FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

RHIZOSPHERE OBSERVATIONS OPTIMIZING TERRESTRIAL SEQUESTRATION (ROOTS)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001565
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Funding Opportunity Announcement (FOA) Issue Date:	April 12, 2016
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, May 19, 2016
Submission Deadline for Concept Papers:	5 PM ET, May 26, 2016
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	5 PM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	TBD
Total Amount to Be Awarded	Approximately $30 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

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

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

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

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: o Concept Summary o Innovation and Impact o Proposed Work o Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, May 26, 2016
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

The Advanced Research Projects Agency – Energy (ARPA-E), an organization within the Department of Energy (DOE), is chartered by Congress in the America COMPETES Act of 2007 (P.L. 110-69), as amended by the America COMPETES Reauthorization Act of 2010 (P.L. 111-358) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in—
(i) reductions of imports of energy from foreign sources;
(ii) reductions of energy-related emissions, including greenhouse gases; and
(iii) improvement in the energy efficiency of all economic sectors; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

ARPA-E issues this Funding Opportunity Announcement (FOA) under the programmatic authorizing statute codified at 42 U.S.C. § 16538. The FOA and any awards made under this FOA are subject to 2 C.F.R. Part 200 as amended by 2 C.F.R. Part 910.

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

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector or the applied technology offices within DOE. By contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly lower than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have the clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met" and defines "development" as the "systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."[1] Applicants interested in receiving financial assistance for basic research should contact the DOE's Office of Science (http://science.energy.gov/). Office of Science national scientific user facilities (http://science.energy.gov/user-facilities/) are open to all researchers, including ARPA-E applicants and awardees. These facilities provide advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere. Projects focused on the improvement of existing technology platforms along defined roadmaps may be appropriate for support through the DOE offices such as: the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy (http://fossil.energy.gov/), the Office of Nuclear Energy (http://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

Agricultural intensification has resulted in a ten-fold increase in crop yield over the past hundred years, but these advances have not occurred without costs: soils have eroded and soil quality has decreased, incurring a soil carbon debt equivalent to 65 ppm of atmospheric CO_2. Increased fertilizer use causes the majority of the emissions of the greenhouse gas N_2O, and drought stress increasingly threatens yields. Given the scale of domestic (and global) agriculture resources, there is great potential to reverse these trends by focusing plant breeding toward new cultivars with enhanced root systems to improve soil quality and improve biogeochemical cycling. Development of new root-focused cultivars could dramatically and economically reduce atmospheric CO2 concentrations without decreasing agricultural yields. To this end, the ARPA-E program, Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS), is pursuing technologies that increase the precision and throughput of crop breeding for

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

improved root-soil biogeochemical function. ROOTS seeks to develop novel, non-destructive, field deployable technologies to: (1) measure root functional properties; (2) measure soil functional properties; and (3) advance predictive and extensible models that accelerate cultivar selection and development. These technologies—especially integrated systems—could greatly increase the speed and efficacy of discovery, field translation, and deployment of improved crops and production systems that significantly improve soil carbon accumulation and storage, decrease N_2O emissions, and improve water efficiency. The aspiration of the ROOTS program is to develop crops that enable a 50% increase in carbon deposition depth and accumulation, a 50% decrease in fertilizer N_2O emissions, and a 25% increase in water productivity. Taken over the 160 million hectares of actively managed U.S. cropland, such advances could mitigate ~10% of total U.S. greenhouse gas emissions (GHG) annually over a multi-decade period, while also improving the climate resiliency of U.S. agricultural production.

2. MOTIVATION

The challenge of greenhouse gas mitigation and the potential for soil carbon storage

Carbon dioxide—the most prevalent GHG—is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon through the atmosphere, oceans, and terrestrial biosphere). Human activities are altering the carbon cycle—both by adding more carbon dioxide (CO_2) to the atmosphere and by influencing the ability of natural sinks, like forests, pastures and cropland, to remove CO_2 from the atmosphere. The main anthropogenic activity that emits CO_2 into the atmosphere is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation. To avoid the predicted increases in global temperatures associated with increased atmospheric concentrations of GHGs, the U.S.—and the world—needs to drastically decrease GHG emissions and find ways to reduce the concentration of GHGs in the atmosphere.

Soils constitute the largest terrestrial organic carbon pool, estimated at 2400 petagrams of carbon (PgC), integrated from the surface to 2 m depth.[2] This is three times the amount of CO_2 currently in the atmosphere (on a C equivalent basis: ~830 PgC) and 240 times current annual fossil fuel emissions (~10 PgC/y).[3]

The primary carbon exchange between the atmosphere and the terrestrial ecosystem is the incorporation of CO_2 (~120 GT/yr^{-1}) into plant biomass through photosynthesis and the release of CO_2 from previously fixed carbon through plant and microbial respiration. A large fraction of the carbon dioxide that is captured during photosynthesis is rapidly returned to the atmosphere, and only a minor fraction, approximately 2.5 percent, enters the stable pool of soil

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[2] Batjes, N. H. Total carbon and nitrogen in the soils of the world. *European journal of soil science* **47**, 151-163 (1996).

[3] Ciais, P. *et al.* Cambridge University Press, Working Group I Contribution to the Intergovernmental Panel on Climate Change Fifth Assessment Report Climate Change: The Physical Science Basis edition TF Stocker et al (2013).

carbon. Hence, manipulation of the soil carbon balance, by even a few percent, represents significant greenhouse gas mitigation potential.

