $3,000 at high volume (e.g., 1 million unit scale) (excluding $1,400 installation and balance of plant costs). These technologies must meet the emissions requirements documented in detail in Section I.E of this FOA. The key program objectives are outlined below in detail:

Achieve 40% fuel-to-electrical power generation efficiency

The goal of the ARPA-E GENSETS program is to leverage existing technologies and encourage disruptive concepts that can realize the 40% electrical efficiency target and deliver low cost 1 kW_e systems for residential CHP applications.

Comply with emissions standards

As described above, widespread deployment of CHP systems would result in significant reduction in CO_2 emissions as compared to central-station power plants. However, significant challenges exist in reducing CO, NOx and VOCs in natural gas powered CHP systems at the 1 kW_e size. Through the GENSETS FOA, ARPA-E is expecting generator concepts with high combustion efficiencies that produce emissions that comply with both the 2007 CARB emissions regulations on NOx, CO and VOCs and the EPA NSPS limit on PM. A system-out GHG limit is set at 1100 CO_2eq lb/MW-hr to ensure compliance with prevailing state-level environmental standards.

[41] http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/19252/1/98-0546.pdf
[42] Caillat et al., Nuclear and Emerging Technologies for Space, 2012 (http://www.lpi.usra.edu/meetings/nets2012/pdf/3077.pdf)
[43] Lee et al., Applied Thermal Engineering, V.37, 2012, pp.30-37

Achieve long lifetime/durability

The target for the total system life is 10 years with a capacity factor of 99.9%, i.e., the system should have the capability of running continuously between services (e.g., oil change or cathode replacement) which should not be more than once a year, corresponding to about 8,000 running hours between service intervals. Based upon reported performance, this is a realistic goal to achieve for ICEs and Stirling engines. For example, for a 1 kW_e CHP system,[14] a manufacturer reports 6,000 running hours or 3 years between service, which is close to the target set by this FOA. Also, a Stirling engine manufacturer has demonstrated maintenance-free operation for 100,000 hours (11 years) and eight other engines have more than 8,000 hours and are still running. The system lifetime target will be a challenge for new device types that are still rapidly-evolving in design such as solid state devices and micro-turbines. Accelerated testing should be used by GENSETS performers to project actual field lifetimes from shorter duration test data.

Reduce system cost to enable widespread penetration of residential CHP

The total CAPEX here includes the system cost but excludes the installation and balance of plant costs. The CAPEX target for the 1 kW_e system is no more than $3,000.

D. TECHNICAL CATEGORIES OF INTEREST

The ARPA-E GENSETS program will fund transformational technologies that can create a paradigm shift in the residential heat and power generation process. ARPA-E expects GENSETS to open pathways for high-efficiency, low-emissions, long-life, cost-effective, 1-kW_e generators that can enable significant energy savings and CO_2 emissions reduction.

Applicants must present a well-justified, realistic proposal for the design, construction, and demonstration of a complete engine/generator system that meets all the technical performance targets. Specifically, the systems should accept natural gas at standard residential delivery pressures as their only fuel input and produce 60 Hz ac electrical output at 110 V.[44]

Example technologies of interest, either as standalone solutions or in combinations, include, but are not limited to:

- Internal combustion engines
- External combustion engines such as Stirling engines and steam engines
- Any other novel engines (e.g. detonation engines, thermoacoustic engines, free-piston engines, rotary engines etc.)
- Combustion turbines such as micro-turbines

[44] The proposed systems are not required to meet all grid interconnection requirements. However, applicants should explain in the full proposal how low power quality output can be made compatible with grid requirements.

