FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

TRANSPORTATION ENERGY RESOURCES FROM RENEWABLE AGRICULTURE (TERRA)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001211
CFDA Number 81.135

FOA Issue Date:	October 1, 2014
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, November 10, 2014
Submission Deadline for Concept Papers:	5 PM ET, November 17, 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).

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 5 pages in length and must include the following: o Concept Summary o Innovation and Impact o Proposed Work o Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, November 17, 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 <u>not</u> support basic research, defined as a "systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind." While it is anticipated that in some instances some minor aspects of fundamental science will be clarified or uncovered during the conduct of the supported applied research, the major portion of activities supported by ARPA-E are directed towards applied research and development of new technologies.

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

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

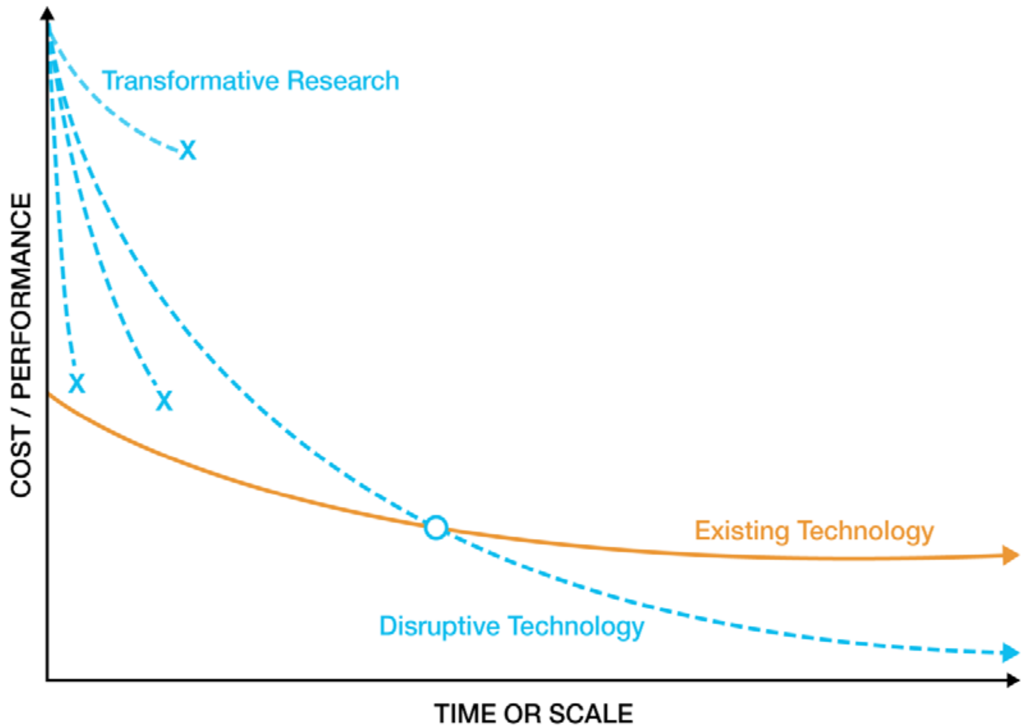

Figure 1: Description of transformational and disruptive technologies in terms of cost per unit performance versus time or scale. ARPA-E seeks to support research that establishes new learning curves that lead to disruptive technologies.

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

ARPA-E funded technology has the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. Energy technologies typically become disruptive at maturity rather than close to inception and the maturation of nascent technologies often require significant incremental development to drives the technology down its natural learning curve to its ultimate equilibrium (see Figure 1 above). Such development might include modification of the technology itself, the means to produce and distribute that technology, or both. Thus, while early incarnations of the automobile were transformational in the sense that they created a fundamentally new learning curve for transportation, they were not disruptive, because of the unreliability and high cost of early automobiles. Continuous, incremental refinement of the technology ultimately led to the Ford Model T: as the first affordable, reliable, mass-produced vehicle, the Model T had a disruptive effect on the transportation market.

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

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

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

B. Program Overview

1. Summary

There is an urgent need to accelerate energy crop development for the production of renewable transportation fuels from biomass. Recent technological advancements have now made it possible to extract massive volumes of genetic, physiological, and environmental data from certain crops, but, even with these resources, the data still cannot be processed into the knowledge needed to predict crop performance in the field. This knowledge is required to improve the breeding development pipeline for energy crops. Building upon precision agriculture innovations and data-intensive computational approaches, ARPA-E believes that it is now possible to accelerate plant breeding, using robust high-throughput precision phenotyping systems, to quantify important agronomic traits in the field throughout the entire lifecycle of an individual plant, and to associate these traits with their genetic and genomic properties. This ARPA-E program, Transportation Energy Resources from Renewable Agriculture (TERRA), is an investment in technologies that increase the precision, accuracy and throughput of energy crop breeding, to enable (a) new predictive algorithms for plant growth, (b) more detailed measurements for plant physiology, and (c) more sophisticated bioinformatics pipelines for gene discovery and trait association. TERRA will enable breeders to evaluate more individual plants, to select appropriate plants for breeding earlier in the growing season, to capture better information about them during their development, and to associate this information with the best genes to propagate. Success will be measured by the prospective ability to predict yield gains early, specifically, to identify which genes can improve carbon capture efficiency in newly cultivated bioenergy crops. Although other crops will be considered, this program intends to focus on energy sorghum as a model system because of its potential for improvement through breeding, its resources for genetic analysis, its geographic adaptability, and its commercial utility.

2. MOTIVATION

Fuel used in the U.S. transportation sector has become more diverse in the past several years. While gasoline remains the dominant fuel, the market penetration of diesel, biofuels, and hybrid-electric systems is growing, eroding gasoline's share of the light duty vehicle fuel market. This trend is too slow to reduce energy-related CO_2 emissions: petroleum remains, by far, the largest source of transportation fuel in the world, a significant, but non-renewable, resource. In 2013, 36% of U.S. energy consumption was from petroleum, producing 42% of its energy-related carbon dioxide emissions.[1] Thus, the more rapid development of transportation fuels with decreased, neutral, or negative carbon emissions is required to reduce the amount of foreign oil imports and limit the rate of increase of CO_2 in the atmosphere, addressing two of ARPA-E's core missions.

Economical production of the large amounts of biomass needed to displace petroleum will require significant productivity and efficiency improvements from the agricultural sector, which is also responsible for human and animal nutrition. In 2014, the United Nations warned that world agriculture must increase its output 60% by 2050 (1.6% per year, on average) to support global population growth and economic development.[2] Meanwhile, Hall and Richards report that the annual genetic gain for the main cereal crops best varieties and hybrids falls well below 1.16–1.31% per year and are not able to satisfy projected growing demand.[3] Consequently, the realization of commercially viable agriculture for energy purposes requires unprecedented increases in productivity and resource use efficiency.

[1] Annual Energy Outlook 2014, United States Department of Energy, Energy Information Agency, http://www.eia.gov/forecasts/aeo/

[2] United Nations Food and Agriculture Organization (FAO), World Agriculture Towards 2030/2050, 2014: Europe.

[3] Antonio J Hall and Richard A Richards, Field Crops Research, 2013. 143: p. 18-33.