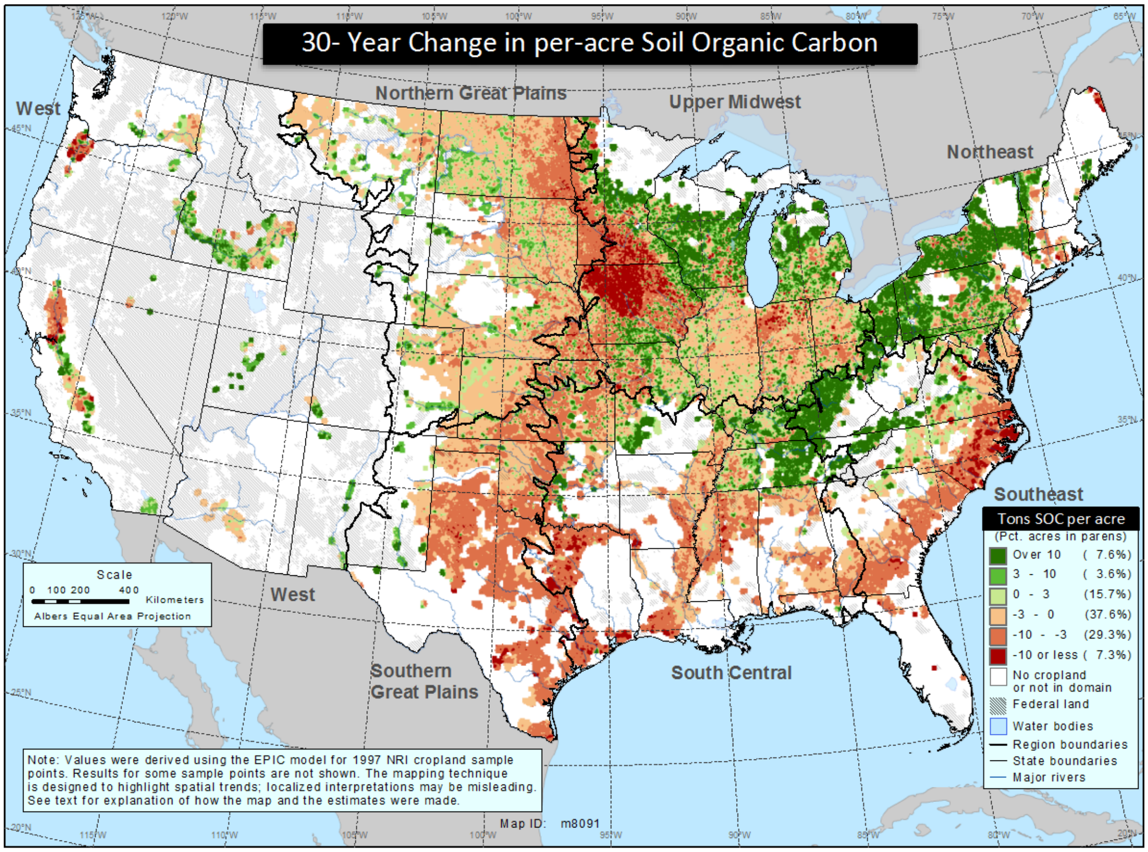

Figure 1: USDA/NRCS 2006 model simulation reporting change in tons of soil organic carbon per acre in U.S. croplands over 30 years. The total percentage of all cropland acres is shown in parentheses on the right side of the Figure.[4] The green areas on the map show increases in soil organic carbon and the red areas indicate losses.

Unfortunately, there has been considerable loss of soil organic matter (SOM) in key farming regions across the U.S. over the past several decades. The Northern and Southern Great Plains combined have lost almost four percent of soil organic carbon on a per acre basis over the last 30 years.[4] About a third of the world's soil has already been degraded—because of increasing atmospheric temperature, over-exploitation, extensive mining of soil nutrients, inappropriate tillage, poor crop management, indiscriminate use of fertilizer, and accelerated erosion. In the U.S., the SOM degradation trend is acute: a USDA/NRCS simulation of the change in soil organic carbon estimated that nearly three-fourths of the cropland acres lost soil organic carbon over 30 years, see Figure 1.[4] Moreover, losses in SOM are accompanied by real economic costs. It is estimated that the total annual cost of erosion from agriculture in the U.S. is about US$44

[4] USDA, National Resource Conservation Service. Model Simulation of Soil Loss, Nutrient Loss, and Change in Soil Organic Carbon Associated with Crop Production. June 2006.

billion per year—$247 per hectare of cropland and pastureland.[5] On a global scale, the annual loss of more than 75 billion tons of topsoil costs the world about $400 billion per year, or approximately $70/person/year.[5]

These continuing and sustained losses of soil carbon and soil economic value provide clear motivation for soil improvement programs. Soil carbon stocks can be augmented by increasing the rate of carbon additions to the soil or by reducing the rate of decomposition of organic matter already present in the soil.[6] To varying degrees both can be achieved through a variety of soil management practices.[7,8] SOM primarily enters the soil as root carbon.[9] A potential path to increases soil carbon stocks is the development of crop cultivars that input a greater quantity of carbon into the soil through their roots or grow deeper root systems, which would increase the mean residence time of deposited carbon in the soil.[10] If developed, such plants could be deployed rapidly, and at scale, due to continuous genetic turnover and active land management in agricultural croplands. Improving plants to increase soil carbon sequestration represents an untapped and economic net carbon sink with significant economic potential.

ARPA-E commissioned researchers at Colorado State University to analyze the impact of increased root depth and increased root input on soil carbon stocks. The analysis was performed using the CENTURY ecosystem biogeochemistry model[11], which is a process model that uses data on climate, soil physical properties and land management practices to estimate soil organic carbon (SOC) stock changes. Data on root depth distributions and soil depth-related controls on SOC turnover rates, were coupled to an analytical steady-state solution for SOC pools in CENTURY, to estimate SOC changes through the full soil profile as a function of changes in plant root carbon inputs. Multiple scenarios of altered crop root systems were analyzed: the quantity of carbon allocated to the roots was increased between 0%-100%, and root depth profiles were shifted between representations of relatively shallow maize root

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[5] Eswaran, H., Lal,R. and Reich R.F. 2001. Land degradation: an overview. In: Bridges, E.M., I.D. Hannam, L.R. Oldeman, F.W.T. Pening de Vries, S.J. Scherr, and S. Sompatpanit (eds.). Responses to Land Degradation. Proc. 2nd. International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India.

[6] Paustian, K., Agren, G. & Bosatta, E. Modelling litter quality effects on decomposition and soil organic matter dynamics. *Driven by nature: Plant litter quality and decomposition* (1997)

[7] Paustian, K., J. Lehmann, S. Ogle, D. Reay, G.P. Robertson and P. Smith. Climate smart soils. *Nature* **532**, 49-57 (2016)

[8] Smith, P. Soil carbon sequestration and biochar as negative emission technologies. *Global Change Biology* **22**, 1315-1324 (2016)

[9] Rasse, D. P., Rumpel, C. & Dignac, M.-F. Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. *Plant and Soil* **269**, 341-356 (2005)

[10] Kell, D. B. Large-scale sequestration of atmospheric carbon via plant roots in natural and agricultural ecosystems: why and how. *Phil. Trans. R. Soc. B* **367**, 1589-1597 (2012)