- Micro Rankine cycles
- Novel concepts that incorporate exhaust and coolant waste-heat recovery, reduced mechanical friction and reduced heat transfer
- Novel concepts to improve combustion efficiency and emissions reduction such as exhaust gas recirculation (EGR) or flue gas recirculation (FGR), homogeneous charge compression ignition (HCCI), spark-assisted HCCI (SA-HCCI), corona ignition, and laser ignition
- Thermophotovoltaics
- Thermionic emitters
- Thermoelectric generators
- Pyroelectrics
- Ion expansion electrochemical devices for electricity generation
- Innovative integration of topping cycles and/or bottoming cycles
- Combinations of the above devices and concepts

E. TECHNICAL PERFORMANCE TARGETS

Only technologies with potential to meet or exceed all GENSETS primary targets will be considered for funding. Program teams must propose to meet the following primary targets and will need to demonstrate these targets by the end of the award period.

Number	Property	Primary Target
1.1	Electric power generation capacity	1 kW_e
1.2	Fuel to electricity conversion efficiency	≥40%
1.3	Useful heat energy output (> 80°C)	>1 kW/kW_e
1.4	Capacity factor	≥99.9%
1.5	Complete system up front cost (not including balance of plant and installation)	≤$3000/$kW_e$
1.6	Lifetime	≥10 years
1.7	Total system-out NOx	≤0.07 lb/MW-hr
1.8	Total system-out CO	≤0.10 lb/MW-hr
1.9	Total system-out VOC	≤0.02 lb/MW-hr
1.10	Total system-out CO_2eq (CO_2 + CH_4 only)	≤1100 lb/MW-hr
1.11	Particulate matter (PM)	≤0.4 g/kW-hr
1.12	System noise	≤55 dB(A) (3-feet away)

In addition, technologies should propose to meet the following secondary targets:

Number	Property	Secondary Target
1.13	Methane number for operation	≥70
1.14	Number of regular maintenance services	≤1/year
1.15	Operation and maintenance cost	≤ $0.005/kWh
1.16	Time for regular maintenance	≤ 60 minutes/service
1.17	System mass	≤ 150 kg

Supplementary Explanations of Targets

1.1 The system concept should target 1-kW_e generation. However, if the efficiency target is demonstrated in a device which has < 1-kW_e power producing capacity, then a detailed scaling analysis should be presented to project efficiency at 1-kW_e. Systems larger than 1-kW_e are not of interest.

1.2 Natural gas fuel to ac electricity conversion efficiency is based on lower heating value (LHV) of pipeline natural gas with 983 Btu per cubic foot. Individual component efficiencies of 40% are not sufficient. A device delivering 40% electrical efficiency relative to its input heat energy is not acceptable. Solid-state devices should be treated as external combustion engines and electrical efficiency should be described as in Eq. 1 ($\eta_e = \eta_{comb} \cdot \eta_{ind} \cdot \eta_m \cdot \eta_{alt}$).

1.3 Residential hot-water and space heating output provided by CHP system should be > 1 kW/kW_e at > 80 °C.

1.4 The system is expected to run continuously between the scheduled regular maintenance and restart easily.

1.5 The engine/generator system, including emissions mitigation and dissipation of exhaust heat (when not fully used), must plausibly cost less than $3,000 per kW_e in large production volumes (e.g., one million units). The $3,000 cost of the generator system itself includes all components needed to take pipeline natural gas and produce electricity (ac, 60 Hz) and exhaust heat as outputs; the costs of installation (labor) and balance of plants (smart meters and heat exchangers for integration with other systems) of ~$1,400 are not included. An alternator efficiency (η_{alt}) of 0.8 to 0.96 can be assumed for the purpose of FOA application if the alternator is not integral to the generator under development. The alternator cost needs to be included in the system CAPEX. The cost of commercially available alternators varies essentially linearly as the efficiency increases from 0.8 to 0.96 according to: Alternator cost [$] = 3250*$\eta_{alt}$ – 2520. Systems that do not need an alternator can exclude this cost.

1.7-1.9 Emissions for NOx, CO and VOCs should comply with CARB 2007 emissions limits for distributed power generation. Concept papers should briefly address needed strategies for limiting emissions. Full applications must provide a more complete discussion relative to the state-of-the-art numbers in a specific category of technology (e.g. ICE) and how improvements are made with respect to the baseline performance in the literature. Mitigation technologies are allowable as long as the cost is included in the system CAPEX.

