FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

ADVANCED RESEARCH IN DRY-COOLING (ARID)

Announcement Type: ~~Modification 01~~ Modification 02
Funding Opportunity No. DE-FOA-0001197
CFDA Number 81.135

FOA Issue Date:	September 26, 2014
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, November 03, 2014
Submission Deadline for Concept Papers:	5 PM ET, November 10, 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 $30 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.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).

MODIFICATIONS

All modifications to the Funding Opportunity Announcement (FOA) are highlighted in yellow in the body of the FOA.

Mod. No.	Date	Description of Modifications
01	09/29/2014	• On page 1, changed Concept Paper deadline to November 10.
02	10/28/2014	• Clarified equation of COP_{cool} for subcategory 2A: Sorption/Desorption Cooling System. See section I.E of the FOA.

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE

Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline.
	• The Concept Paper body must not exceed 4 pages in length and must include the following:
	  o Concept Summary
	  o Innovation and Impact
	  o Proposed Work
	  o Team Organization and Capabilities
	• An illustration of an example full cooling system, incorporating the novel technology being proposed, may be appended to the Concept Paper body. This illustration may not exceed 1 page. For all technologies that fall into Category 3 (as described in Section I.E) the appended full cooling system illustration is ***required***.
		Mandatory	IV.C	5 PM ET, November 10, 2014

Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2015]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 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.

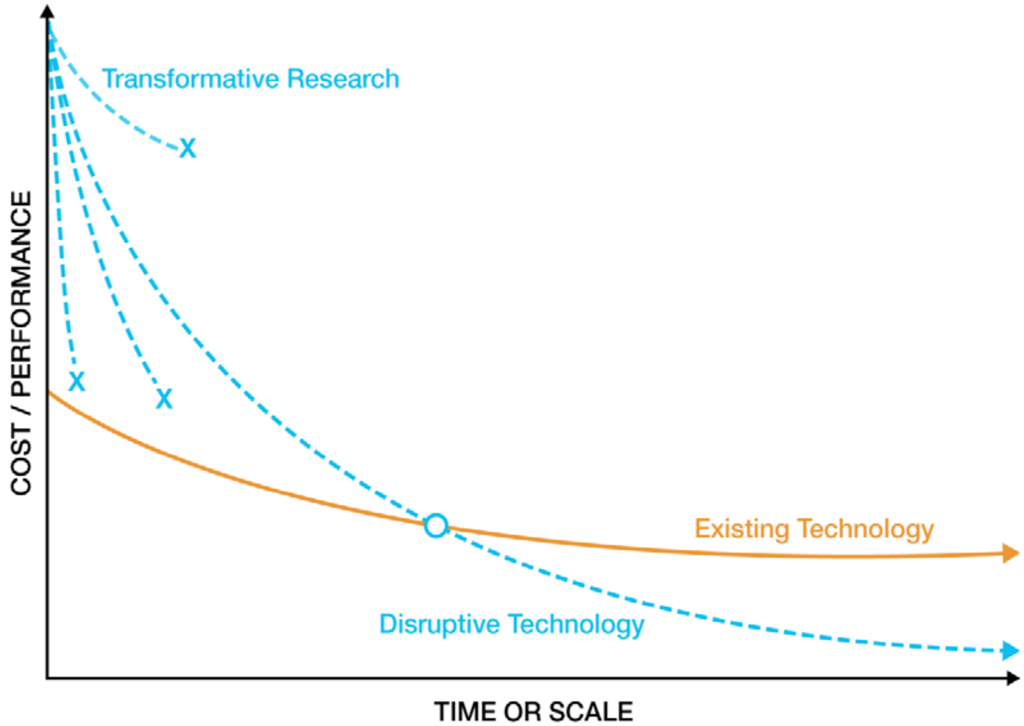

Figure 1: Description of transformational and disruptive technologies in terms of cost per unit performance versus time or scale. ARPA-E seeks to support research that establishes new learning curves that lead to disruptive technologies.

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

The interdependency between water and energy, commonly known as the "water-energy nexus," has many facets, but perhaps none is so easily described as the use of water in the generation of electricity. The U.S. electric power industry has relied primarily on water cooling technologies to remove low grade heat from thermoelectric power plants. Of these technologies, cooling towers and spray ponds dissipate a substantial amount of water into the atmosphere via evaporation. It is anticipated that within a 20 year time horizon a combination of environmental concerns, increased water demand due to population growth, and the impact of climate change will significantly constrain the available water supply that can be allocated to power plant cooling. It is also anticipated that smaller scale distributed electric power generation will continue to penetrate the market, including in regions where water cooling for low-grade heat removal is not feasible.[1]

This program seeks to fund transformative new power plant cooling technologies that enable high thermal-to-electric energy conversion efficiency with zero net water dissipation to the atmosphere. Of particular interest to this program are technologies that incorporate air cooling, sorption-based cooling, multimode (convection/radiant) cooling, large capacity cool storage, or any other innovative heat rejection technology that addresses the programmatic goals. Successful technologies emerging from this program will enable continued reliable and efficient domestic electric power production, independent of population growth and climatic variations and with minimal impact on the aquatic environment. Market penetration of these technologies will significantly reduce the risk of lost thermoelectric power production. This program aims to bridge the gap between fundamental scientific advances, such as those arising from the NSF Thermal Transport Processes Program[2], ONR Ship Systems and Engineering Research Program (Thermal Energy Management)[3], and the NSF/EPRI Advanced Dry Cooling for Power Plants program[4], and technology that will have a transformative impact in dry-cooling of power plants.

1. WET COOLING

Fresh water withdrawal for thermoelectric power generation in the U.S. is approximately 139 billion gallons per day (BGD), or 41% of all fresh water withdrawal, making it the largest single use of fresh water in the U.S.[5,6] For perspective, this is equivalent to filling 10,000 Olympic sized swimming pools every hour. Of the fresh water withdrawn for the thermoelectric sector, 4.3 BGD was dissipated to the atmosphere by cooling towers and spray ponds.[5] This consumed water is then unavailable to the local environment for other important uses[6]; for example, this amount of water could be used to produce 17.4 million tons of potatoes[7], approximately the annual U.S. potato yield[8] (the potato is a staple crop grown worldwide, thus motivating the comparison).

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[1] Owens, Brandon. “The Rise of Distributed Power”. General Electric, 2014
[2] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13367
[3] http://www.onr.navy.mil/Science-Technology/Departments/Code-33/All-Programs/331-ship-systems-engineering.aspx
[4] NSF/EPRI Collaboration on "Water for Energy - Advanced Dry Cooling for Power Plants”. Program Solicitation NSF 13-564, 2013
[5] U.S. Department of Energy. “The Water-Energy Nexus: Challenges and Opportunities”. Jun 2014
[6] Williams E. D. and Simmons J. E. “Water in the energy industry”. BP, 2013
[7] Assumes 287 m^3 water required per metric ton of potatoes produced.
[8] USDA National Agricultural Statistics Service. “National Statistics for Potatoes”. USDA, 2013

The average energy conversion efficiency of a power plant ranges from about 35–55%[9] using water cooling strategies. Plants that produce hundreds of megawatts of electricity must also dissipate hundreds of megawatts of low-grade waste heat. The temperature at which this heat is rejected to the environment directly impacts energy conversion efficiency; heat rejection at a lower temperature increases the net power production and energy efficiency. A lower cooling water temperature allows for a lower steam condensation pressure in a steam Rankine cycle[10], reducing the backpressure on the turbine outlet and allowing for more power to be extracted by the turbine. A 3°C rise in the steam condensation temperature is estimated to result in about a 1% reduction in power production from the turbine.[11]