[11] Parton, W. J., Schimel, D. S., Cole, C. & Ojima, D. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* **51**, 1173-1179 (1987)
For more information: http://nrel.colostate.edu/projects/century5/reference/html/Century/overview.htm
Accessed 3/30/2016

systems to representations of deep rooting grass species. The analysis covered approximately 160 million hectares of actively managed US cropland that have suitable soil types and depth. The model predicted that even modest gains in soil carbon deposition or rooting depth would provide significant offsets to U.S. GHG emissions. Therefore, a breeding platform that enables selection of plant roots with greater carbon deposition and depth is likely to provide real GHG mitigation benefits. Highly optimized root systems—those that have the largest increases in mass and depth—have the potential to increase equilibrium SOC stocks by more than 3.5 times the current content. As seen in Figure 2, annual CO_2 sequestration in a highly optimized scenario is close to 60% of U.S. transportation emissions.[12]

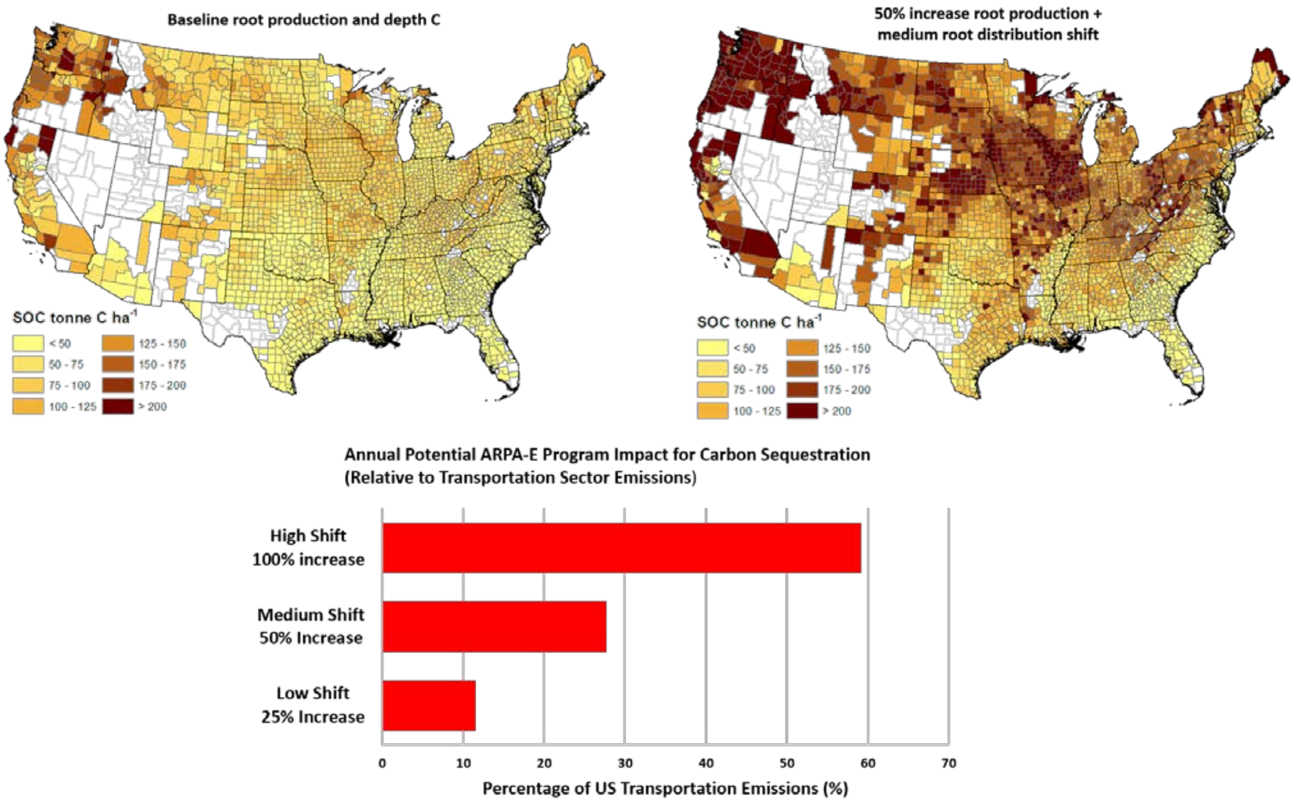

Figure 2: Geographic distribution of steady-state soil organic carbon (SOC) stocks (0-200 cm) on cropland and pasture/hay land under baseline (i.e. current) conditions and under a scenario for 50% increased root C inputs and deeper root distributions.[11] In the bar chart at the bottom, the sequestration potential of the modeled acres is the aggregation of simulations of increased root mass [+25,50,100%] and increased root depth [Low (20% of biomass shifted to next lowest root layer), Medium (annual crops shifted to grass/hay root profiles), High Shift (all crops shifted to a model root distribution)] at steady state.

Inherent value of soil carbon

While industrial carbon capture methods incur significant cost and efficiency penalties, carbon captured and stored as soil organic matter is inherently valuable and enables greater agricultural efficiencies. Advanced root systems that increase SOM can improve soil structure,

[12] Paustian, K., Campbell, N., Dorich, C., Marx, E., and Swan, A. Assessment of potential greenhouse gas mitigation from changes to crop root mass and architecture. *Report to ARPA-E. Accessible at:* (https://arpa-e-foa.energy.gov/Default.aspx#FoaId40aa63a7-689b-4307-90b2-c1b98a2148a3)

fertilizer use efficiency, water productivity, crop yield, climate resiliency, and limit topsoil erosion—all of which provide near-term and sustained economic value to farmers and ecological value to the public. SOM is a key component of soil quality that sustains many important soil functions by providing the energy, substrates, and biological diversity to support metabolic and physical processes that influence aggregation, infiltration, and decomposition. According to the USDA Natural Resources Conservation Service, every 1 percent of SOM can provide ~$29 per acre in the U.S. Midwest through improved nutrient and water availability. SOM helps retain water in two ways. First, SOM has higher water holding capacity compared to mineral soil, which translates into more water available to plants.[13] Second, SOM improves the soil structure and stability—porosity, water infiltration and water transport.[14] Finally, SOM supports rich communities of microbes and insects that enhance soil structure and unlock nutrients for plant growth.[15,16]

Need for increased nitrogen use efficiency

Nitrogen use on U.S. agricultural and range lands is responsible for ~74% of nitrous oxide (N_2O) emissions, principally caused by fertilizer inefficiency. Expressed in CO_2 equivalents, this is 2.5% of all U.S. GHG emissions. Unlike anthropogenic CO_2 sources, N_2O is often emitted diffusely through N fertilizer oxidation. As such, prevention of N_2O emissions is likely the best method to mitigate this potent GHG. Given current efficiencies, N_2O emissions will increase as more fertilizer is used to drive higher productivity. However, as more fertilizer is applied, the fraction of fertilizer incorporated into the crop decreases. This limits crop yield and leads to substantial nitrogen leaching and reactivation to N_2O. Selection for cultivars with enhanced nitrogen capture capacity will enable greater productivity and complement the gains made by precision agriculture-enabled management changes.