1.10 For GHG emissions, only CO_2 and CH_4 are considered by the GENSETS Program. CO_2eq value for CH_4 must be evaluated using its 100 year GWP value of 28, i.e., 1 g of CH_4 corresponds to 28 g of CO_2eq. The total system-out CO_2eq must be less than 1100 lb/MW-hr.

1.13 The system must be able to operate at methane numbers as low as 70. Methane number is defined using the following equations[45]:

Motor octane number (MON) = $-406.14 + 508.04*(H/C) - 173.55*(H/C)^2 + 20.17*(H/C)^3$

Methane number (MN) = $1.624*MON - 119.1$. H/C is the fuel hydrogen to carbon ratio.

A Wobbe index[46] of 1328 ±8% is allowed to accommodate different natural gas compositions.

F. APPLICATIONS SPECIFICALLY NOT OF INTEREST

The following types of applications will be deemed nonresponsive and will not be reviewed or considered (see Section III.C.2 of the FOA):

- Applications that fall outside the technical parameters specified in Section I.E of the FOA
- Applications that were already submitted to pending ARPA-E FOAs.
- Applications that are not scientifically distinct from applications submitted to pending ARPA-E FOAs.
- Applications for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Applications for large-scale demonstration projects of existing technologies.
- Applications for proposed technologies that represent incremental improvements to existing technologies.
- Applications for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).

[45] http://www.arb.ca.gov/regact/cng-lpg/appd.pdf
[46] https://www.naesb.org//pdf2/wgq_bps100605w2.pdf

- Applications that do not address at least one of ARPA-E's Mission Areas (see Section I.A of the FOA).
- Applications for proposed technologies that are not transformational, as described in Section I.A of the FOA and as illustrated in Figure 1 in Section I.A of the FOA.
- Applications for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress (see Figure 1 in Section I.A of the FOA).
- Applications that are not scientifically distinct from existing funded activities supported elsewhere, including within the Department of Energy.
- Applications that propose the following:
    - CHP systems that employ fuel cells (ARPA-E has previously solicited for innovative fuel cell technology for distributed generation applications through its REBELS FOA)
    - Internal and external combustion systems that are powered by fuels other than natural gas, e.g., gasoline and diesel engines.
    - Employment of dual-fuel combustion such as diesel/natural gas fuel blends
    - Concepts with more than 1-kW_e power generation capacity

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 12-18 awards under this FOA. ARPA-E may 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 OCTOBER 2015, 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 project period. These applications should contain an appropriate cost and project duration plan that is described in sufficient technical detail to allow reviewers to meaningfully evaluate the proposed project. If awarded, such projects should expect a rigorous go/no-go milestone early in the project associated with the proof-of-concept demonstration.

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."[47] Accordingly, ARPA-E has substantial involvement in the direction of every project, as described in Section II.C below.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[48]

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.

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

2. FUNDING AGREEMENTS WITH FFRDCS, GOGOS, AND FEDERAL INSTRUMENTALITIES[49]

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

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

When a FFRDC is a *member* of a Project Team, ARPA-E generally executes a funding agreement directly with the FFRDC 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 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, and Federal instrumentalities (e.g., Tennessee Valley Authority) generally take the form of Interagency Agreements. Any funding agreement with a FFRDC will have substantially 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 as supporting project team members on an applicant's project. The Non-DOE GOGO/Agency support would be obtained via an Interagency Agreement between ARPA-E and the non-DOE GOGO/Agency, and provided as part of ARPA-E's standard substantial involvement in its funded projects.

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.

[49] DOE/NNSA GOGOs are not eligible to apply for funding, as described in Section III.A of the FOA.

A TIA is more flexible than a traditional financial assistance agreement. In using a TIA, ARPA-E may modify standard Government terms and conditions.

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

4. GRANTS

Although ARPA-E has the authority to provide financial support to Prime Recipients through Grants, ARPA-E generally does not fund projects through Grants. ARPA-E may fund a limited number of projects through Grants, as appropriate.