A conventional breeding approach takes many years to improve crop varieties. The rate of crop improvement through breeding is strongly correlated to technology, increasing with better and more complete field data, i.e. the precision and accuracy of trait measurements and the throughput of screening. The ability to rapidly identify plants in a breeding population with desirable traits will increase the rate of genetic gain of the crop and improve the yield of bioenergy from agriculture.[4]

It is important to define the terminology of breeding: A **phenotype** is an observable or measurable physical trait, such as color, height, size, shape, behavior or chemical composition. Phenotype is determined by the individual's **genotype**, the information encoded in the DNA polymers present in its genome, as well as how that genome interacts with the environment. **Phenotyping** is the measurement of phenotypes, a process that can require substantial effort and may be highly dependent on data interpretation by a plant breeder. The development of advanced plant phenotyping technologies is substantially behind that of genotyping, and thus poses a key bottleneck on the path toward increased bioenergy crop yields. While agriculture has the capability to increase biomass yields and mitigate the effects of anthropogenic greenhouse gas emissions, the slow pace of conventional breeding limits this capability. Advancing and integrating cutting edge technology phenotyping platforms in genomics, computational analytics, proximal sensing, and automation, within the TERRA program, will contribute to breaking through this barrier to bioenergy crop development.

3. STATE OF THE ART

AGRICULTURAL PHENOTYPING

Plants use solar energy to convert atmospheric CO_2 into fixed carbon, which is then further used as a source of food, feed, fiber, and fuel. Plant breeding is the process of mating sexually compatible plants to generate agriculturally superior varieties. Traditional breeding methods are slow and inefficient; the challenge is to rapidly identify which genotype-phenotype combinations lead to substantial crop improvement from a large and diverse population.[5]

High throughput phenotyping technologies have been developed, and have the capability to accurately characterize large numbers of plants with much less time and labor than in the past. To date, these technologies have been applied only under tightly controlled laboratory and greenhouse conditions. Much of the technology improvement has focused on fully automated greenhouse systems using plants grown in uniform pots under precise conditions, or laboratory techniques that aim to correlate tissue culture observations with those of plants in the field.[6,7,8,9,10] While these systems are valuable, they are not easily scalable and the relationship

[4] Stephen P Moose and Rita H Mumm, Plant physiology, 2008. 147(3): p. 969-977.
[5] Stephen P Moose and Rita H Mumm, Plant physiology, 2008. 147(3): p. 969-977.
[6] Christian Klukas, Dijun Chen, and Jean-Michel Pape, Plant physiology, 2014. 165(2): p. 506-518.
[7] Anja Hartmann, T. Czauderna, R. Hoffmann, N. Stein, and F. Schreiber, BMC bioinformatics, 2011. 12(1): p. 148.

to crop responses in field situations is controversial, because soil volumes, solar radiation, wind speeds and evaporation rates in greenhouses are often much lower than in the field.[11,12,13]

The set of tools that currently exists for use in field environments is small and underdeveloped. These tools range from handheld devices aimed at capturing reflectance and spectral data, to prototype mobile platforms outfitted with crop sensors.[14,15,16,17,18] Today, the primary tool for measuring phenotype in the field is the harvest combine, which accurately collects the most relevant performance metric: terminal yield. However, terminal yield is captured destructively only at the very end of the season, and provides very little feedback or insight on crop development throughout the growing season. Thus, there is an urgent need for robust field-based high-throughput phenotyping systems for quantifying agronomic important traits at field scales throughout the crop lifecycle.[19,20]

ENERGY CROPS

Numerous crops are under consideration for energy production, and many factors must be taken into account when selecting an energy crop for a particular growing location.[21] *Sorghum bicolor* (a phenotypically-diverse species, currently available in grain, sweet and energy varieties) is a highly productive C4 grass that has been identified as a particularly useful crop for improvement. It is an important cultivated food, feed, and bioenergy crop worldwide, and is the third most widely cultivated cereal crop in the U.S., which is also its number one producer and exporter.[22] Among sorghum types, energy sorghum has exceptional potential as a high biomass bioenergy crop, with yields in certain regions reaching nearly 60 dT ha^{-1} (dry metric tons per hectare) under ideal conditions. Energy sorghum adapts well to drought and heat conditions that are inhospitable to food crops, making it an excellent model for studying plant-

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[8] Nora Honsdorf, T. John March, Bettina Berger, Mark Tester, and Klaus Pillen, PloS one, 2014. 9(5): p. e97047.
[9] Stefan Paulus, Henrik Schumann, Heiner Kuhlmann, and Jens Léon, Biosystems Engineering, 2014. 121: p. 1-11.
[10] Michael Malone, PhenoDay. 2011: Wageningen, Netherlands.
[11] J. Cobb, G. DeClerck, A. Greenberg, R. Clark, S. McCouch, Theoretical Applied Genetics, 2013. 126(4): p. 867-887.
[12] Robert T Furbank and Mark Tester, 2011. 16(12): p. 635-644.
[13] Jeffrey W White, Pedro Andrade-Sanchez, Michael A Gore, Kevin Bronson, Terry Coffelt, Matthew Conley, Kenneth Feldmann, Andrew French, John Heun, Douglas Hunsaker, Field Crops Research, 2012. 133: p. 101-112.
[14] Robert T Furbank and Mark Tester, Trends in plant science, 2011. 16(12): p. 635-644.
[15] Jeffrey White, Pedro Andrade-Sanchez, Michael Gore, Kevin Bronson, Terry Coffelt, Matthew Conley, Kenneth Feldmann, Andrew French, John Heun, and Douglas Hunsaker,. Field Crops Research, 2012. 133: p. 101-112.
[16] Kyle H Holland and James S Schepers,. Precision Agriculture, 2013. 14(1): p. 71-85.
[17] P. Andrade-Sanchez, John Heun, Michael Gore, Andrew French, E. Carmo-Silva, and M. Salvucci, Proceedings of the 2012 American Society of Agricultura and Biological Engineers Annual International Meeting. 2012: Dallas, TX.
[18] Fabio Fiorani and Ulrich Schurr, Annual review of plant biology, 2013. 64: p. 267-291.
[19] Robert T Furbank and Mark Tester, Trends in plant science, 2011. 16(12): p. 635-644.
[20] Jeffrey White, Pedro Andrade-Sanchez, Michael Gore, Kevin Bronson, Terry Coffelt, Matthew M Conley, Kenneth A Feldmann, Andrew N French, John T Heun, and Douglas J Hunsaker,. Field Crops Research, 2012. 133: p. 101-112.
[21] C. Somerville, H. Youngs, C. Taylor, S. Davis, and S. Long, Science, 2010. 329(5993): p. 790-792.
[22] Crop Production 2013 Summary, United States Department of Agriculture, http://usda.mannlib.cornell.edu/usda/current/CropProdSu/CropProdSu-01-10-2014.pdf

environment interactions. In addition, sorghum is an annual crop, meaning that it can be bred rapidly and evaluated easily in diverse environments to enable the testing and optimization of automated precision phenotyping, both in the field and in well-controlled environments.[23,24]

GENOMICS AND BIOINFORMATICS

The field of genomics aims to decipher the information content of the genome. Enabled by the extremely rapid progress of high-throughput gene sequencing technologies, valuable computational analysis at the genomic level using advanced bioinformatics techniques is now possible. The genome interacts with the environment in a complex manner to form a plant's many phenotypes, which develop over the plant's lifecycle. The bioinformatics field of statistical genetics aims to elucidate the dependence of a particular genetic background on a phenotype, given environmental inputs. Analytically, understanding *and predicting* this interaction between genetics (G) and environment (E) that produces a particular phenotype (P), as given by Eq 1, is the central goal of the TERRA program.

$$P = G \times E \qquad \text{(Eq. 1)}$$

Determination of a genotype need not require complete genome sequencing. Biologists have traditionally used genomic assays such as allele-specific polymerase chain reaction (PCR), which requires the *a priori* identification of characteristic alleles (alternative gene forms) in the genome. The most common of these changes are called single nucleotide polymorphisms (SNPs)[25]; identification of common SNPs in populations has been the subject of much research over the past few decades. As illustrated by Eq 1, assaying these known SNPs in energy crop populations and correlating them with phenotype is one of the foundations of statistical genetics.