The trade-off between yield and nitrogen emissions only holds for a given efficiency regime, see Figure 3. ARPA-E hopes to disrupt this relationship through improved root and root-soil function. For this reason, ARPA-E believes that increased root carbon, increased above-ground carbon and decreased N_2O emissions are fundamentally compatible and mutually reinforcing outcomes. Achieving the goal of reducing net GHG emissions requires that increased carbon storage is not offset by N_2O emissions.[17] Therefore, traits are required that improve both carbon deposition and nitrogen uptake.

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[13] Hudson BD. Soil organic matter and available water capacity. *Journal of Soil and Water Conservation* **49**, 189-94 (1994)

[14] Franzluebbers A. Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil and Tillage Research* **66**, 197-205 (2002)

[15] Richardson, A. E. & Simpson, R. J. Soil microorganisms mediating phosphorus availability update on microbial phosphorus. *Plant physiology* **156**, 989-996 (2011)

[16] Pennsylvania State University Extension Service: http://extension.psu.edu/plants/crops/soil-management/soil-quality/earthworms Accessed 3/30/2016

[17] Li, C., Frolking, S. & Butterbach-Bahl, K. Carbon Sequestration in Arable Soils is Likely to Increase Nitrous Oxide Emissions, Offsetting Reductions in Climate Radiative Forcing. *Climatic Change* **72**, 321-338 (2005)

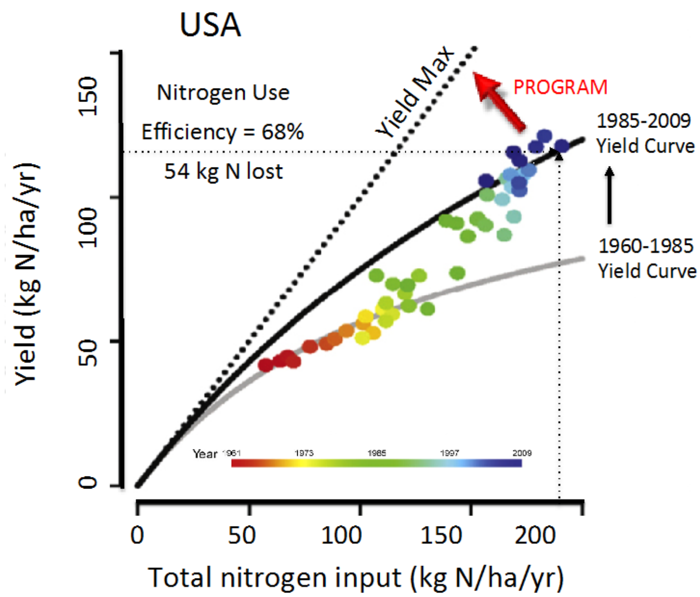

Figure 3: Historical yield of plant-nitrogen uptake as a function of nitrogen fertilizer in the U.S., demonstrating the potential for nitrogen savings in U.S. agriculture. The Yield Max indicates 100% fertilizer efficiency, while the yield curves project the maximum production per acre in a given fertilizer regime demonstrating the importance of improving nitrogen uptake to enable further yield increases[18].

Water productivity

The impacts of drought in the United States impose significant economic costs. The economic impacts of the recent California drought, for instance, are estimated to be $2.7 billion.[19] These impacts are likely to increase as drought risks throughout the U.S. are exacerbated by the changing precipitation patterns resulting from climate change. Model projections indicate that the impact of climate change on drought frequency and severity will vary by region, with the southwestern U.S. and Rocky Mountain states likely to experience the largest increases in drought frequency. Additionally, data suggest that climate change may increase the longevity of droughts in many regions, causing events that would otherwise be mild droughts to become severe or even extreme droughts.

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[18] Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J. & Garnier, J. 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. *Environmental Research Letters* **9**, 105011 (2014)

[19] Richard E. Howitt, Duncan MacEwan, Josué Medellín-Azuara, Jay R. Lund, Daniel A. Sumner. Economic Analysis of the 2015 Drought for California Agriculture. Center for Watershed Sciences, University of California – Davis, Davis, CA (2015)

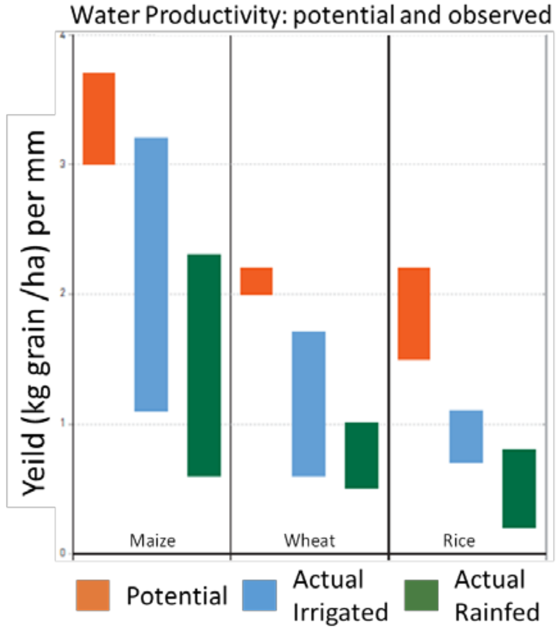

Figure 4: Water productivity gap for major irrigated and rain-fed crops[20].

As shown in Figure 4, the gap in productivity between rain-fed and irrigated systems illustrates how water can be a limiting factor to plant yield. Optimized root systems with deeper architecture are predicted to improve season-long water productivity, particularly under drought conditions.[21] In fact, drought resiliency is a key risk to meeting the future demands for food, fuel, and feed. Water productivity and drought resilience traits have the potential to mitigate the social and economic risks of systemic crop failure and help maintain high levels of agricultural feedstock production.