C. STATEMENT OF SUBSTANTIAL INVOLVEMENT

Generally, 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:

- ARPA-E does not limit its involvement to the administrative requirements of the ARPA-E funding agreement. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole. Project teams must adhere to ARPA-E technical direction and comply with agency-specific and programmatic requirements.

- ARPA-E may intervene at any time to address the conduct or performance of project activities.

- 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. Prime Recipients document the achievement of these milestones and deliverables in quarterly technical and financial progress reports, which are reviewed and evaluated by ARPA-E Program Directors (see Attachment 4 to ARPA-E's Model Cooperative Agreement, available at http://arpa-e.energy.gov/arpa-e-site-page/award-guidance). ARPA-E Program Directors visit each Prime Recipient at least twice per year, and hold periodic meetings, conference calls, and webinars with Project Teams. ARPA-E Program Directors may modify or terminate projects that fail to achieve predetermined technical milestones and deliverables.

- ARPA-E works closely with Prime Recipients to facilitate and expedite the deployment of ARPA-E-funded technologies to market. ARPA-E works with other Government agencies and nonprofits to provide mentoring and networking opportunities for Prime Recipients. ARPA-E also organizes and sponsors events to

educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E establishes 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,[50] as the lead for a Project Team,[51] or as a member of a Project Team.

2. DOMESTIC ENTITIES

For-profit entities, educational institutions, and nonprofits[52] 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 are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team, but not as a Standalone Applicant.

DOE/NNSA GOGOs are not eligible to apply for funding.

Non-DOE/NNSA GOGOs 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.

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

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

[50] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[51] 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.
[52] 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.

3. FOREIGN ENTITIES

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. All work by foreign entities must be performed by subsidiaries or affiliates incorporated in the United States (including U.S. territories). The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. CONSORTIUM ENTITIES

Consortia, which may include domestic and foreign entities, must designate one member of the consortium as the consortium representative to the Project Team. The consortium representative must be incorporated in the United States. The eligibility of the consortium will be determined by reference to the eligibility of the consortium representative under Section III.A of the FOA. Each consortium must have an internal governance structure and a written set 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 agreement binds the individual consortium members together and should discuss, among other things, 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[53]

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, the Prime Recipient must provide at least 20% of the Total Project Cost[54] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[55]

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"). If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the costs incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80%, but less than 100%, of the total work under

[53] Please refer to Section VI.B.3-4 of the FOA for guidance on cost share payments and reporting.
[54] 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.
[55] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.

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.

- 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, and/or FFRDCs 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) 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 project period, the Prime Recipient is required to contribute at least the cost share percentage of total expenditures incurred through the date of termination.

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

5. COST SHARE ALLOCATION

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

6. COST SHARE TYPES AND ALLOWABILITY

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

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

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

- Revenues or royalties from the prospective operation of an activity beyond the project period;
- 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[56] to meet their cost share obligations under cooperative agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under Technology investment Agreements.

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

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

[56] As defined in Federal Acquisition Regulation Section 31.205-18.

Applicants may wish to refer to 10 C.F.R. parts 600 and 603 for additional guidance on cost sharing, specifically 10 C.F.R. §§ 600.30, 600.123, 600.224, 600.313, and 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.

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.

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 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 uploaded all required documents to ARPA-E eXCHANGE by the deadline stated in 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. Any "Applications Specifically Not of Interest," as described in Section I.F of the FOA, are deemed nonresponsive and are not reviewed or considered.

3. LIMITATION ON NUMBER OF APPLICATIONS

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

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E eXCHANGE

The first step in applying to this FOA is registration in ARPA-E eXCHANGE, ARPA-E's online application portal. For detailed guidance on using ARPA-E eXCHANGE, please refer to Section IV.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. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria in Section V.A.1 of the FOA.

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

3. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 30 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.C of the FOA. ARPA-E reviews only compliant and responsive Full Applications.

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, 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 or not select 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, Budget Justification Workbook/SF-424A, and Business Assurances & Disclosures Form. A sample response to the Business Assurances & Disclosures Form and a sample Summary Slide are also available on ARPA-E eXCHANGE. Applicants must 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, and the template for the Reply to Reviewer Comments.