Marker-assisted breeding has used selected genetic landmarks such as SNPs for decades to help breeders determine which lines to cross to confer given phenotypes, usually with little knowledge of the underlying physiological basis. Inexpensive DNA sequencing has added depth of information to this field, leading to the sub-discipline of genomic prediction. In genomic prediction studies, models of *all* the SNP data can be created, allowing for a prediction and earlier selection of the phenotype of offspring from knowledge of only the parental genotypes. Genome Wide Association (GWA) studies are empirical studies that use statistical genetic tools to associate discrete or continuous traits within a population to the specific DNA sequences that underlie that variation. GWA studies can identify regions of the genome (known as quantitative trait loci, or QTLs) that are statistically associated with the variation in phenotype.

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[23] Sara N Olson, Kimberley Ritter, William Rooney, Armen Kemanian, Bruce A McCarl, Yuquan Zhang, Susan Hall, Dan Packer, and John Mullet, Biofuels, Bioproducts and Biorefining, 2012. 6(6): p. 640-655.
[24] S. Olson, K. Ritter, J. Medley, T. Wilson, W. Rooney, and J. Mullet, Biomass and Bioenergy, 2013. 56: p. 307-316.
[25] Xuehui Huang and Bin Han, , 2014. 65: p. 531-551.

The genes or regulatory elements within each QTL are inferred to be the mediators of the variation, and the particular genetic differences that comprise those variants.

A commonality between GWA and genomic prediction studies is the goal of predicting phenotypes from genetic information. In the context of agriculture, accurate and early prediction could enable a transformational shift in breeding resources: tens of thousands of crosses could be analyzed *in silico*, and only those with the highest probability of an improved phenotype moved into the breeding pipeline. Because energy crops have received much less attention from breeders than food and feed crops (and therefore have much more unrealized genetic potential)[26,27,28], rapid analysis is particularly important. However, realizing predictive genomics in bioenergy crops *depends on* the generation and availability of large amounts of high quality phenotypic data.

SENSING AND AUTOMATION

Sensors and automation have already made significant contributions toward lowering production costs in agriculture, reducing manual labor and raising the quality of production.[29,30] Over the past decade, automated precision farming technologies that employ vision systems, laser sensors, and satellite positioning instruments have emerged. The most widely adopted technologies include autonomous equipment navigation, yield mapping, and variable rate technologies for planting and application of fertilizers and crop protection chemicals.[31] The investments in precision agriculture have enabled better specificity in the field as well. As opposed to classical techniques of measuring or manipulating the field that focus on entire rows or plots, high-precision systems incorporate GPS and other positional accuracy aids to enable plant level specificity of 2 cm or better.[32]

Current methods for plant phenotyping using sensor measurements span many modalities and include imaging across various spectral channels, fluorescence measurements, topographical analysis using LiDAR or stereo cameras, and environmental sensing.[33,34,35,36,37,38] Numerous

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[26] Philip G Pardey, Julian M Alston, and Connie Chan-Kang, Agricultural Economics, 2013. 44(s1): p. 103-113.
[27] OECD, Improving Agricultural Knowledge and Innovation Systems: OECD Conference Proceedings, 2012, http://dx.doi.org/10.1787/9789264167445-en
[28] Jenifer Piesse and C Thirtle, Agricultural R&D, technology and productivity. Philosophical Transactions of the Royal Society B: Biological Sciences, 2010. 365(1554): p. 3035-3047.
[29] Yael Edan, Shufeng Han, and Naoshi Kondo, 2009, Springer. p. 1095-1128.
[30] Tony Grift, Qin Zhang, Naoshi Kondo, and KC Ting, Journal of Biomechatronics Engineering, 2008. 1(1): p. 37-54.
[31] David Schimmelpfennig and Robert Ebel,. 2011: US Department of Agriculture, Economic Research Service.
[32] Jeffrey W White, Pedro Andrade-Sanchez, Michael A Gore, Kevin F Bronson, Terry A Coffelt, Matthew M Conley, Kenneth Feldmann, Andrew French, John Heun, Douglas Hunsaker, Field Crops Research, 2012. 133: p. 101-112.
[33] Michael Malone, High-throughput phenotyping – taking crop biotechnology to the next level, in PhenoDay. 2011: Wageningen, Netherlands.
[34] Joshua N Cobb, Genevieve DeClerck, Anthony Greenberg, Randy Clark, and Susan McCouch, Theoretical and Applied Genetics, 2013. 126(4): p. 867-887.
[35] Robert T Furbank and Mark Tester, Trends in plant science, 2011. 16(12): p. 635-644.

phenotypes are important for agricultural breeder selections, but accurate measurements of aboveground biomass throughout the growing season (from which growth rates can be derived) are of critical importance. Such estimates are possible using greenhouse systems that measure individual plants from several angles (*R* values of 0.98 have been demonstrated).[39] Furthermore, some of these collection methods are faster than others. For example, hyperspectral and fluorescence measurements take much longer than camera, thermal, or reflectance measurements, but provide a wealth of additional data.

Spectroscopic measurements taken in the field can be correlated with quantitative phenotypes of interest using indices such as leaf area index (LAI), vegetation fraction, and canopy nitrogen. These indices are typically measured by taking reflectance spectroscopy measurements of two or more specific spectral bands. Examples include the Normalized Difference Vegetation Index (NDVI) and Visible Atmospheric Resistant Index (VARI) indices. Such methods have spawned a small community of researchers discovering new spectral indices that correlate with various phenotypic quantities of interest. Combining indices or adding other modalities such as thermal imaging can further enhance phenotypic accuracy. This approach, however, has several shortcomings: (1) the correlation between the proposed index and a quantity of interest is often weak, (2) these indices often do not account for changes in the environment, weather, or across testing domains, and do not necessarily translate among different crops/species, (3) the indices often have limited observational regimes, making prediction above a certain value (of LAI, for example) impossible, and (4) the development of these indices is largely empirical. Researchers propose a new index (for example, selecting two spectral channels and taking their ratio) and then determine its correlation with some phenotypic quantity of interest. Not surprisingly, this often leads to weak correlations that lack robustness.

As researchers have deployed the first set of field-based automated sensing platforms for phenotyping, critical tradeoffs have emerged between collection time, phenotypes of interest, and data volume or data precision. At this point breeders still have to choose between employing a slow system (≤2 km h^{-1}) to achieve plant-level specificity, or a fast system such as an aerial survey that can cover an entire field within seconds but focuses more on plot-level specificity.[40] Neither of these approaches offers breeders access to data on individual plants with the capacity for frequent (daily or better) updates across a large area (tens to hundreds of acres). And without knowing which phenotypes are the most essential, selecting the appropriate sensor suite and corresponding collection rate is exceedingly challenging.

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[36] Jeffrey White, Pedro Andrade-Sanchez, Michael Gore, Kevin Bronson, Terry Coffelt, Matthew Conley, Kenneth Feldmann, Andrew French, John Heun, Douglas Hunsaker, Field Crops Research, 2012. 133: p. 101-112.
[37] Kyle H Holland and James S Schepers, Precision Agriculture, 2013. 14(1): p. 71-85.
[38] P. Andrade-Sanchez, John T Heun, Michael Gore, Andrew French, E. Carmo-Silva, and M. Salvucci, Proceedings of the 2012 American Society of Agricultura and Biological Engineers Annual International Meeting. 2012: Dallas, TX.
[39] Nora Honsdorf, Timothy John March, Bettina Berger, Mark Tester, Klaus Pillen, PloS one, 2014. 9(5): p. e97047.
[40] Jeffrey W White, Pedro Andrade-Sanchez, Michael A Gore, Kevin F Bronson, Terry A Coffelt, Matthew M Conley, Kenneth Feldmann, Andrew French, John Heun, Douglas Hunsaker, Field Crops Research, 2012. 133: p. 101-112.