3. State of the Art

Root Phenotyping and Environmental Characterization

Although significant progress has been made in plant genetics and bioinformatics, a primary obstacle for continued crop improvement is in plant phenotyping, particularly phenotyping for root traits. Plant phenotypes (P) result from the complex interactions of genetics (G), environment (E), and management (M), commonly represented as P = G x E x M. Plant breeders drive crop improvement by observing component phenotypes and crossing parental lines to generate offspring with desirable combinations of traits. When possible, causal genes are identified and then the breeding progress can be accelerated and maintained by genetic

[20] Sadras, et al. Status of water use efficiency of main crops. *SOLAW Background Thematic Report – TR 07*, United Nations FAO (2010).
FAO. The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London (2011).
[21] Zhan, A., Schneider, H. & Lynch, J. Reduced lateral root branching density improves drought tolerance in maize. *Plant physiology*. **168**, 1603-1615 (2015)

screening. Modern methods such as genomic selection (GS) have the potential to drive rapid genetic gain, but creating and maintaining GS models requires high-throughput phenotypic observation. To address the gap in above-ground phenotypic data, ARPA-E is currently sponsoring a high-throughput field phenotyping program, TERRA (Transportation Energy Resources from Renewable Agriculture), focused on crop canopy attributes. As described in detail below, root phenotyping is more challenging than measuring above-ground traits. In the absence of direct observations, improvements to complex phenotypes, such as drought tolerance, are constrained because the phenotypic trait is generally controlled by multiple genes. The most desirable combinations can be found and realized much faster in breeding trials if breeders individually assess and optimize each component phenotype. Today, however, there are no high-throughput screening technologies or techniques that allow this resolution for below-ground traits.

Current root phenotyping platforms are generally split between lab-based technologies that are high-resolution with lower throughput and poor translation to the production setting, and field-based techniques that are lower resolution, destructive, and low-throughput but that generate data more relevant to crop production and breeding.[22] Methods reflecting the current state of the art are described below.

Lab-Based Methods

Plants grown in transparent gels, against glass panes, or against transparent tubes, termed rhizotrons,[23] provide opportunities to observe roots in a manner that is non-destructive, allowing for multiple time points to be observed per plant. The concern with these systems is that the conditions do not simulate the field, and furthermore, observable roots that grow against glass may not be representative of the bulk of the root system. Improved transparent substrates have demonstrated more realistic root systems, but it is unclear how representative these systems are of the field production system.[24] These reductionist approaches are very informative, but the complex interactions of environment and management on phenotypes and gene activity confound the approach, and new methods are needed to translate lab performance to field performance to provide breeders with confidence that lab-developed genetics will perform predictably in the field.

[22] Topp, C. How Can We Harness the Quantitative Genetic Variation in Crop Root System Architecture for Agricultural Improvement? *Journal of Integrative Plant Biology*. **58**, 213-225 (2016)
[23] Rellán-Álvarez, R. *et al.* GLO-Roots: an imaging platform enabling multidimensional characterization of soil-grown root systems. *Elife* **4**, e07597 (2015)
[24] Downie, H. *et al.* Transparent soil for imaging the rhizosphere. *PLoS One* **7**, e44276 (2012)

The most technologically advanced root architecture measurements have been made with custom MRI, PET, and X-ray CT scanners. These measurements are done in pots and the plants are grown in real soils.[25] Using MRI scanners it is possible to visualize the movement of water,[26] while PET scanning allows the visualization of plant metabolites moving through the plant,[27] generating unprecedented physiological insight. The resolution of X-ray CT scanners permits visualization of soil clumps and monitoring of the roots' effects on the soil. While these techniques generate functional data useful for plant science advances, high-cost and low-throughput render them unsuitable for use in cultivar development or plant breeding. Phenome-genome linkages made in potted greenhouse samples, even if measured in natural soil, often replicate poorly in field trials.[28] These techniques face substantial challenges in deploying to field environments. For example, the resolution of MRI measurements decreases in the presence of ferromagnetic materials. Most labs remove these materials to achieve higher resolution, which limits the replicability and the range of measurement to applicable soil types.

Field-Based Methods

Many field-based methods are destructive and include soil coring and root excavation. Excavation, termed "shovel-omics," is a leading method and has been used by plant breeders for root phenotyping. Soil coring does not kill the plant per se, but is destructive to the field, and select samples may not be representative of the whole root system. The throughput and objectivity of both coring[29] and shovel-omics[30] has been greatly improved by digital analysis of the soil core or excavated root crown.[31] Applications of these technologies have made great progress in root phenotyping, but cannot be used to observe a single root at more than one point in its lifecycle. As currently practiced, these processes are manual or semi-manual, significantly limiting their throughput.

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[25] Metzner, R. *et al.* Direct comparison of MRI and X-ray CT technologies for 3D imaging of root systems in soil: potential and challenges for root trait quantification. *Plant methods* **11**, 17-28 (2015)
[26] Gruwel, M. L. In situ magnetic resonance imaging of plant roots. *Vadose Zone Journal* **13** (2014)
[27] Hubeau, M. & Steppe, K. Plant-PET Scans: In Vivo Mapping of Xylem and Phloem Functioning. *Trends in plant science* **20**, 676-685 (2015)
[28] Paez-Garcia, A. *et al.* Root Traits and Phenotyping Strategies for Plant Improvement. *Plants* **4**, 334-355 (2015)
[29] Wasson, A., Bischof, L., Zwart, A. & Watt, M. A portable fluorescence spectroscopy imaging system for automated root phenotyping in soil cores in the field. *Journal of experimental botany* **67**, 1033-1043 (2016)
[30] Trachsel, S., Kaeppler, S. M., Brown, K. M. & Lynch, J. P. Shovelomics: high throughput phenotyping of maize (Zea mays L.) root architecture in the field. *Plant and Soil* **341**, 75-87 (2011)
[31] Bucksch, A. *et al.* Image-based high-throughput field phenotyping of crop roots. *Plant Physiology* **166**, 470-486 (2014)

Other techniques allow researchers to obtain data about roots throughout the plant life cycle, but only over a fraction of the spatial extent of the root system. Field based rhizotrons[32,33] are clear plastic tubes that are placed at the time of planting and left in place as the root system develops around them. Cameras are placed down the tubes and provide very high resolution images of the limited parts of the root system that grow near the tube. These techniques have been very useful for determining numbers of root classes and growth rates but are limited by the quantity of roots that associate with the tube, concern that the tube influences the phenotypes, and general applicability to broad-scale field breeding populations. Ground penetrating radar (GPR)[34] provides relatively low-resolution images that can be used to quantify biomass and have reached resolution that is sufficient to view tuberous crops such as potato and cassava. However, it requires significant improvement to meet the needs of cost, throughput and resolution on fibrous rooted row crops, particularly when used in electrically polarizable soils.