To adequately reject megawatts of low-grade heat from low pressure condensing steam, a massive cold sink is required. The two principle heat sinks historically used for heat rejection are large water bodies and atmospheric air. Water is favored because rivers, lakes, and oceans tend to be cooler than ambient air (resulting in higher energy conversion efficiency), have more uniform temperatures, and water enables higher heat flow rates through a given surface. Water-cooled condensers are considerably less expensive than air-cooled units owing to the high rate of convective heat transfer afforded by water flow. This is fundamentally due to the fact that the thermal conductivity of water is approximately twenty-fold that of air. The economic and energy conversion efficiency advantages afforded by water cooling have led to the current U.S. paradigm where 99% of base-load thermoelectric power plants are water cooled, while only 1% of power plants are air cooled. Wet-cooling systems include once-through configurations (43%), cooling towers (42%), and cooling ponds (14%).[12]

Once-through cooling systems are the most basic, but environmental regulations have made them increasingly less viable. The Clean Water Act[13] and its implementing regulations require limits on the effluent temperature discharged to local water bodies and require the “best available technology” be used to limit fish impingement at water intakes of power plant cooling systems.[14] Some states, like California, have decided to try phasing out once-through cooling

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[9] Calculated from heat rate values in Table 8.2 of “Assumptions to the Annual Energy Outlook 2014”, U.S. Energy Information Administration. June 2014. [Available from: http://www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf]

[10] Moran, Michael J., et al. “Fundamentals of engineering thermodynamics”. John Wiley & Sons, 2010.

[11] Stephens, Mark. “Keeping Customers Competitive & Productive with Energy Efficiency & Power Quality Solutions”. EPRI, 2012

[12] Report of Department of Energy, National Energy Technology Laboratory, “Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements”, DOE/NETL-400/2008/1339, 2008

[13] 33 U.S.C. § 1251, et. seq.

[14] e.g. 33 U.S.C. § 1326; See also, Environmental Protection Agency, *EPA Finalizes Standards to Protect Fish, Aquatic Life from Cooling Water Intakes* (News Release, May 2014).

altogether.[15] Similarly, in anticipation of recent updates to the Clean Water Act implementing regulations, recently proposed new power plants have focused on closed-cycle cooling rather than once-through cooling systems.[5, 16]

Cooling towers and spray ponds currently seem best equipped to address the effluent temperature limits set by environmental laws and regulations. As a result, many once-through cooling systems employ a cooling tower or spray pond on the backend to perform additional cooling before the effluent is released back to the initial source. Many cooling tower systems are also part of recirculating cooling systems in which the cooling water is continuously recirculated through a closed-loop cooling system. Both cooling towers and spray ponds take advantage of latent heat transport due to water evaporation and convective heat exchange with air. However, a significant amount of water consumption results through evaporation from cooling towers and cooling ponds.

The U.S. has had abundant fresh water resources and throughout the twentieth century evaporative cooling for thermoelectric power plants has been an acceptable practice. However, with growing population, industry, farming, aquaculture, drought, and changing precipitation patterns, several regions within the U.S. are beginning to experience fresh water as a limited resource. As the demand for fresh water approaches or exceeds supply, regions are becoming water stressed. States that have recently experienced significant water stress include California, Texas, and Florida. As a result, these regions have employed water conservation measures and have incorporated alternative water sources (reclaimed, treated, desalinated) into their supply. A study by the Electric Power Research Institute (EPRI) examined the impact of projected population growth on water availability across the United States and projected the water sustainability by county in 2030.[17] ARPA-E examined a list of water-cooled thermoelectric power production by county and cross-referenced it to the EPRI study. Assuming the status quo is maintained, it appears that by 2030, more than 3 Quads out of the 13 Quads (delivered) of U.S. electrical power production could be generated in counties that are at moderate to severe risk of water stress. This analysis did not include impacts of climate variability on water availability.

Uncertainty in future water supply and quality due to climate change adds further complexity in understanding the sustainability of water cooling thermoelectric power plants in many regions of the country. Northeastern University recently studied the impact of different climate change

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[15] "Tracking Progress: Once-Through Cooling Phase-Out". California Energy Commission. August 2014. [http://www.energy.ca.gov/renewables/tracking_progress/documents/once_through_cooling.pdf]

[16] Office of Nuclear Energy, U.S. DOE, "Cooling water issues and opportunities at U.S. Nuclear Power Plants". at pg. ES-2, December 2010. pg. 70; [get second support citation from James]

[17] "Water Use for Electricity Generation and Other Sectors: Recent Changes (1985-2005) and Future Projections (2005-2030)", EPRI Report 1023676

scenarios in combination with population growth on future water supply and demand. Details of this study can be found in the report made available as a supporting document to this FOA.[18] These results quantify the amount of future power production at risk due to water stress. The study found that with expected population growth (as set by projections from the U.S. Census Bureau) and the median result of an ensemble of climate change and environmental model combinations, about 4.5 Quads are currently produced in regions that will be water stressed in 2040. The most extreme scenario suggests that number could be as high as 9 Quads. Additionally, the results of this analysis suggest that there will be multiple regions where maximum stream temperatures approach the limits established as a result of the Clean Water Act regardless of the scenario considered. The combination of water stress and increasing water temperatures will likely interrupt power production, as it has before.[19,20]

Whether or not sufficient water resources will be widely available for continued cooling of future thermoelectric power production is uncertain at best. It is clear that development of cost competitive power plant cooling systems that do not rely on a continuous water supply will significantly add reliability to the U.S. thermoelectric power production infrastructure, as well as free up precious fresh water resources that can be utilized for other important uses. Moreover, distributed power generation deployment can be further enhanced since large bodies of water would not be required for cooling.

2. DRY COOLING

Dry-cooling systems installed at thermoelectric power plants are commonly classified as direct or indirect. Direct dry cooling utilizes a large standalone air-cooled condenser and is used as far north as Alaska and as far south as Southern California. Approximately 1% of thermoelectric power plants in the U.S. utilize air-cooled condensers.[4] Indirect dry cooling combines a water-cooled condenser with a convective air-cooled heat exchanger and water is continuously recirculated between the two in a closed loop. Indirect dry cooling is not common and there are no units in operation within the U.S.[21] In regions of the U.S. where water scarcity and environmental concerns make permitting for wet-cooled systems difficult there has been a recent trend toward dry-cooling systems.

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[18] Ganguli, P., Kumar, D., and Ganguly, A. R. "Water Stress on U.S. Power Production at Decadal Time Horizons". Sept. 2014

[19] U.S. Department of Energy. "The Water-Energy Nexus: Challenges and Opportunities". pg. 1. Jun 2014

[20] US Department of Energy, "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather", July 2013.

[21] "Assessment of Indirect Dry Cooling Systems". EPRI, July 2008.

With current technology, power producers are reluctant to use dry-cooling systems for two principle reasons: (1) the low air-side heat transfer coefficient necessitates massive heat exchangers that are costly and occupy a large land footprint and (2) air cooling imposes a performance penalty when ambient temperatures are high, as detailed below.