C. PROGRAM OBJECTIVES

The overall objective of the TERRA program is to develop tools that enable an increase in the rate and extent of genetic improvement of the yield of bioenergy crops grown in the field. If successful, the program will enhance land use efficiency, reduce competition between bioenergy and food crops, improve environmental sustainability, and provide a more stable supply of biomass for transportation fuels and bio-refineries.

Equation 2: Breeders' Yield

$$R_t = \frac{ir\sigma_A}{y}$$

R_t (genetic gain over time)
i (selection intensity)
r (selection accuracy)
σ_A (genetic variance)
y (years/cycle)
J. Poland, KSU - ARPAE Workshop 2014

As shown in Equation 2, the rate of genetic gain or crop improvement per cycle of breeding R_t is related to the intensity of genetic selection, i, the extent of phenotypic variation controlled by genetics within the materials being screened (phenotypic variance, σ_A), the selection accuracy (r) impacted by the heritability of the trait(s) under selection, and the length of the breeding cycle, y. Automated precision phenotyping for renewable energy has the potential to increase the intensity of genetic selection by providing more detailed phenotypic information (multiple times during a growing season, with spatial information and more information content) and by allowing more genetic material with a greater range of phenotypes to be screened per breeding cycle, thus accelerating the rate of genetic gain.

Therefore, the TERRA program will emphasize development of innovative phenotyping systems that increase the precision, accuracy and throughput of breeding by developing approaches that can predict terminal phenotypes earlier in the growth cycle.

As shown in Figure 2, ARPA-E seeks to establish multidisciplinary teams to leverage advancements in sensor technologies, computational analytics and low-cost nucleotide sequencing. It is the objective of the program to establish the key intermediate phenotypes related to yield, that can be collected with enough accuracy to predict the growth of an individual plant or population of plants of a particular genetic makeup, and to do so across a high volume (multiple thousands of breeder plots) at the field level.

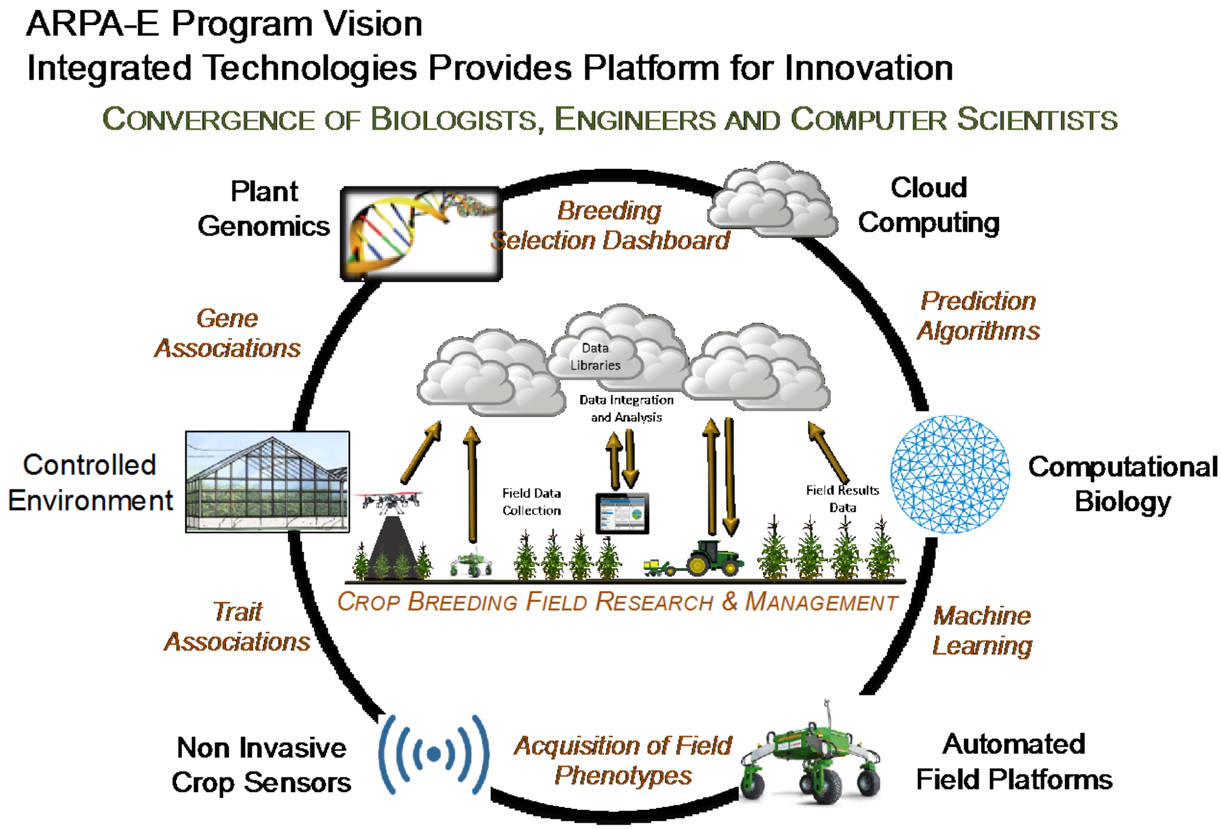

Figure 2: ARPA-E Advanced Phenotyping Vision[41]

[41] ARPA-E Plant Phenotyping Workshop. 2014: Chicago, IL.

D. TECHNICAL CATEGORIES OF INTEREST

Precision phenotyping of bioenergy crops under natural field conditions is a complex systems challenge that requires the integration of multiple scientific and engineering disciplines.

ARPA-E is primarily interested in applications that propose complete systems solutions that combine genetics, automation, sensors, and computation into integrated phenotyping platforms. Each platform should be capable of quantifying, modeling, and accurately predicting plant performance in the field and include provisions for data quality control, standardization, and digital communication of data and algorithms to the community. However, applications are also sought for partial system solutions that comprise the key components of the complete integrated phenotyping system: high throughput automated hardware and sensing technology; computational solutions for phenotype selection and prediction; and genomic and bioinformatic genotype by phenotype trait associations. Finally, applications are also sought for programmatic reference data generation and hosting.

CATEGORY 1: COMPLETE INTEGRATED PHENOTYPING SYSTEMS SOLUTIONS

ARPA-E seeks applications describing complete solutions that span crop breeding, field automation, plant sensing, genomics, computational analytics and bioinformatics, all of which are critical to the success of the TERRA program. This program should be conducted under both field and controlled environmental conditions, where exploration of genotype-phenotype associations in controlled environments can be used to help predict trait associations in the field.

Applicants should propose automated host platforms and sensor suites, along with the initial phenotypes that will be measured. Applicants should have a plan for selecting to a minimum set of phenotypes necessary to drive yield gain. Based on that selection, the phenotyping platform must be able to evolve further into a simpler, faster, and less costly system. Applicants are expected to demonstrate how their proposed system will meet the in-field throughput and cost metrics outlined in Section I.E of the FOA.

Category 1 integrated phenotyping systems solutions applicants must include ALL of the elements enumerated below in component Categories 2, 3 and 4.

CATEGORY 2: HIGH THROUGHPUT AUTOMATED HARDWARE AND SENSING TECHNOLOGIES

ARPA-E seeks applications that develop high throughput automated sensing technologies to acquire phenotypic data in the field across diverse breeding populations, with a preference for energy sorghum. Teams should generate high-fidelity image - and spectrum-based phenotype data and whole-plant assessments throughout the plant's growth cycle for sorghum accessions/lines analyzed in field. This category requires high-precision data on growth rates, biomass accumulation, and the physiological state of each genotype to infer variation in the carbon-system traits of interest. TERRA teams may propose more than one platform solution in order to provide full season and/or complete crop phenotyping capabilities.