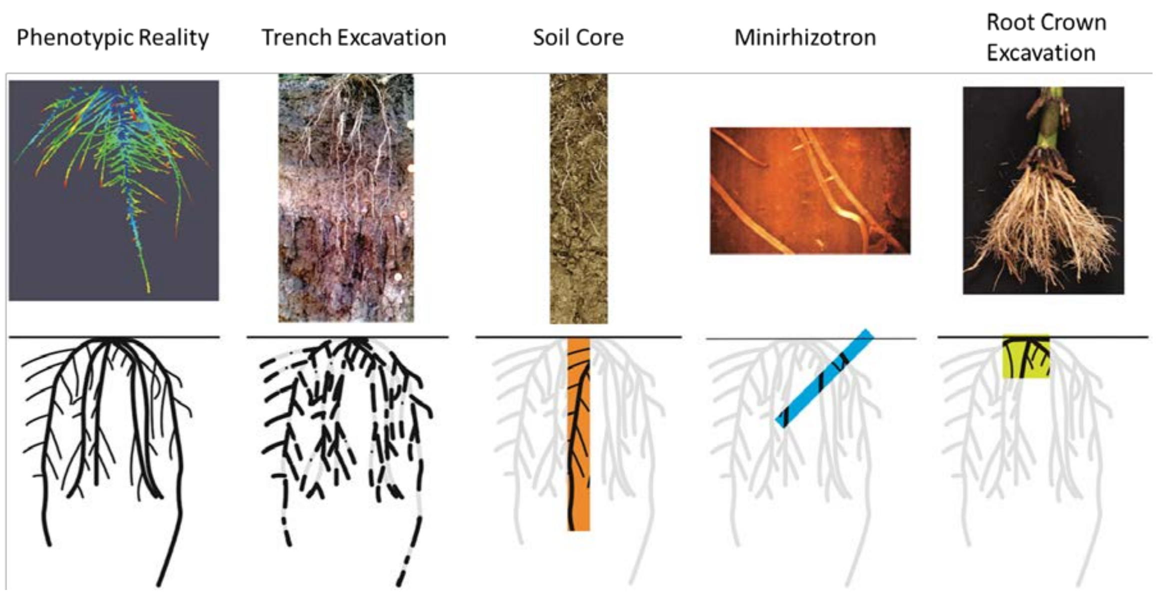

Figure 5: Current field tools for root phenotyping are low-throughput, and most are destructive and allow only partial measurement of root architecture.[21]

[32] Gray, S. B. *et al.* Minirhizotron imaging reveals that nodulation of field-grown soybean is enhanced by free-air CO_2 enrichment only when combined with drought stress. *Functional Plant Biology* **40**, 137-147 (2013)
[33] Iversen, C. M. *et al.*, Advancing the use of minirhizotrons in wetlands. *Plant and Soil* **352**, 23-39 (2012)
[34] Thompson, S. M. *et al.*, https://dl.sciencesocieties.org/publications/meetings/download/pdf/2013am/78536, accessed 3/30/2016

Sensing Soil Properties

In addition to measuring roots in the soil, there is much work done to measure the distribution of nutrients and water in the soil and to quantify the physical properties of the soil. The ability to measure plant effects on nutrients and water has been used to provide indirect trait determination,[35] and there is potential to tune imaging technologies based on soil properties to improve resolution. Current systems include nutrient and water sensors.[36,37.] These systems of sensors can be introduced into a field and provide a farmer information with respect to the most efficient application of fertilizer and water. More recent sensors under development include those that leverage microelectromechanical systems (MEMS) to provide information on the water content of the soil.[38] Advanced soil sensors, when integrated with plant functional phenotyping, may allow selection of germplasm suited to specific real-world environmental conditions.

Understanding the flux of gasses in and out of the soil could provide significant benefits to cultivar development and precision crop management. Current systems, like eddy covariance, can measure gas fluxes, but are expensive and cover a limited amount of land relative to the country's agricultural footprint. In order to better understand and screen for plant and soil properties, cheaper and distributed sensors that measure CO_2, N_2O, and water vapor, among other gasses, are needed. An appendix is included at the end of this document to provide additional background information on soil and root properties.

Survey of Additional Technologies

The problems of imaging through complex media are similar to challenges faced by the medical, aerospace, mining, oil exploration, and defense industries.[39,40] Several classes of novel sensors and imaging platforms may be adapted to the tasks of root phenotyping. One example is low-field magnetic resonance imaging (MRI), which limits risks arising from ferromagnetic materials in soil.[41] Thermoacoustic imaging has demonstrated promising preliminary results in highly dispersive media.[42] Other examples include nuclear quadrupole resonance and X-ray computed

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[35] Vadez, V. et al. LeasyScan: a novel concept combining 3D imaging and lysimetry for high-throughput phenotyping of traits controlling plant water budget. *Journal of Experimental Botany* (2015).

[36] Aquaspy: http://www.aquaspy.com/ Accessed 3/30/2016

[37] Trimble: http://www.trimble.com/Agriculture/sis.aspx Accessed 3-30/2016

[38] Cornell University News: http://news.cornell.edu/stories/2013/10/new-micro-water-sensor-can-aid-growers Accessed 3/30/2016

[39] MacDonald, J., Lockwood, J. Alternatives for Landmine Detection http://www.rand.org/pubs/monograph_reports/MR1608.html, Accessed 3/30/16

[40] Shell Gamechanger, MRI. http://www.shell.com/energy-and-innovation/innovating-together/shell-gamechanger.html, Accessed 3/30/16

[41] Sarracanie, M. et al. Low-Cost High-Performance MRI. *Scientific Reports* **5**, 15177 (2015)

[42] Nan, H. *et al.* Non-contact thermoacoustic detection of embedded targets using airborne-capacitive micromachined ultrasonic transducers. *Applied Physics Letters* **106**, 084101 (2015)

tomography with sophisticated reconstruction algorithms. In addition to the potential to "see" through the soil, innovative robotics may deliver sensors by coupling small profile mobile probes[43] to a range of analytical techniques that can be implemented in extremely low profile endoscopic configurations[44]. Sensor packages may include photoacoustics, fluorescence, and coherent anti-Stokes Raman spectroscopy, among others, and have the potential for a disruptive increase in capability over state of the art. A partial survey of existing and experimental technologies is shown in Figure 6. These are representative examples only, and are not intended to limit the range of technologies proposed in response to this FOA.