Challenge 1: Air-side heat transfer coefficient

The air-side convective heat transfer coefficient (10–100 W/m^2K) is roughly two orders of magnitude lower than that for water (1,000–10,000 W/m^2K), depending on the operating regime (laminar or turbulent). Therefore, an air-cooled system requires significantly more surface area and higher fan power compared to a wet-cooled system with the same heat rejection requirements. Both the capital and operating costs for an air-cooled condenser can each be 3.5 times of a comparable wet-cooled system carrying the same heat load. [22]

Challenge 2: Ambient dry bulb temperature and second law limitation

The dry bulb ambient air temperature and the second law of thermodynamics set the lower limit steam condensation temperature within an air-cooled condenser. In contrast, evaporative water cooling within a cooling tower utilizes latent heat transport (due to evaporation) to drop below the ambient air dry bulb temperature. The lower limit for evaporative cooling is the wet bulb temperature, which equals the dry bulb temperature only at 100% relative humidity (i.e. when the ambient air is fully saturated). Under all other conditions, water can evaporate into the ambient air and the wet bulb temperature is lower than the dry bulb temperature, by an average of 3–5°C.[23]

As a result of this fundamental thermodynamic limitation, the use of air-cooled condensers result in an average 2% loss of power output from the steam turbine compared to water-cooled operation.[22] Periodically, there are ambient temperature excursions that result in large differences between the wet and dry bulb temperatures. For such temperature excursions, there can be upwards of 10% reduced power production when using dry cooling.[4]

In addition to the two principle challenges with dry cooling cited above, there are other considerations such as wind loading, fan failure, fan noise, and leakage that impede adoption of dry-cooling systems. Due to increased capital and operating costs and lost power production,

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[22] "Comparison of Alternate Cooling Technologies for U. S. Power Plants: Economic, Environmental, and Other Tradeoffs", EPRI, 2004.

[23] U.S. Environmental Protection Agency. "Technical Development Document for the Final Regulations Addressing Cooling Water Intake Structures for New Facilities". Docket No. EPA-821-R-01-036, Nov 2001

the utilization of air-cooled condensers for thermoelectric power plants increases the levelized cost of electricity (LCOE) by approximately 5-9% relative to wet cooling.[24,25,26]

3. Summary

The United States is heavily reliant on water to cool its thermoelectric power plants, yet the future promises both reduced water availability and more stringent requirements to maintain water quality. Continued dominant reliance on water for cooling is therefore risky and undesirable. Moreover, making thermoelectric power plants more independent from the nation's water supply infrastructure, while operating with high efficiency, can yield significant benefits to agricultural, municipal, and industrial sectors. Principle challenges with currently available dry-cooling systems highlight several needs and point to some possible solutions, such as (1) significant cost reduction (via significant air-side heat transfer enhancement to reduce size and/or low cost materials and manufacturing) and (2) the ability to cool below the dry bulb temperature limit and address temperature excursions with supplemental cooling systems and/or cool storage. The development of transformative cooling technologies to address future challenges of thermoelectric power production (fossil, solar, and nuclear) is the focus of the ARID FOA.

C. Program Objectives

The ARID program seeks to enable the development of transformational power plant cooling technologies that:

1. Dissipate no net water to the atmosphere (note that in cases where water vapor is dissipated to the atmosphere, not including surface water evaporation, an equal or greater amount of water vapor must be captured);
2. Result in no loss of efficiency for the power plant (note that while any single technology may not be able to accomplish this goal in standalone operation, ARPA-E seeks to fund a suite of technologies that when operating synchronously or asynchronously within a cooling system can meet the objective); and
3. Result in less than 5% increase in the levelized cost of electricity.

[24] Ku, A. Y.; Shapiro, A. P. "The Energy−Water Nexus: Water Use Trends in Sustainable Energy and Opportunities for Materials Research and Development". MRS Bull. 2012, 37 (4), 439−447.
[25] Turchi, C. S., M. J. Wagner, and C. F. Kutscher. "Water Use in Parabolic Trough Power Plants: Summary Results from Worley Parsons' Analyses." Contract 303: 275-3000, 2010
[26] The potential cost savings associated with easier permitting is not considered in the 9% LCOE increase.

1. PROGRAM VISION

In order to meet the programmatic objectives outlined above, ARPA-E seeks to develop transformational cooling technologies including, but not limited to, ultra-high-performance air-cooled heat exchangers, supplemental cooling systems, and cool storage systems. As previously discussed, the limiting cool-side temperature for an air-cooled heat exchanger is dictated by the ambient dry bulb temperature that is subject to large temperature excursions. The development of transformational supplemental cooling and cool storage technologies are needed to work synchronously with air-cooled units in order to cool below the dry bulb temperature and preserve the power plant energy conversion efficiency, especially during large ambient temperature excursions. Supplemental cooling and cool storage systems are most easily integrated within an indirect dry cooling system configuration as shown schematically in Figure 2. This representative indirect dry-cooling system includes a water-cooled condenser, where the discharge cooling water is recirculated and cooled through an air-cooled heat exchanger and a supplementary cooling or cool storage system. For the sake of convenience, the indirect dry-cooling architecture will henceforth be used for outlining the ARID program vision. However, *all transformative* technologies being proposed for other system cooling architectures will be considered *as long as the system performance and cost are able to satisfy the program objectives* and are justified using sound technical and economic analysis. Applicants proposing alternate cooling system architectures are required to clearly explain and illustrate the entire cooling system design.

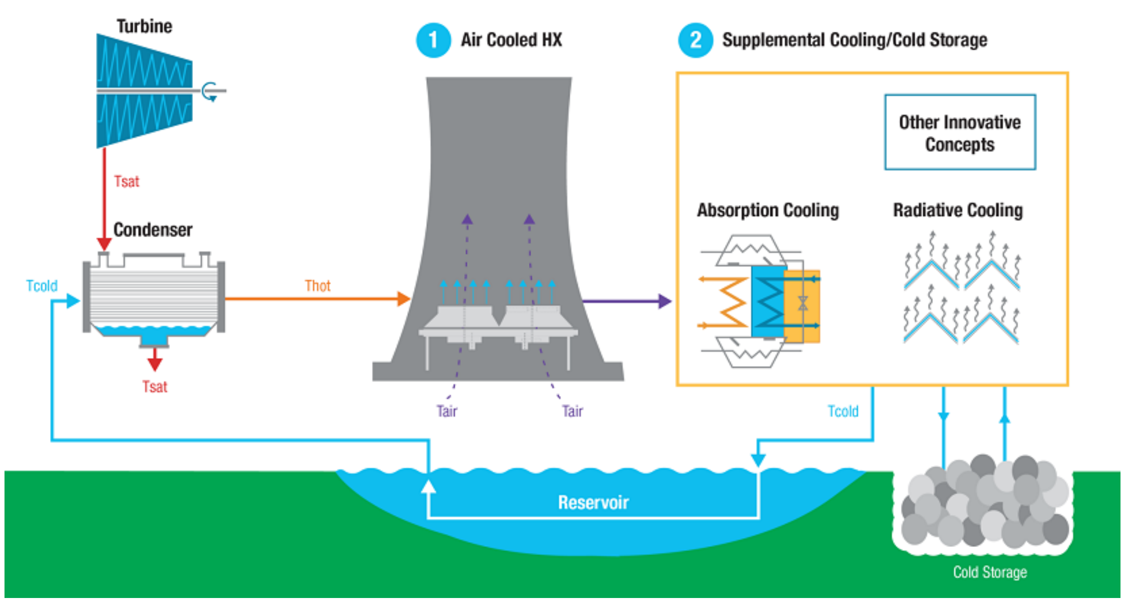

Figure 2: Schematic of representative indirect dry-cooling system that satisfies ARID program objectives.

2. Techno-economic Analysis for Indirect Dry-cooling System

ARPA-E has created a techno-economic model to study the economic feasibility of installing the indirect dry-cooling system, shown in Figure 2, within a Greenfield natural gas combined-cycle (NGCC) power plant. The 550 MW NGCC power plant model, DOE Office of Fossil Energy National Technology Laboratory (NETL) Case 13 described in *Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity*[27], was used as the base case. The NETL report and reference cases contained within are well-regarded standards in the power generation community and have sufficient transparency and level of detail in plant design, operating conditions, costs, and accounting methodology to be useful for the present analysis. The ARPA-E cost model was used to compute the LCOE for NETL Case 13 parameters (including the original wet-evaporative cooling system) and it was confirmed that the ARPA-E model could reproduce the performance and cost parameters of the NETL plant.