Teams are asked to propose the phenotypes they expect to be most predictive of end of season biomass growth/yield. Examples of types of phenotype data, as well as the sensory and platform collection means required to gather the data, are presented in Table 1.

Table 1: Examples of candidate representative phenotypes, sensors, and platforms sought from teams submitting in Category 2 (not exhaustive)

PHENOTYPES	SENSORY SYSTEMS	PLATFORMS
• Biomass yield • Carbon (energy) yield per unit time, synthetic input, and moisture (genetic efficiency) • Carbon partitioning to sinks • Growth rate, height, lodging • Maturity, photoperiod sensitivity • Compositional traits (nonstructural and structural carbohydrates and other carbon and mineral compounds) • Photosynthetic efficiency • Drought tolerance and water use efficiency • Cold tolerance and regrowth potential	• Active reflectance • Spectral indices (e.g. NDVI) • Visual imaging for morphometric analysis (stereo cameras) • Thermal imaging • Hyperspectral / multispectral imaging • Fluorescence measurement • Environmental monitors (temperature, rainfall, humidity, insolation, CO_2, etc.) • Spatial imaging (LiDAR, ultrasonic)	• Unmanned or optionally piloted ground vehicles, wheeled or otherwise • Gantry and/or crane systems • Cable-based systems • Select unmanned aerial vehicles (UAV), with appropriate government approvals

Applicants should have a plan for selecting to a minimum set of phenotypes necessary to drive yield gain. Based on that selection, the phenotyping platform must be able to evolve further into a simpler and faster system. Applicants are expected to demonstrate how their proposed technologies will meet the in-field throughput and cost metrics outlined in Section I.E of the FOA.

Further, it is understood that some nascent technologies may not be at a development stage to address all of the attributes described above. Consequently, ARPA-E will support the development of novel enabling technologies that could transformationally and significantly contribute to progress towards the objectives in this category.

ARPA-E is particularly interested in key enabling technologies that include, for example:

- Novel sensors (spectrometers, electrochemical sensors, etc.) that provide significantly improved performance and/or lower cost than existing sensor technologies.
- Technologies that enable measurements of individual plants beneath the closed leaf canopy of the crop.
- Technologies that enable non-destructive below-ground field characterization, e.g. root architecture or mass.
- Sensor approaches for soil profile characteristics, soil microbiome analyses.

CATEGORY 3: COMPUTATIONAL SOLUTIONS FOR SELECTION AND PREDICTION

ARPA-E seeks applications to develop algorithm-based computational solutions that enable the discovery of the most important and predictive attributes of the crop phenotypic data. Phenotyping systems should encompass automated data collection, data reduction, data interpretation and model fitting (Figure 3) to include plant identification (segmentation of plant from background), feature detection (e.g. height, area, color), and feature analysis (e.g. growth rate).

Teams must develop a robust informatics pipeline that addresses quantitative approaches to image and data processing that must include, at a minimum:

- Calibration: Manage inconsistent orientations and alignments of multiple images, image effects due to sensor noise, and image variance due to the variety of conditions found in the field (e.g., light intensities, air temperatures, and humidity levels). Of particular importance is proper registration and georeferencing of images, in addition to turn-key solutions for converting hyperspectral scans to “data-cubes” of accurate reflectance values.
- Segmentation: Effective methods and algorithms for separating plant foreground from field background. Included in this should be more specialized computer vision algorithms to extract canopy boundaries, for example.
- Feature extraction: Computer vision techniques for identifying inputs to machine learning classification or regression algorithms for phenotyping (below).

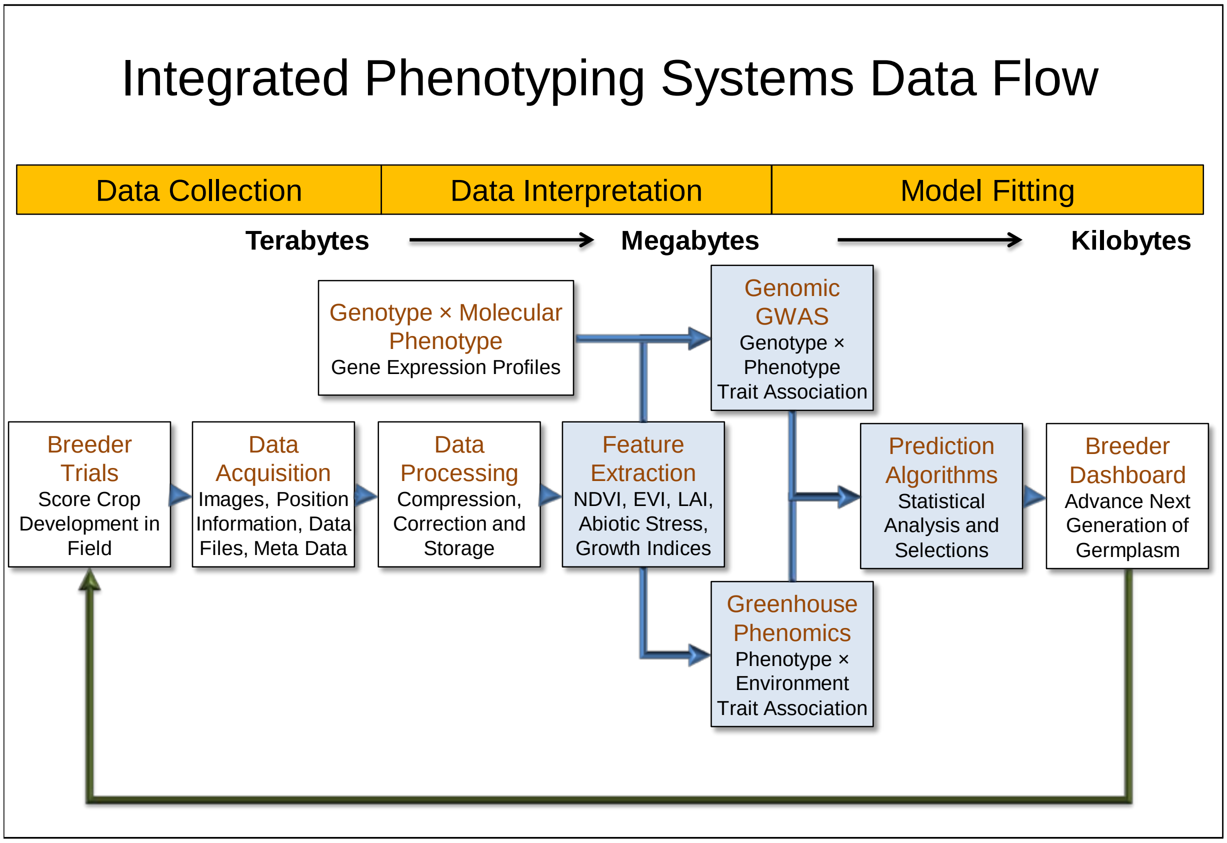

Figure 3: Integrated Phenotyping Systems Data Flow[42]

As shown in Figure 3, after data acquisition and processing, performers must apply machine learning regression and classification algorithms that operate on multimodal data-streams to extract key features for phenotyping. In addition to the imaging data described above, performers should consider adding other multimodal data streams as inputs. These streams may include text input (such as field reports) or qualitative information such as breeder visual scores (e.g. lodging), or prior beliefs and observations. Applicants should include information concerning the structure of their models, particularly regarding the algorithms employed. For example, phenotyping algorithms might include any number of machine learning or biological models, such as:

- Static Machine Learning Models: Least squares regression, logistic regression, support vector machines, sparse regression, ridge regression, random forests, etc.
- Dynamic Machine Learning Models: Markov models, Gaussian processes, etc.

[42] ARPA-E Plant Phenotyping Workshop. 2014: Chicago, IL. http://arpa-e.energy.gov/?q=arpa-e-events/plant-phenotyping-workshop

- Biophysical Models: Functional growth analysis, canopy models, etc.