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.

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

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

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

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

1. CONCEPT PAPER CONTENT

a. CONCEPT SUMMARY/OVERVIEW

- Provide a concise description of the proposed concept with minimal jargon, explain the innovations relative to the state-of-the-art, and how the proposed effort represents a transformational and potentially disruptive solution to the technical targets in Section I.E of the FOA.

- Include a descriptive schematic of the proposed innovative concept with various key components and rough dimensions of the system.

- Include a fuel to electrical conversion system efficiency cascade of the entire system similar to the one prescribed in Eq. 1 ($\eta_e = \eta_{comb} \cdot \eta_{ind} \cdot \eta_m \cdot \eta_{alt}$) of the FOA, and address the pathway for attaining the 40% fuel to (ac) electricity conversion efficiency target [For solid-state devices, combustion efficiency should be included in the overall efficiency equation when heat is used as input to the devices].

- Include a brief description of the emissions mitigation strategy for meeting the emissions targets as described in Section I.E. of the FOA.

- Provide a brief statement about the system cost, including all components of the systems such as an alternator and emissions mitigation subsystem if used.

b. PROPOSED WORK

- Describe the overall technical approach to be used to achieve project objectives.

- Describe concisely the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach; include appropriate citations wherever necessary.

- Describe why the proposed effort is a significant technical challenge and highlight the key technical risks; explain whether the approach requires one or more entirely new technical developments to succeed and how will the technical risks be mitigated; and list two components in the system that will likely be the first to fail during long-term operation.

c. TEAM ORGANIZATIONS AND CAPABILITIES

- List key personnel and partner organizations and their roles in the project team.

- Describe the capabilities and experiences of the team in designing and fabricating the various key innovative components of the proposed systems.

- Specify the proposed funding and the proposed budget for each organization.

2. ADDITIONAL INSTRUCTIONS

- Do not justify your project in terms of energy-savings, CO_2 reductions, and other benefits of CHP as ARPA-E is already well aware of these benefits. Focus your Concept Paper on describing what innovations your team brings to achieve the technical targets specified in Section I.E of the FOA.

- Do not compare different technology types; compare only to the state-of-the-art within a technology type. For example, an application proposing a Stirling engine should compare to other Stirling engines and not to internal combustion engines.

- Use of the term “no moving parts” alone is insufficient to justify durability and long lifetime, as systems with no moving parts do not necessarily last longer than those with moving parts. Identify the failure modes of the proposed system and justify why it can attain the lifetime target.

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

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 FEBRUARY 2015]

H. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

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

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

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

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

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

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

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

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

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

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

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

1. CRITERIA FOR CONCEPT PAPERS

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

- The extent to which the proposed quantitative material and/or technology metrics demonstrate the potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;

- The extent to which the proposed concept is innovative and will achieve the technical performance targets defined in Section I.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and

- The extent to which the Applicant demonstrates awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over the current state-of-the-art.

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

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;

- The extent to which the Applicant proposes a sound technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches within a particular category of

technology (e.g., Stirling engines) and how technical risk will be mitigated;

- The extent to which project outcomes and final deliverables are clearly defined;
- The extent to which the Applicant identifies techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and
- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

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

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

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

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 FEBRUARY 2015]

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

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

2. CONCEPT PAPER NOTIFICATIONS

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

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

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

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN FEBRUARY 2015]

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.

- 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 "Frequently Asked Questions" 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 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.

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.

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. Such data should be clearly marked as described in Section VIII.E of the FOA. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

I. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

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

- Social Security Numbers in any form;
- Place of Birth associated with an individual;
- Date of Birth associated with an individual;

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

IX. 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: Advanced Research Projects Agency-Energy.

Cost Share: The Prime Recipient share of the Total Project Cost.

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.

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

Key Participant: Any individual who would contribute in a substantive, measurable way to the execution of the proposed project.

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

R&D: Research and development.

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 and FFRDCs.

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