The ARPA-E indirect dry-cooled NGCC plant model was then created by replacing the original open-loop evaporative cooling system (NETL Case 13) with the indirect dry cooling system shown in Figure 2. Detailed water-cooled condenser and air-cooled heat exchanger design modules were developed for the analysis that include associated pumps and fans. The baseline air-cooled heat exchanger design was based on heat transfer and pressure drop characteristics associated with high performance louver-finned tube heat exchangers.[28] An optimization algorithm was used to explore power plant cooling system configurations, resulting in designs with a global minimum LCOE. To help understand the performance necessary to achieve the program objectives, ARPA-E then incorporated modules of air-cooled heat exchangers with "aspirational" performance. Essentially, the air-side heat transfer coefficient was artificially increased beyond the baseline louver-finned tube heat exchanger (up to a factor of 5), while also increasing the pressure drop (up to a factor of 1.5). These aspirational target cases were then also run through the optimization algorithm.

The baseline louver-finned tube air-side heat transfer coefficient (h_{air}) and pressure gradient (dP/dL) for the air-cooled heat exchanger operating at different Reynolds numbers (Re) is shown in Figure 3. Also shown are the most aggressive ARPA-E targets. For the baseline heat exchanger performance, the increase in LCOE at the global minimum using the indirect dry-cooling system is 2.3% operating at the steady-state design condition. When the air-cooled heat exchanger operates at the aspirational target performance, its size and cost is significantly reduced and the increase in LCOE is only 1.6%.

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[27] DOE/NETL, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity", Rev. 2, DOE/NETL-2010/1397, Nov 2010.
[28] Achaichia and Cowell, "Heat Transfer and Pressure Drop Characteristics of Flat Tube and Louvered Plate Fin Surfaces", Experimental and Thermal Fluid Science 1 (1988) 147-157.

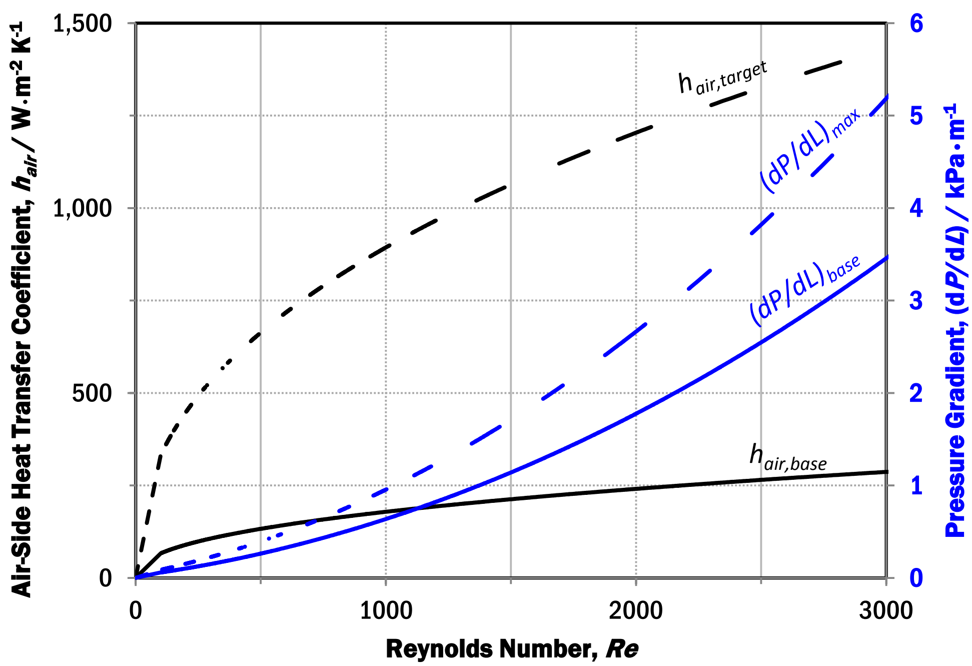

Figure 3: Air-side heat transfer coefficient and pressure gradient as a function of Reynolds number for the baseline and target finned-tube heat exchanger designs.

The required cooling water temperature into the condenser used in the model was 29°C. When the dry bulb ambient air temperature is 15°C the entire 318 MW heat load can be carried by the air-cooled heat exchanger without the need for supplemental cooling. When the ambient air temperature increases, the power plant energy conversion efficiency drops off rapidly with a corresponding increase in LCOE, as shown in Figure 4. Such ambient air temperature excursions can be mitigated by integrating supplemental cooling into an indirect dry-cooling system, as shown in Figure 2. However, the challenge with supplemental cooling is that it will almost always cost more than the approximate $50/kW for air-cooling systems. The estimated allowable costs for 1-4°C of supplemental cooling that result in no more than a 4% increase in LCOE (over the wet-cooled base case) for the aspirational air-cooled heat exchanger is shown in Figure 5. At 3°C of supplemental cooling, which accounts for 90 MW of the 318 MW load, the allowable cost for supplemental cooling is approximately $150/kW with a 4% increase in LCOE. Since this level of supplemental cooling is sufficient to maintain power plant energy conversion efficiency, the indirect dry-cooling system shown in Figure 2 with the target air-cooled heat exchanger and supplemental cooling described above would be a transformational cooling system that meets the ARID program goals. Accordingly, this analysis was used to guide the establishment of the technical targets for heat exchangers and supplemental cooling in Section I.E.

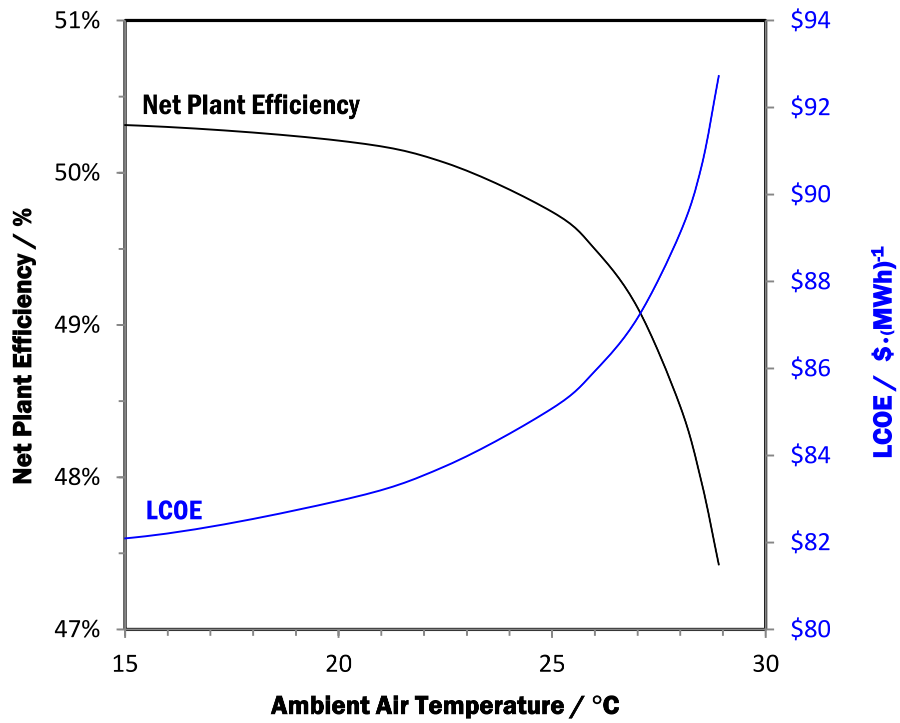

Figure 4: Variation in power plant energy conversion efficiency and LCOE as a function of increasing ambient air temperature for an aspirational target air cooled heat exchanger).