A crucial component is expected to be cloud computation and parallel analysis (possibly in the field) of the very large data sets necessary to train the algorithms for more accurate phenotypic prediction. Data will be derived from a series of sensors (thermal, hyperspectral, moisture, CO_2, fluorescence, etc.) that collect a high-volume "data-cube" of information. The data size for integrated systems has been estimated to be up to terabytes per 24 hour run. Finding combinations of algorithms and hardware platforms that apply to this "data-at-scale" will be a research challenge that must be addressed.

As the program matures, applicants will be expected to identify the dimensions of the data that are most predictive for phenotypic quantities of interest (this would be an example of new index discovery by principled data reduction from the full volume of collected information). This will require dimensional reduction and feature selection algorithms. It is expected that the relevant data will not have a simple linear structure, making a straightforward Principle Component Analysis (PCA) inappropriate. Applicants are expected to develop more refined, non-linear dimensional reduction algorithms (such as manifold learning, etc.) to achieve the goals of this program.

Further, it is understood that some nascent technologies may not be at a development stage to address all the attributes described above. Consequently, ARPA-E will support the development of novel technologies that could transformationally and significantly contribute to progress towards the objectives in this category.

ARPA-E is particularly interested in key enabling technologies that include, for example, data-processing algorithms and predictive models that have unique capabilities for evaluating plant performance.

CATEGORY 4: GENETICS, GENOMICS AND BIOINFORMATICS

ARPA-E seeks applications to develop high-resolution genetic maps to provide the foundation for elucidating genotype-phenotype associations. The applicants should endeavor to correlate genetic markers with physiological phenotypes, using applicable tools such as genotyping-by-sequencing (GBS), whole genome re-sequencing, and other -omic (in particular transcriptomic) profiling.

The application must integrate these high-throughput sequencing derived genotypes with phenotypic data collected in the field and under controlled-environments (greenhouse and laboratory) to drive statistical genetics (QTL, eQTL, GWAS, genetic prediction, etc.) analyses focusing on traits associated with carbon productivity, for example: photosynthesis, accumulation and partitioning, plant idiotype (height, leaf angle, and tillering), plant composition, and terminal yield (grain, sugar, or biomass).

TERRA Category 4 teams are expected to generate a number of significant resources, such as:

- Genomic characterization and high-quality molecular markers suitable for whole-genome predictions and genome selection, identified as single nucleotide polymorphisms (SNPs) through genotyping-by-sequencing (GBS) and analysis of genomic re-sequencing data obtained from sorghum individuals.
- Identification of putative functional SNPs to enable increased resolution in marker-assisted breeding and provide further mechanistic insight into such biomass traits.
- Statistical genetics resources and outcomes (or analyses) including GWAS, QTL, eQTL elucidation of epistasic interactions and epigenetics.
- Controlled environment gene expression data from a diverse collection of genotypes from the juvenile stage to harvest; enabling elucidation of eQTLs and correlations of gene expression, juvenile traits, and terminal yields.
- Detailed phenotypic data determined through controlled environment high-throughput phenomics platforms and field based platforms developed during the program throughout the entire growing season.

Further, it is understood that some nascent technologies may not be at a development stage to address all the attributes described above. Consequently, ARPA-E will support the development of novel technologies that could transformationally and significantly contribute to progress towards the objectives in this category.

ARPA-E is particularly interested in key enabling technologies that include, for example, algorithms for improving predicting genes, regulatory elements, or genetic loci associated with biomass or other yield phenotypes.

CATEGORY 5: PROGRAMMATIC REFERENCE DATA GENERATION AND HOSTING

The successful applicant for Category 5 will generate and host for TERRA teams reference phenotyping data through an energy sorghum field test plot monitored by a state-of-the-art field phenotyping system provided by ARPA-E.

To facilitate the development of accurate, predictive phenotyping algorithms and support all program teams, ARPA-E will collaborate with the Category 5 awardee to make available to other awardees a high-fidelity dataset collected on sorghum field plots throughout the program. This will be accomplished by way of an automated platform that will deliver raw sensory data to all teams starting in 2015. This dataset can be used in advance of and in conjunction with any data collected by the teams using their own field platforms.

Data from a wide array of sensors on the phenotyping system will deliver high-resolution imagery and other sensory products. The data will be transferred continuously to an on-line, awardee-accessible system within 48 hours of collection. This system will offer a rich amount of spectral data, and will offer per-pixel resolution and positional accuracy suitable for plant-level (sorghum) specificity. The high degree of sensor instrumentation on this system is expected to provide insight into the use of a diverse array of sensors, and this insight can inform the design of the low-cost field sensing platforms to be developed by TERRA teams.

Metadata will be appended to all sensory products for the purpose of timestamping and georeferencing all collected information, with standards clearly documented for the performer teams. With this metadata and a fairly continuous stream of environmental information (wind speed, temperature, etc.), the environmental context of each data product can be determined. The data generated by the reference platform will be available to all TERRA teams and all necessary interface specifications for accessing and working with the data will be provided.

The reference team, with the substantial involvement of the ARPA-E Program Director, will install, operate and maintain a reference field phenotyping system provided by ARPA-E.

ARPA-E is selecting and will provide to the reference team a state-of-the-art field phenotyping system (hereafter referred to as Government Furnished Equipment, GFE). The GFE will have the features provided in Table 2.

Table 2. Features of the GFE field phenotyping system.

Performance Characteristic	**Specification**
Form Factor	• Gantry system, sensor bay height range 0-6 meters
Resolution and Accuracy	• Payload bay positional accuracy of 1-5 cm or better in x, y axes, and 0.5 cm or better in z-axis • Imagery (hyperspectal, IR, RGB) resolution of 1 mm or better
Sensor Suite	• Hyperspectral imager (400-2500 nm range objective, ~700-2000 nm threshold) • Thermal infrared (IR) • Dedicated NDVI sensor • LIDAR imager • Stereo RGB cameras • Active reflectance sensor • Fluorescence measurement system • Environmental sensors – rainfall, temp, humidity, light intensity, CO_2 • Possible side-look or slant-angle RGB and LIDAR sensors distinct from primary look angle

AREA AND COVERAGE RATES	• MINIMUM 1 ACRE FOR FIELD TEST PLOT, WITH ADDITIONAL SURROUNDING AREA • 20 METER USABLE WIDTH FOR ASSAYING PLANTS • PRIMARY SENSORS: COLLECTED 2-4× DAILY, 2×/WEEK • ENVIRONMENTAL SENSORS: COLLECTED EVERY 15 MINUTES

The reference team is expected to have: space and personnel available to install the GFE in the 2015 growing season; for the gantry form factor, concrete foundations poured in the field; a dedicated field site with at least 20 meters of usable width and at least 200 meters long; a power supply (10s of kW expected) to the field phenotyping system; and all relevant construction and safety permits for operation of this system. Subject to the specific provisions of the ARPA-E award, the GFE may be a permanent installation at the reference team's site, with the system remaining with the reference team at the end of the project.

The reference team award will provide for the operation of the GFE for the duration of the project, including obtaining any necessary repairs and modifications from the GFE provider under a separate budget. As part of the GFE installation, training will be provided by the manufacturer. In collaboration with ARPA-E, the reference team will host at least one field day each year to demonstrate the GFE to the other TERRA performers.

<u>The reference team will provide the TERRA teams access to the raw data and computational workflows</u>.