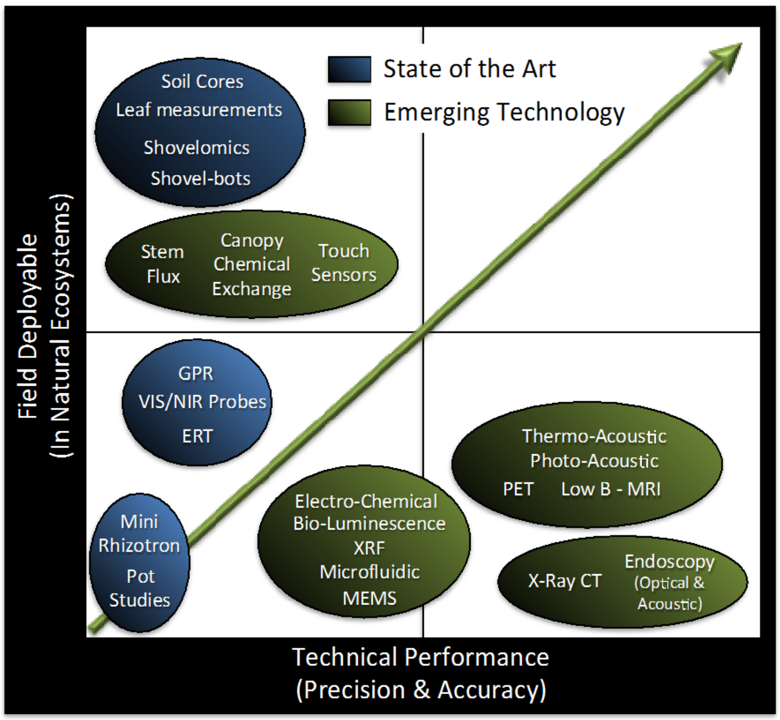

Figure 6: Survey of tools classified by qualitative measures of field deployability and technical performance. Tools of interest are not limited to those listed, and may include sophisticated above-ground sensors, tools that provide information about the flux of nutrients to the root system, sensors that provide information about the soil and the nutrients in it, or sensing/imaging tools that directly probe plant roots. (ERT – Electrical Resistivity Tomography, PET – Positron Emission Tomography, XRF – X-Ray Fluorescence, GPR – Ground Penetrating Radar, MEMS – Micro-Electromechanical Systems, CT – Computed Tomography).

Root-Soil Modeling

Design, discovery, and development of traits with high heritability requires high-throughput measurement of functionally important plant phenotypes (e.g., physiology) and environmental (*e.g.*, soil) characteristics. Modeling represents an excellent opportunity to determine characteristics that are costly to measure, and improve them faster, by establishing correlations to cheaper-to-measure features. For example, it may be possible to estimate and improve the fine-root structure of fine roots in deep soil by making soil density surveys and combining them

[43] Tully, S. & Choset, H. A Filtering Approach for Image-Guided Surgery with a Highly Articulated Surgical Snake Robot. *IEEE Transactions on Biomedical Engineering* **63**, 392-402 (2015)
[44] Seibel, E. J. *et al.* in *SPIE BiOS.* 82180B-82180B-82189 (International Society for Optics and Photonics)

with above-ground physiological or morphological measurements, or to determine correlations between features present in early stages of development with those determinable at the end of the growing season. Such models would reduce the cost of sensor data needed to validate a new root ideotype design or screen for a phenotype in field populations. Multiple root models have been created and have already shown success for trait improvement.[45] For example, a mechanistic model has been used to predict root system water efficiency (a physiological phenotype) by optimizing a lateral root branching trait[46] (an architectural phenotype). This prediction was then validated by testing recombinant inbred lines with divergent phenotype values for the later root branching trait, and thereby demonstrated a wide range of grain yield under drought conditions. Given this validation, this trait became a strong candidate to introduce into elite cultivars to improve their drought tolerance.

C. Program Vision

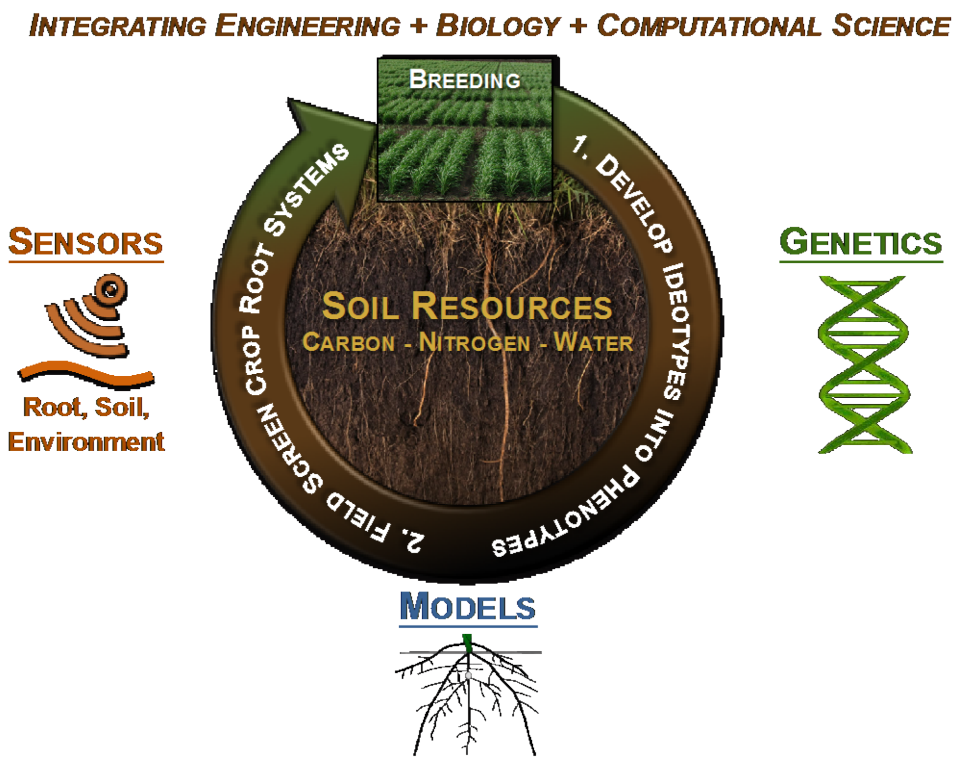

Figure 7: Program Vision - Breeding for Enhanced Soil Quality, Crop Productivity and Greenhouse Gas Mitigation

Precision phenotyping of roots and their interactions with soils under natural field conditions is a complex, system-level challenge that requires the integration of multiple scientific and engineering disciplines. ARPA-E encourages interdisciplinary teams that will improve crop breeding with sensing technology and mechanistic modeling. This funding opportunity should create integrated systems that enable crop genetic improvement of root-soil functional traits

[45] Warren, J. M. *et al.* Root structural and functional dynamics in terrestrial biosphere models–evaluation and recommendations. *New Phytologist* **205**, 59-78 (2015)

[46] Zhan, A., Schneider, H. & Lynch, J. Reduced lateral root branching density improves drought tolerance in maize. *Plant physiology* **168**, 1603-1615 (2015)

that increase soil organic carbon, increase fertilizer efficiency, decrease N_2O emissions, and increase water productivity. The key technical challenges ROOTS aims to solve are: low-throughput for field screening; poor phenotypic correlation of traits measured in controlled environments to field environments; and lack of systematic integration of roots, shoot, and soil properties in the process of ideotype design and development. Ideal systems should include substantial technical development across some, or all, of the following areas: tools for root phenotyping; tools for soil functional characterization; modeling that helps make linkages between environmental, phenomic, and genomic variation that are relevant to breeding; and identification and integration of phenotypes-into-cultivars.