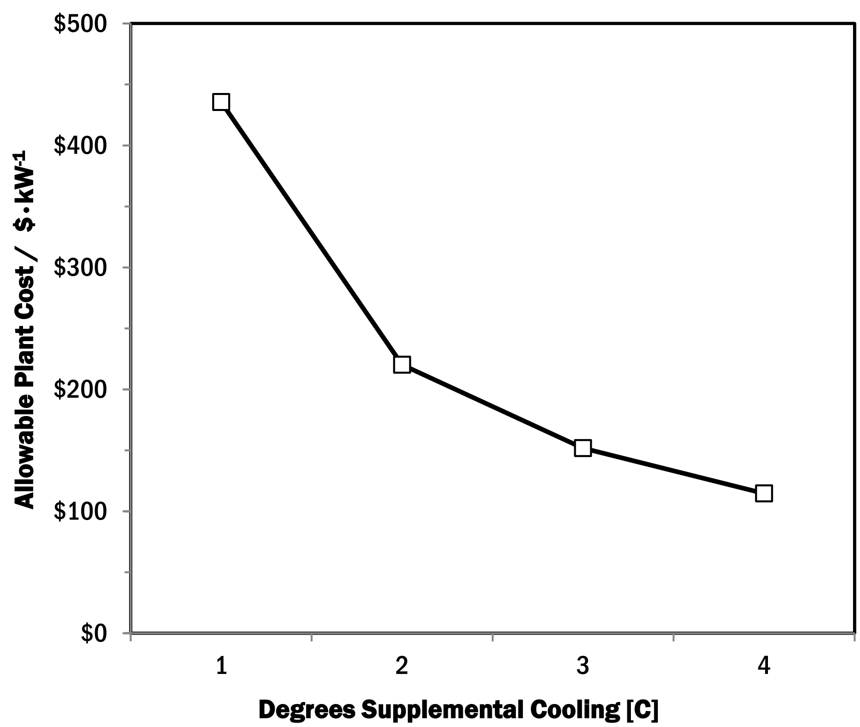

Figure 5: Projected allowable supplemental cooling cost for a 4% increase in LCOE when operating with an aspirational target air-cooled heat exchanger.

3. Air-cooled Heat Exchanger

The development of low cost and durable heat exchangers that can dissipate heat with minimal pumping power is central to the success of the ARID program. With the advent of novel manufacturing techniques and capabilities, as well as advancements in material science, the design space for heat exchangers has been widely expanded in recent years. The ARID program will enable the exploration of this exciting new heat exchanger design space to identify and realize technological innovations that address the program goals.

Due to its relative simplicity and lower cost compared to supplemental cooling and cool storage systems, air cooling is expected to handle at least 70% of the power plant heat load. One intriguing technology path that supports the program goals is the development of ultra-high performance, finned-tube metallic heat exchangers that meet the target heat transfer and pressure drop performance shown in Figure 3. A high rate of heat transfer significantly reduces the heat exchanger size, resulting in reduced capital cost and lower pumping load, provided the accompanying increase in pressure drop is limited.

Many different air-cooled heat exchanger operating conditions were considered in the ARPA-E techno-economic model, but under all cases studied the global minimum LCOE corresponded to *laminar* flow regime operation, with Reynolds number ranging from 1000–2000. Thus, a transformative metallic heat exchanger design that can achieve a five-fold increase in air-side heat transfer coefficient (operating in the 1000-2000 Reynolds number regime) must be capable of introducing flow disturbances to generate significant vorticity without large frictional losses as air flows across the heat transfer surfaces.

Another possible transformative route to achieving a low cost heat exchanger that supports the program goals is to use very inexpensive materials of construction, such as polymers. The inevitable decrease in overall heat transfer coefficient due to low thermal conductivity polymers will result in a much larger heat exchanger to handle the heat load. But, as long as the capital, installation, and operating costs are low enough and the lifetime of the unit is sufficient, such a solution could meet the program goals. Care must be taken to consider the increase in pumping load that will result with a larger heat exchanger and could negatively impact both the operating cost and power plant energy conversion efficiency.

Due to large heat loads and inherently small temperature differences, an air-cooled heat exchanger for power plant applications will be massive no matter what technical path is pursued. Therefore, a desired outcome from the ARID program is that the emerging transformative heat exchanger designs can be applied to not only power plants, but to also much smaller applications, such as residential and commercial heat pumps. Thus, a preferred design will be highly scalable and modular. The low cost, high throughput manufacturability of the heat exchanger design must be considered as part of the program. As such, collaboration with the advanced manufacturing community is encouraged.

The metallic finned-tube and polymeric heat exchangers mentioned are merely examples, and are not intended to be exclusive. All transformative air-cooled heat exchanger technologies that address the program goals will be considered by ARPA-E.

4. Supplemental Cooling and Cool Storage

A major drawback to managing the entire power plant heat rejection load solely with air cooling is that temperature excursions on hot days can lead to dramatically reduced energy conversion efficiency, as shown in Figure 4. To overcome this limitation, supplemental cooling is required. The need for supplemental cooling varies regionally, seasonally, and daily. An EPRI study considered power plant cooling in five locations across the U.S. that represent a range of major climate types (humid/dry, hot/temperate/cold, etc.).[22,29] For each of these locations, a wet-cooled system was modeled and an optimal cool water temperature feeding the condenser was identified. To study the need for supplemental cooling using the indirect dry cooling system in Figure 2, ARPA-E compiled hourly temperature data across one full year for each of these five locations from the EPRI data set.[30] The hourly ambient temperatures were compared to the required cool water design temperatures established in the EPRI study, factoring in a typical 7°C approach temperature for air-cooled systems.[22] This comparison was used to compute, for each hour, the amount of supplemental cooling required to lower the exit cool water temperature from the air-cooled heat exchanger to the required cool water inlet temperature to the condenser. The analysis revealed that supplemental cooling is required for 10–40% of the year, depending on the region, and 90 MW of supplemental cooling is sufficient to meet the required load for all regions considered. Different options for meeting the supplemental cooling load are described next.

Sorption/Desorption Supplemental Cooling

One intriguing option for supplemental cooling is sorption/desorption cooling technology driven by waste heat from a fossil-fired or solar thermal power plant. For example, the model 550 MW NGCC plant (NETL, Case 13)[27] has 150 MW of waste sensible heat that could be extracted from exhaust stack gasses, assuming a temperature drop of 106 to 60 °C. The condenser component of a fluid absorption cooling system typically rejects heat at relatively high temperature and can be transferred to liquid condensate discharged from the power plant steam condenser. Putting this waste heat back into the power block can boost the power plant energy conversion efficiency. In this way, sorption cooling systems and power plants have the potential to be highly complementary.

[29] The locations chosen were El Paso, TX; Portland, OR; Jacksonville, FL; Pittsburgh, PA; and Bismarck, ND.
[30] National Solar Radiation Data Base. 1991- 2005 Update: Typical Meteorological Year 3. Available from: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html [accessed may 2014]

Despite the potential synergy between sorption-based cooling systems and power plant cooling, many challenges still remain. For example, the coefficient of performance (COP) for state-of-the-art sorption-based cooling systems remains low, limiting the amount of cooling that can be achieved with available waste heat. Single-effect absorption cooling systems have a COP of about 0.7[31] and multi-effect units can achieve a COP just above 1, but are complex and expensive. The range of COP for various sorption cooling technologies over a range of regeneration temperatures and sorption media is shown in Figure 6.