ARPA-E has concluded that progress in phenotyping will be accelerated if raw data and computational workflows can be shared as widely and quickly as possible among the TERRA teams. For this reason the reference team is expected to make available the raw and processed data obtained using the GFE, along with all of the metadata and environmental data relevant to the interpretation and use of the measurements. This data will be provided in a format established by a data and computational standards committee (see below). ARPA-E anticipates approximately 1 Terabyte of data per day to be generated by the GFE, such that over a growing season hundreds of Terabytes may be generated, and over the course of the program on the order of several Petabytes may be generated. Given the large data volumes that will be produced, the data will be stored on a server to which TERRA teams can obtain a terminal window in order to access and analyze the data, rather than needing to move it to a local computer storage system.

In addition to providing access to the raw data, the reference team is expected to establish a data analysis pipeline similar to the one shown in Figure 3, and make its use (though not necessarily the source code of each component) available to performers in the TERRA program.

It is possible that no one website or software product will be uniquely poised to address the large data and computational demands of sensor streams, the complicated analytical tools of bioinformatics, and maintain a collaborative user environment. Applicants are therefore encouraged to partner with experts in particular areas relating to components of the data storage and analysis pipeline.

Finally, the GFE system provided by ARPA-E will include software not only for gantry and sensor controls and data handling, but also for phenotype extraction. The reference team will be expected to provide results from the GFE system to provide a clear benchmark to TERRA performers in phenotype extraction from a variety of types of images. This should take the form of documenting the phenotypes extracted from a set of raw images generated by the GFE sensors. At this time, it is the intent of ARPA-E for the Category 5 awardee to release all data to the public at an appropriate time determined by ARPA-E that is consistent with DOE regulations.

The reference team will convene a data and computational standards committee.

The standards committee – selected in collaboration with the ARPA-E TERRA Program Director - will create the foundation for the straightforward sharing and processing of data among the numerous participants of diverse backgrounds involved in the TERRA program. The standards committee will be composed of experts in data fusion (the combination of multiple streams of data of different formats, time increments, context, etc), image analysis and feature extraction, bioinformatics, and computational pipelines, and have representatives from each of the other TERRA performers.

The reference team must have access to a controlled chamber / greenhouse phenotyping system.

A controlled chamber / greenhouse system will be required to enable direct comparisons and correlations between lines grown under controlled environment and field conditions. In addition, the greenhouse will allow year-round operation. Given the growth potential of energy sorghum (heights exceeding 5m by maturity) and the corresponding root system needs, ARPA-E expects the greenhouse studies to focus primarily on the early stages of plant growth.

E. TECHNICAL PERFORMANCE TARGETS

Advanced plant phenotyping platforms should increase the utility (information content), time resolution (seasonal, daily), and amount (# phenotypes × # populations) of crop phenotyping data in order to accelerate energy crop breeding. The TERRA program's primary objective is to enable breeders and geneticists to identify crop phenotypes/traits of interest, genetic architecture of traits, and alleles in breeding pools that can be used to accelerate genetic gain relative to current breeding approaches.

Category 1: Complete Integrated Phenotyping Systems Solutions

Primary Technical Targets

ID	Description	Target
1.1	Complete integrated phenotyping systems solutions targets include all of the targets given below for component Categories 2, 3, and 4.	
1.2	Total System Cost	<$20K/covered hectare, three year payback

Explanation of technical targets:

1.2: Total system cost (amortized capital cost + operating cost) is less than $20k per covered hectare for a three-year payback period. For additional information on this cost metric see Section I.F of the FOA.

Category 2: High Throughput Automated Hardware and Sensing Technologies

Primary Technical Targets

ID	Description	Target
2.1	Phenotypic Selectivity	top 10%
2.2	Technical Repeatability	$R^2 > 0.99$
2.3	Platform Scalability	>50 hectares

Secondary Technical Targets

ID	Description	Target
2.4	Phenotype Data Capture Rate	2 times/day and 2 times/week
2.5	Environmental Tolerance	Operational range 32-110 °F, 30 mph wind gusts, dust/rain protected to IEC 60529 rating of IP54
2.6	Image Resolution	Suitable for plant-level specificity, per pixel resolution 1 cm^2 or less

Explanation of technical targets:

2.1: The platform should have sufficient resolution, accuracy, and precision to be able to identify the top 10% of phenotypes/traits from the analyzed populations in the relevant range of growing environments.

2.2: For phenotypic measurements taken one right after another obtain values with $R^2 > 0.99$.

2.3: The platform needs to operate over an area of 50 hectares.

2.4: The platform should ideally be able to measure an area of >50 hectares multiple times per day, as well as multiple times per week, in order to obtain phenotypic data at much higher temporal frequency than is presently collected.

2.5: The platform needs to be able to operate outdoors in a range of environmental conditions.

2.6: Sensors should be able to resolve the phenotypic information of individual plants, requiring per-pixel resolution of no more than 1 cm^2, and preferably less.

Category 3: Computational Solutions for Selection and Prediction

Primary Technical Targets

ID	Description	Target
3.1	Above Ground Biomass Prediction Accuracy	R^2>0.97
3.2	Other Phenotype Predictions	Significant improvement vs existing state of the art (see explanation below)
3.3	Determine the Phenotypes That Correlate With the Variation in Terminal Biomass Yield	Find phenotypes that account for 95% of the variation in terminal biomass yield

Secondary Technical Targets

ID	Description	Target
3.4	Data Processing Speed/Turnaround	1 Week's Phenotyping Data within 48 hrs

Explanation of technical targets:

3.1: Above ground biomass should be predicted from sensor data and then compared with ground truth measurements. Above ground biomass predictions from emergence to full maturity are required.

3.2: While ARPA-E is targeting a high value of R^2 for above ground biomass prediction, numerous other phenotypes (see Table 1 above for examples) are expected to correlate with terminal biomass yield, not all of which can be determined with such high prediction accuracy. Ground truth measurements for other phenotypes are also required.

3.3: In addition to the extraction of phenotypes from sensor data, ARPA-E also expects applicants in Category 3 to determine *which* phenotypes correlate most highly with the variation in terminal biomass yield. Given the fact that phenotypes will be collected frequently and are in the context of environmental conditions, finding the truly important phenotypes will require data-intensive algorithms. The determination of the phenotypes that are most important for producing high-yielding plants will ultimately allow for the design of low-cost sensor and computation platforms that include components targeting only the most important phenotypes. In addition, ARPA-E is particularly interested in the correlation of phenotypes that can be identified early in the season with terminal biomass yield in order to reduce the length of the breeding cycle.

3.4: Algorithms should be parallelizable and capable of being run on a standard Hadoop cluster to produce an analysis of one week's data within 48 hrs.

Category 4: Genetics, Genomics and Bioinformatics

Primary Technical Targets

ID	Description	Target
4.1	Genetic Basis for Biomass Accumulation	Identify genetic components that are responsible for at least 70% of the phenotypic variance in terminal biomass yield

Secondary Technical Targets

ID	Description	Target
4.2	Genotype to Phenotype Associations	Screen thousands of accessions and/or breeder lines and identify putative functional SNPs and molecular markers linked to phenotypic traits of interest, $p<5\times10^{-6}$

Explanation of technical targets:

4.1: Elucidate the genetic architecture and heritability of trait/phenotypes that impact biomass yield (P=G×E). Determine the portion of variation in field biomass accumulation that is explained by genetics. Explain at least 70% of the genetic component of the phenotypic variance for biomass accumulation in a population designed for technology validation, based on field phenotypic data collected from more than one environment.

4.2: Identify molecular markers and associate traits that will significantly improve the efficiency of breeder efforts to increase biomass genetic gain. Identify field-validated markers corresponding to functional variation in specific genes/traits that modify biomass yield.