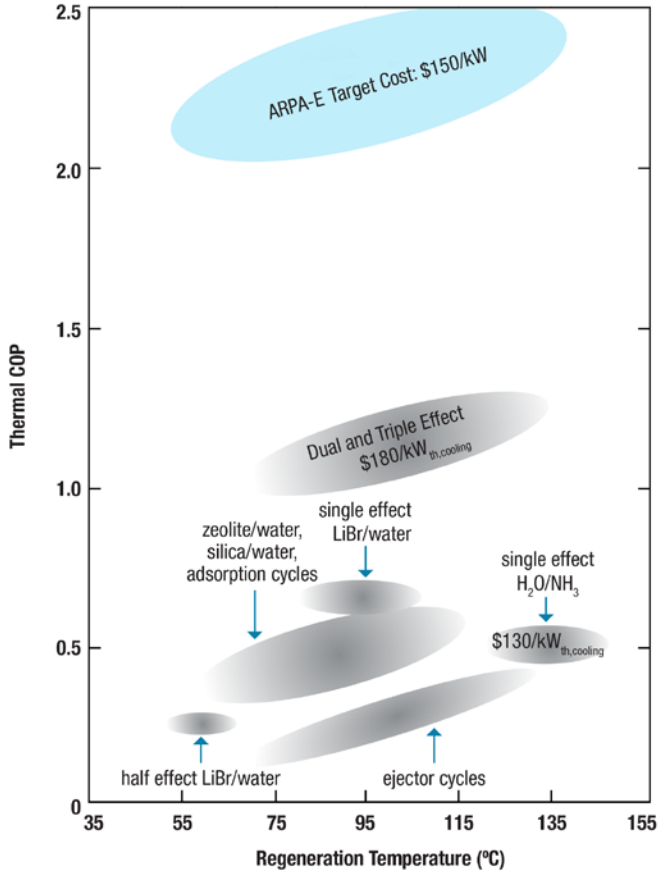

Figure 6: Coefficient of performance (COP) as a function of regeneration temperature for various sorption-based cooling media.[31]

Recent proprietary advancements with sorption media suggest that a COP of 2 may be possible with single-effect sorption cooling systems, motivating ARPA-E to target a high COP with a low enough cost to be economically attractive to dry power plant cooling. High COP and low cost sorption cooling technologies will be disruptive to the market, however achieving this aim will

[31] Beith, Robert, ed. "Small and micro combined heat and power (CHP) systems: Advanced design, performance, materials and applications". Elsevier, 2011. [Figure adapted].

require transformative ideas. ARPA-E is interested in all innovative sorption/desorption cooling concepts that have the potential to reach a high COP at low cost.

Cool Storage

Cool storage during nighttime hours could be an attractive option to mitigate daily ambient air temperature excursions. In order to determine the usefulness and appropriate size of a cool storage system, the hourly temperature profiles of the five representative locations were considered. Since a cool storage system could be charged 10 h per day or more when the cool water condenser temperature (T_{cool}) is below its design temperature, any day that the ambient air temperature exceeded the cool water condenser design temperature ($T_{ambient} > T_{cool}$) for less than 14 h was assumed to be a feasible day for using cool storage. The distribution of daily cool storage and the annual number of days of needed storage in the five U.S. regions is shown in Figure 7. As indicated in Figure 7, 80 MW of cool storage charged for 10 h/day or more (800 MWh/day) could mitigate the majority of temperature excursions across all five U.S. regions considered.

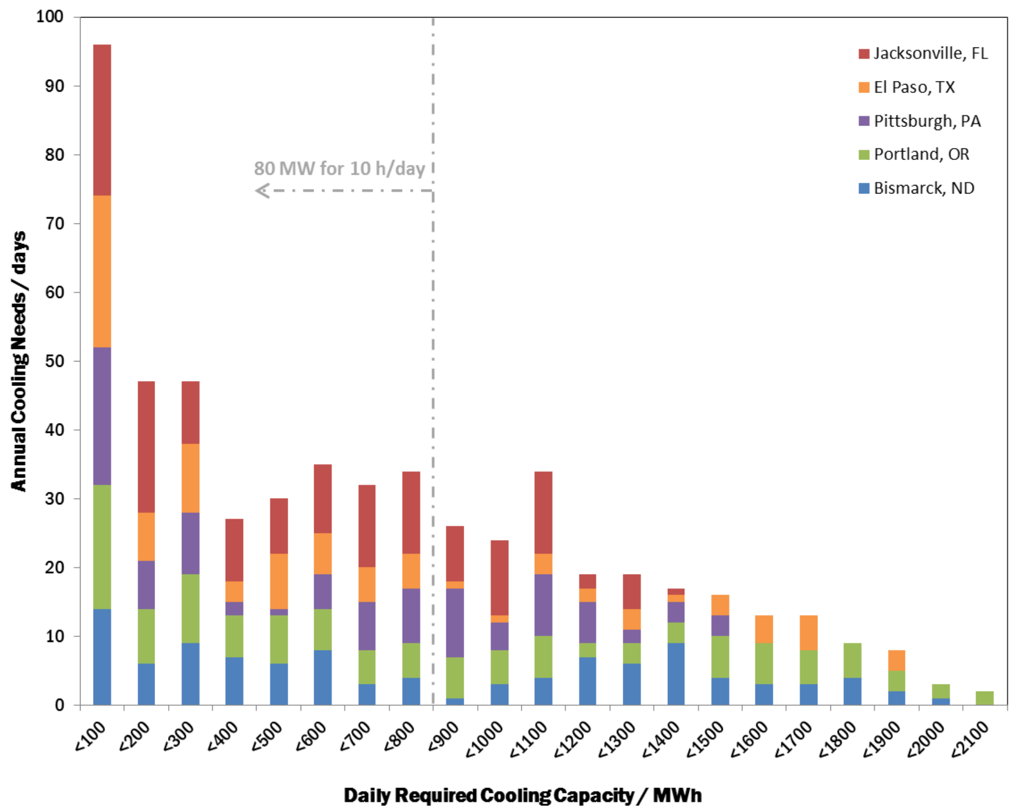

Figure 7: Amount of daily cool storage (MWh/day) and number of days needed for five U.S. regions.[30]

Many different schemes could be employed to charge a cool storage system. One intriguing approach is to use radiative cooling to the sky during nighttime hours. Nighttime radiative cooling takes advantage of the sky as a cold sink, which has not traditionally been considered for dumping a large waste heat load. A radiative cooling system could be envisioned, in which heat is dissipated by long-wavelength infrared radiation emitted within a narrow 8–13 μm wavelength band, assuming 30°C water exiting a heat exchanger.[32] On a clear arid night, this radiative emission would be absorbed in the atmosphere at a height of approximately 25 km above the earth's surface.[33] The sky temperature is approximately -50°C at this altitude and assuming ideal emission and absorption over this spectral band, the maximum theoretical heat flux is approximately 120 W/m^2.[34] This relatively low heat flux may not be practical to dissipate large heat loads in a standalone solution; however, the implementation of a heat exchanger that includes multimode heat transfer (both radiation and convection) may provide an interesting solution for charging a cool storage system.

Although a multimode radiative and convection heat exchanger is highlighted here as a possible cool storage charging technology, it is recognized that many other solutions exist. For example, transformative heat pipe or thermosyphon technology could provide a solution for passively charging the cool storage medium. ARPA-E is interested in all cool storage system concepts that meet the programmatic objectives and specified technical targets.

5. Scalability and Modularity for Commercialization

Since 2002, an average of 15-20 thermoelectric power plants of at least 50MW nameplate capacity have been built each year in the U.S.[35] A business model that relies on low sales volume of high capital cost units is very challenging to sustain. As such, it is important to develop highly scalable thermal management solutions that meet the needs for large-scale power plant cooling, as well as small and intermediate-scale emerging applications in order to cultivate and sustain business opportunities. Another consideration is the recent trend towards distributed power generation solutions with larger sales volumes of smaller capacity power plants. It is conceivable that future power production will be significantly more distributed than today with unit level power production capacity as small as the kilowatt-scale.[1] These considerations suggest that next-generation power plant cooling technologies developed through the ARID program need to be highly scalable. Here scalable implies that sound engineering principles can be used to design a transformative cooling concept to operate with equally high performance at the kilowatt and megawatt-scales. In addition, modular systems

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[32] Catalanotti, S., et al. "The radiative cooling of selective surfaces". Solar Energy 17.2 (1975): 83-89.
[33] Determined from data from NOAA Satellite and Information Services. National Environmental Satellite, Data, and Information Service. IGRA Interface, Station Selection. Sept 2013. Available from: http://nomads.ncdc.noaa.gov/cgi-bin/ncdc-ui/igra/main-station.cgi [accessed May 2014].
[34] Assumes a water temperature of 28 C, a sky temperature of -50 C, and no convection at the radiative surface.
[35] Calculated from data from U.S. Energy Information Administration. Form EIA-860 detailed data. Dec 2013. Available from: http://www.eia.gov/electricity/data/eia860/ [Accessed May 2014]

lend themselves to low-cost mass-manufacturing. As the final task for each of the projects funded through the ARID program, ARPA-E will require prototype testing of the cooling technologies at a scale of 20–100 kW, depending on the testing capabilities available to the research teams. Prototype cooling technologies will be expected to scale-up to megawatt-cooling capacity without a loss in performance. Research teams are encouraged to plan for offsite testing if internal testing capabilities at the 20–100 kW scale are not available.

D. Technical Categories of Interest

ARPA-E seeks to develop transformational power plant dry cooling technologies, including: (1) ultra-high performance air-cooled heat exchangers, (2) supplemental cooling/cool storage systems, and (3) other transformative power plant dry cooling technologies that meet all of the programmatic objectives. To accommodate the synchronous operation of different cooling technologies that meet the ARID program objectives, ARPA-E has envisioned an indirect dry-cooling architecture; however, technologies that are better-suited for other power plant system architectures, such as direct dry cooling, may be proposed *so long as such a system is capable of meeting the program objectives and technical targets.* In cases where supplemental cooling and/or cool storage systems are required for these alternative architectures, applicants will need to clearly explain and illustrate the design of the entire cooling system and demonstrate that system level operation can meet the objectives and relevant targets of the program.

Regardless of the system architecture, it is recommended that applicants focus on developing a single cooling technology as opposed to dispersing the team effort by trying to advance multiple technologies. For all cooling concepts proposed, it is acceptable to propose the development of only the enabling technology, provided the remainder of the system is already commercially available. Applicants are expected to clearly explain the cooling technology concept being offered, how it fits into a power plant cooling system architecture, the technical risks and challenges to be addressed through transformative research, and the supporting analysis to justify a development path to meet the performance and cost requirements.

Category 1: Air-Cooling Systems

Transformative air cooling technologies of interest include, but are not limited to, one or more of the following elements:

(1) Ultra-high performance air-side heat transfer with low pressure drop;
(2) Flow path features that induce vorticity and disrupt the development of a laminar boundary layer;
(3) Concepts incorporating phase change materials (non-volatile in cases where the PCM will be directly exposed to the environment);
(4) Construction with low-cost and durable materials;
(5) Concepts that incorporate large throughput advanced manufacturing methods;
(6) Concepts that are highly scalable and/or modular.

Category 2: Supplemental Cooling/Cool Storage

Transformative supplemental cooling and cool storage technologies of interest may include, but are not limited to, one or more of the following:

(1) Low-cost, high-COP sorption/desorption cooling systems driven by captured waste heat from stack gases, solar thermal energy, or other sources;
(2) Systems where rejected heat is reused in the power cycle;
(3) Multimode convective/radiative cooling systems with tuned spectral properties for night time operation;
(4) Advanced heat pipes coupled with a large-capacity heat sink;
(5) Novel cool storage media with high capacity.

Category 3: Other Transformational Cooling Concepts

The indirect dry cooling system described above is only one possible approach to achieve the program objectives and is not intended to be prescriptive. Other transformative power plant cooling technologies are of interest, so long as they meet the programmatic objectives.

E. TECHNICAL PERFORMANCE TARGETS

It is customary for ARPA-E to set aggressive technical and economic targets in order to encourage applicants to propose transformative solutions and creative alternatives to existing solutions. Only those technologies that have a well-justified potential to approach, meet, or exceed the technical and economic performance targets will be considered for funding. It is recognized that prototype technologies may not meet the cost targets without projection to full-production manufacturing. For such cases, a well-justified cost analysis is necessary. The analysis presented in Section I.C.2 above served as a guide in setting some of the technical performance targets. In addition, assumptions regarding other key working parameters used to arrive at the performance targets are listed in Table 1.

Working Parameters	Units	Value
Depreciation period	y	20
Plant operating period	y	30
Estimated fraction of LCOE due to cooling	%	1.2%
Estimated cooling CapEx	$/kW	50
Max increase in LCOE	%	5%
Max increase in CapEx	$/kW	215
Max cooling CapEx	$/kW	265

Table 1: Working parameters used in the derivation of technical performance targets

Category 1: Air-Cooling Systems

Category 1 contains two subcategories: (A) metallic air-cooling heat exchangers and (B) all other air-cooling heat exchangers. The primary heat transfer surface material determines the appropriate subcategory. In the case(s) where the heat exchanger will incorporate more than one heat transfer surface material (e.g. metal/polymer hybrid), the concept should go to subcategory (B). Metallic heat exchangers are most common in practice today. The cost of materials for metallic heat exchangers is inherently high. As such, the primary goal for the metallic heat exchangers subcategory is to dramatically improve heat transfer performance to meet the cooling load with a smaller volume, lower cost, and without an excessive fan load. Also of interest are polymeric air-cooled heat exchangers. Here, the material costs are cheaper, so larger systems might be acceptable, so long as the parasitic load, especially that of the fans, is not excessive. Polymeric heat exchangers are not expected to achieve the dramatic heat transfer performance enhancement that is needed for metallic heat exchangers. Another example of a non-metallic heat exchanger is one that incorporates phase change materials as the primary heat transfer surface. Other innovative material solutions to advanced heat exchangers can also be envisioned.

For concepts that fall within Category 1, the size of the final prototype should be at the 20–100 kW scale. Since air-cooled heat exchangers for power plant application are typically driven by small temperature differences, all concepts in Category 1 must assume that the ambient air temperature is no greater than 20°C below the working fluid entering the air-cooled system ($T_{work,inlet} - T_{air,inlet} < 20°C$) as part of any relevant analysis.

Subcategory 1A: Metallic Air-Cooling Heat Exchanger

ID	Description	Target
1A.1	Air-side heat transfer coefficient (h_{air})	$h_{air} \geq 5\ h_{air,base}$
1A.2	Pressure gradient	$\Delta P/\Delta L \leq 1.5\ (\Delta P/\Delta L)_{base}$
1A.3	Capital cost of heat exchanger	Cost ≤ $50/$kW_{th}$

Explanations:

The baseline heat transfer coefficient and pressure gradient are taken to be those shown in Figure 3 for Reynolds number between 1000 and 2000.