CATEGORY 5: PROGRAMMATIC REFERENCE DATA GENERATION WITH GFE AND DATA HOSTING PRIMARY TECHNICAL TARGETS

ID	DESCRIPTION	TARGET
5.1	FIELD SITE	>1 ACRE SUITABLE FOR THE INSTALLATION AND OPERATION OF THE GFE SYSTEM
5.2	GENERATE REFERENCE PHENOTYPIC DATASETS	APPLICABLE PERFORMANCE METRICS DESCRIBED IN CATEGORY 2, EXCLUDING 2.3
5.3	GENERATE REFERENCE COMPUTATION DATASETS	SAME PERFORMANCE METRICS DESCRIBED IN CATEGORY 3
5.4	GENERATE REFERENCE GENOMIC DATASETS	SAME PERFORMANCE METRICS DESCRIBED IN CATEGORY 4
5.5	CREATE DATA STANDARDS AND SOURCE COMPUTATION PIPELINE AVAILABLE TO TERRA PERFORMERS.	HOST DATA PLATFORM CAPABLE OF PROCESSING AND STORING PETABYTES OF PHENOTYPIC DATA

Explanation of technical targets:

5.1: The field site made available by an applicant to Category 5 should be >1 acre of dedicated breeding area suitable for permanent installation of a gantry system, with at least 20 x 200 meters suitable for growing sorghum and appropriate buffer areas. The site should have irrigation, a power supply, a uniform grade, high quality soil, and appropriate site security.

5.2: The GFE will have the hardware specifications to meet the requirements of Category 2 (except for 2.3); a recipient of a Category 5 award should therefore focus on carrying out the tasks described by the Category 2 metrics.

5.5: See the discussion under Category 5 in Section I.D of the FOA for more information on data standards and the data hosting and computation platform.

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 at discovery and 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 in Categories 1-4 that propose to work with maize, or other crops that don't have the following characteristics:
    - A demonstrated yield of >25 dry metric tons biomass/hectare/year on at least a one hectare plot in the continental United States,
    - Existing infrastructure and grower expertise,
    - At least one published and annotated genome sequence.
- Applications in Category 5 that propose to work with a crop other than energy sorghum.

G. ECONOMIC ANALYSIS

In order to achieve these ambitious goals, the value provided by phenotyping platforms in terms of advanced traits must be greater than their capital and operating cost at a reasonable payback period. A standard seed industry trait valuation model was utilized to set the cost and throughput metrics for this FOA. The value of deploying an in-field phenotyping system was calculated by assuming an additional 2% year over year yield gain due to the use of a high-throughput phenotyping system, $50/ton energy crop price, set field input costs and a 5 year new seed adoption rate by the farmer. This value was split so that one-third is assigned to the seed company and two-thirds to the farmer. The "total system" includes robotics, sensors, software, data storage, technical and operating labor and the total allowable capital and operating cost was calculated with a 3 year payback period to the breeder. This calculation does not take into account the value of additional traits that are likely to be identified utilizing these phenotyping platforms; it only takes into account the value from increased yield.

Based on this preliminary economic analysis, the economic metric for this FOA is set at a total system cost of less than $20,000 per hectare covered for field phenotyping systems intended to be used by breeders and bioinformaticians on advanced field research stations. For example, a 50-hectare breeding station system cost should be less than $1M which, again, is for a three-year payback period.

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 5 to 10 awards under this FOA. ARPA-E may issue one, multiple, or no awards.

Individual awards may vary between $250,000 and $10 million. ARPA-E will consider awards at the upper limit of this range only for applications in Category 1, Complete Integrated Phenotyping Systems Solutions, and applications that include Category 5, Programmatic Reference Data Generation and Hosting.

The period of performance for funding agreements may not exceed 48 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. Alternatively, applications requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, the Applicants are required to provide a convincing vision how these partial solutions can enable the realization of the program metrics with further development.

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

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

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

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

B. ARPA-E FUNDING AGREEMENTS

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

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[43] Accordingly, ARPA-E has substantial involvement in the direction of every project, as described in Section II.C of the FOA.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[44]

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, GOGOS, AND FEDERAL INSTRUMENTALITIES[45]

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

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

[43] U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).
[44] The Prime Recipient is the signatory to the funding agreement with ARPA-E.
[45] DOE/NNSA GOGOs are not eligible to apply for funding, as described in Section III.A of the FOA.

the Project Team.

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

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs, and Federal Instrumentalities (e.g., Tennessee Valley Authority) generally take the form of Interagency Agreements. Any funding agreement with a FFRDC will have substantially similar terms and conditions as ARPA-E's Model Cooperative Agreement (http://arpa-e.energy.gov/arpa-e-site-page/award-guidance).

Non-DOE GOGO's and Federal agencies may be proposed as supporting project team members on an applicant's project. The Non-DOE GOGO/Agency support would be obtained via an Interagency Agreement between ARPA-E and the Non-DOE GOGO/Agency, and provided as part of ARPA-E's standard substantial involvement in its funded projects.

3. TECHNOLOGY INVESTMENT AGREEMENTS

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

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,[46] as the lead for a Project Team,[47] or as a member of a Project Team.

2. DOMESTIC ENTITIES

For-profit entities, educational institutions, and nonprofits[48] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

FFRDCs are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team, but not as a Standalone Applicant.

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

Non-DOE/NNSA GOGOs are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

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

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

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

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

[47] 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.

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

United States (including U.S. territories). The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. Consortium Entities

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

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

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

B. Cost Sharing[49]

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

[49] 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[50] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[51]

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.
- 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.

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

- Project Teams where domestic educational institutions, domestic nonprofits, and/or FFRDCs perform greater than or equal to 80%, but less than 100%, of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.

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

4. LEGAL RESPONSIBILITY

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

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

5. COST SHARE ALLOCATION

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

6. COST SHARE TYPES AND ALLOWABILITY

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

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

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

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

In addition, Project Teams may not use independent research and development (IR&D) funds[52] 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.

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.

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

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

8. Cost Share Verification

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

C. Other

1. Compliant Criteria

Concept Papers are deemed compliant if:

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

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.E of the FOA, are deemed nonresponsive and are not reviewed or considered.

3. LIMITATION ON NUMBER OF APPLICATIONS

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

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E EXCHANGE

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

2. CONCEPT PAPERS

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

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria in Section V.A.1 of the FOA.

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

3. FULL APPLICATIONS

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

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

4. Reply to Reviewer Comments

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

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

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

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

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

6. Selection for Award Negotiations

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA. The Selection Official may select or not select a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

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

7. MANDATORY WEBINAR

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

B. APPLICATION FORMS

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

C. CONTENT AND FORM OF CONCEPT PAPERS

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

- The Concept Paper must not exceed 5 pages in length including graphics, figures, and/or tables.
- The Concept Paper must be submitted in Adobe PDF format.
- The Concept Paper must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.

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

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

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

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

1. CONCEPT SUMMARY

- Describe the proposed concept with minimal jargon, and explain how it addresses the Program Objectives of the FOA.
- Concept Papers for the respective categories of interest should include the following:
  - Category 1: Everything outlined below for Categories 2, 3 and 4.
  - Category 2:
    a. A complete **platform system level diagram** that includes all major phenotyping system components and displays how they would be integrated and deployed in the field.
    b. Identification of the target crop, a list of the phenotypic traits that will be measured and environmental parameters measured.
  - Category 3: A complete **data system level diagram** that includes all major data analytics components in order to acquire, model and predict plant performance.
  - Category 4: Identification of the target crop, a list of the phenotypic traits that will be measured, genes of interest, description of breeding populations that will be utilized and environmental parameters measured.
  - Category 5: Everything described above for Categories 2b, 3 and 4, and a description of the field site for installation of the GFE. The site will be >1 acre of dedicated breeding area suitable for permanent installation of a gantry system, with at least 20 x 200 meters suitable for growing sorghum, appropriate buffer areas surrounding the field site, and includes irrigation, a power supply, a uniform grade, high quality soil, and appropriate site security.

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.

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 I.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and

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

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

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

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

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

PI: Principal Investigator.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.

R&D: Research and development.

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

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

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

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

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