Subcategory 1B: Other Air-Cooling Heat Exchangers

ID	Description	Target
1B.1	Heat exchanger coefficient of performance COP_{HX},	$COP_{HX} \geq 200$
1B.2	Heat exchanger effectiveness ε	$\varepsilon > 0.6$
1B.3	Capital cost of heat exchanger	Cost ≤ \$50/kW_{th}

Explanations:

When determining COP_{HX}, all parasitic power requirements need to be accounted for, such as pumping power and other auxiliary loads. Here COP_{HX} is defined as $\frac{\dot{Q}_{transferred}}{\dot{P}_{parasitic}}$.

Applicants should use the following formula for calculating the capital cost of the heat exchanger: $Cost = \frac{\text{Cost}\left(\frac{\$}{\text{kW}_{\text{th}}}\right) \text{x life(yrs)}}{30 \text{ (yrs)}}$.

Category 2: Supplemental Cooling and Cold Storage

Category 2 is organized into three subcategories: (A) sorption/desorption cooling systems, (B) multimode (convective/radiative) cool storage systems, and (C) standalone cool storage systems. For all concepts that fall within Category 2, the size of the final prototype should be at the 20–50 kW scale.

Subcategory 2A: Sorption/Desorption Cooling System

ID	Description	Target
2A.1	Cooling system coefficient of performance COP_{cool}	$COP_{cool} \geq 2$
2A.2	Capital cost of system	Cost ≤ \$150/kW_{th}
2A.3	Regeneration temperature, T_{regen}	T_{regen} = 60–80°C

Explanations:

In COP_{cool}, all parasitic power requirements need to be accounted for, such as pumping power and other auxiliary loads. Here COP_{cool} is defined as $\frac{\dot{Q}_{cool}}{\dot{Q}_{heat,in} + \dot{P}_{parasitic}}$. Note that the Qheat,in term includes all external heat input to the sorption cooling system, excluding that input to the evaporator.

The regeneration temperature assumes ambient temperature, $T_{ambient}$ ~ 20°C.

Subcategory 2B: Multimode (Convection/Radiative) Cooling Plus Storage

ID	Description	Target
2B.1	Radiative heat flux $q''_{radiant}$	$q''_{radiant} \geq 100$ W/m^2
2B.2	Capital cost of system	Cost ≤ \$150/kW$_{th}$

Explanations:

The radiative heat flux is during night time operation. The cost includes the cost of the full system. If a proposed concept will use a commercially available storage unit or a storage media that does not require development, it should not be included in the development plan, but should be specified and factored into the cost analysis.

Subcategory 2C: Cool Storage System

ID	Description	Target
2C.1	Prototype storage capacity P_{cool}	P_{cool} = 200–500 kWh
2C.2	Time to fully charge t_{charge}	$t_{charge} \leq 10$ h
2C.3	Capital cost of system	Cost ≤ \$150/kW$_{th}$

Explanations:

The cost includes the cost of the full system, including heat exchangers for charging. If a proposed concept will use commercially available heat exchangers that do not require development, they should not be included in the development plan, but should be specified and factored into the cost analysis.

Category 3: Other Innovative Concepts

ARPA-E is interested in other innovative power plant cooling technologies that can meet the programmatic objectives, even if they do not fall into one of the subcategories above. These technologies must enable a cooling system to meet the following metrics:

ID	Description	Target
3.1	Capital cost of system	Cost ≤ \$200/kW$_{th}$
3.2	Temperature difference between steam inlet temperature $T_{steam,in}$ and air inlet temperature $T_{air,in}$	$T_{steam,in} - T_{air,in} < 25$°C
3.3	Prototype cooling capacity size Q_{cool}	Q_{cool} = 20–100 kW$_{th}$

Explanations:

The cost includes the cost of the full cooling system architecture, including any supplementary cooling systems that might be required. Only the proposed transformative technology should be included in the development plan, but other components and subsystems should be factored into the cost analysis. In addition to an illustration of the technology concept proposed for the development plan, all Category 3 concepts *must* also provide an illustration of the full cooling system enabled by the proposed technology.

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).
- 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 technologies:
  - Improvements in condensation heat transfer that do not also: (1) incorporate both air cooling and a means for supplemental cooling and/or cool storage and (2) achieve the targeted increase in air side heat transfer coefficient.

- Technologies with <u>net</u> dissipation of water vapor (e.g. when water vapor is dissipated to the atmosphere, not including surface water evaporation, and an equal or greater amount of water vapor is not captured);
- Once-through cooling systems.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $30 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 12 to 15 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 August 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."[36] 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.[37]

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

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

2. FUNDING AGREEMENTS WITH FFRDCS

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

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

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

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 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 (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).

GOGO's and Federal agencies may be proposed as project team members to support an applicant's project. The GOGO/Agency support would be obtained via an Interagency Agreement between ARPA-E and the 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.

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,[38] as the lead for a Project Team,[39] or as a member of a Project Team.

2. Domestic Entities

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

FFRDCs 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.

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.

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.

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

[39] 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.

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

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[41]

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

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

must provide at least 20% of the Total Project Cost[42] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[43]

2. Increased Cost Share Requirement

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

Under 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 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.

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[42] The Total Project Cost is the sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by FFRDCs.
[43] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.

- 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 <u>not</u> 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[44] to meet their cost share obligations under cooperative agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under Technology investment Agreements.

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

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

Applicants may wish to refer to 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.

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

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 Technical Milestones and Deliverables - Instructions and Examples, 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 body must not exceed 4 pages in length including graphics, illustrations, figures, and/or tables.

- An illustration of the full cooling system showing all components and flow paths, not to exceed 1 page, may be appended to the Concept Paper body. For all technologies that fall into Category 3 (as described in Section I.E) the appended cooling system illustration is ***required***.

- 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 page length indicated above, ARPA-E will review only the authorized number of pages and disregard any additional pages. Illustrations and figures may be used to aid in explaining concept(s).

1. Concept Summary

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

2. Innovation and Impact

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

3. Proposed Work

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

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

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

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

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

4. Team Organization and Capabilities

- Indicate the roles and responsibilities of the organizations and key personnel that comprise the Project Team.

- Provide the name, position, and institution of each key team member and describe in 1-2 sentences the skills and experience that he/she brings to the team.

- Identify key capabilities provided by the organizations comprising the Project Team and how those key capabilities will be used in the proposed effort.

- Identify (if applicable) previous collaborative efforts among team members relevant to the proposed effort.

5. Appendix: illustration of an example full cooling system

- This one page appendix is **required** for concepts falling under Category 3 (as described in Section I.E). It is **optional** for concepts falling under Category 1 or Category 2.

- The full cooling system diagram should show all components and flow paths

- The example full cooling system should include the novel concept being proposed and should be able to meet all programmatic objectives (as outlined in Section I.C).

D. Content and Form of Full Applications

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2015]

E. Content and Form of Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 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 JANUARY 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 will have a positive impact on at least one of ARPA-E's mission areas in Section I.A of the FOA;

- The extent to which the proposed concept is innovative and will achieve the technical performance targets defined in Section 1.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and

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

(2) *Overall Scientific and Technical Merit* (50%) - This criterion involves consideration of the following 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 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 JANUARY 2015]

3. Criteria for Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2015]

B. Review and Selection Process

1. Program Policy Factors

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 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 JANUARY 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 JANUARY 2015]

B. Administrative and National Policy Requirements

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2015]

C. Reporting

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 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. Applicants should not include confidential, proprietary, or privileged information in their Concept Papers, Full Applications, or Replies to Reviewer Comments unless such information is necessary to convey an understanding of the proposed project.

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.

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 FFRDCs.

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