By program completion, performers will be expected to demonstrate that these systems can select for these traits in field conditions for either, or both, (1) ideotype identification and translation and (2) field cultivar selection, as shown in Figure 7. Submissions that focus strictly on sensor tool development will be considered for proof-of-concept demonstrations. Submissions that leverage above-ground tools to infer below-ground characteristics are of definite interest, but any sensor development must be technologically distinct from those developed through ARPA-E's TERRA program. All submissions should describe how their project will drive large-scale adoption of agricultural systems that enable carbon sequestration and/or improved agricultural water and nitrogen use.

D. TECHNICAL CATEGORIES AND COMPONENTS

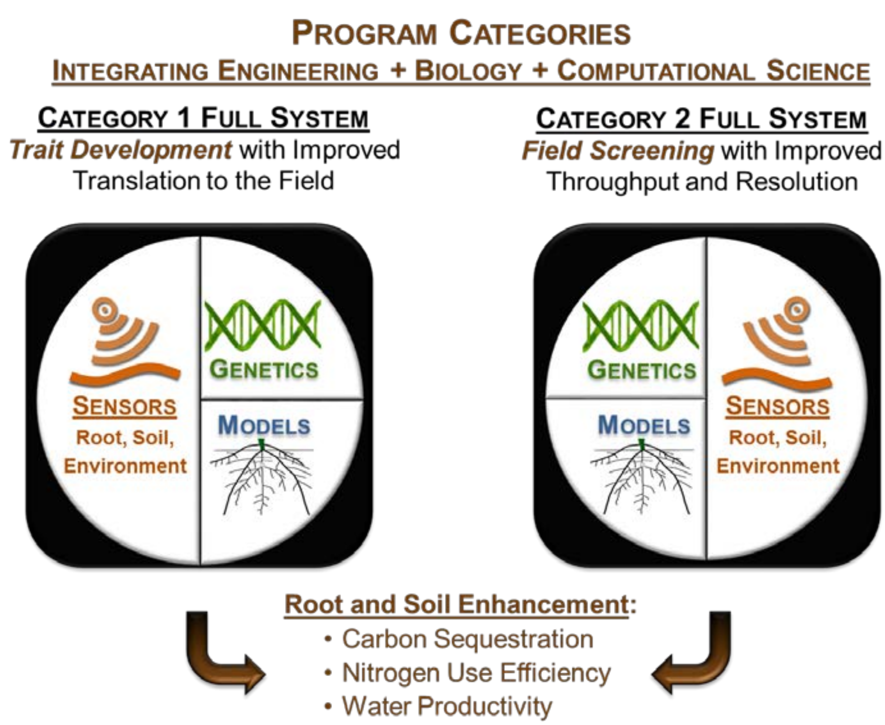

Figure 8: Program Categories - Trait Development and Field Screening

This program will be divided into two functional categories set up to address the fundamental problems of root phenotyping today, as shown in Figure 8. Category 1 projects should address the challenge of poor translation of high quality phenotyping platforms and observations to field sites, by designing and field-validating new root-soil ideotypes. Category 2 projects should address the need for high-throughput and resolution of root and soil screening technologies available to breeders, by demonstrating field deployability of systems for screening cultivars. Teams are encouraged to address both categories in an integrated submission. All submissions (Category 1, Category 2 or combined Category 1 and 2) must explain how the project will address the broader biogeochemical goals of the program: increases soil organic matter, particularly through deeper and increased annual flux of carbon into the soil; decrease in N_2O emissions, particularly through decreasing fertilizer requirements; and improved tolerance of crops to drought conditions, possibly by long term improvement of soil properties such as water holding capacity.

Regardless of which functional categories are addressed, submissions must either discuss the three Components immediately following (i.e., Component A (Sensors), Component B (Models), and Component C (Genetics and Environment)), or Component A exclusively. The latter will be considered for awards of shorter duration and smaller amounts supporting proof-of-concept demonstrations. **ARPA-E's preference is for submissions that address all three Components.**

Component A (Sensors): Advanced sensors and imaging technology for characterization of roots and soils. The terms "sensors" and "imaging technology" *are meant to be broadly interpreted* as referring to any method of measurement (direct or indirect) with breeding relevance. Submissions should explain their strategy for moving sensors from proof-of-principle to in-field and also for automatically collecting, analyzing, and reducing their data.

Component B (Models): Predictive and extensible models of plants and soils to accelerate root breeding programs. Models that predict how traits will react to novel conditions or which traits are desirable in a given geography could limit the number of field trials that are needed to advance a new cultivar. Modeling may also be used during measurements by guiding to sensors toward areas most likely to be informative.

Component C (Genetics and Environment): Genetic resources and characterization of germplasm performance in multiple environments and/or management regimes for phenotypes that address ROOTS biogeochemical goals. Submissions should justify the specific phenotypes or soil characteristics targeted. While ARPA-E expects novel sensors developed in a project should be integrated into a projects' genetic strategy, projects may initially utilize pre-existing technology.

Category 1: Ideotype development platforms – identification of phenotypes and their causal genes for improvements in root system function

Current crops have been designed for high shoot yield and agronomic value, with below-ground biogeochemical function optimized only due to correlation with yield. ARPA-E believes that explicit design of root ideotypes can improve root-soil biogeochemical function and still maintain high yields. The goal of Category 1 projects is a validated root ideotype design and the development of tools for root ideotype design. A project should also identify genetic markers for this ideotype as well environmental (*e.g.*, soil) characteristics highly correlated with phenotypic expression. Finally, these ideotypes should be validated in a representative range of field environments (*e.g.*, multiple soil types) with high correlation to predictions from tests done in a small number of fields or in a controlled environment.

Category 1 sensors should have sufficient resolution for phenotype identification and sufficient throughput for genetic marker identification. If controlled environments / greenhouses are proposed, the applicants must justify their relevance to field conditions and explain their plan for in-field phenotype verification.

Category 1 models should directly support the identification of new root ideotypes, the identification of genetic markers or causal genes, and improve the success rate of field validation trials. The models should be designed to incorporate findings from the novel sensor method and help determine the best field implementation of the sensor methods. Models that help relate diverse measureable characteristics of root-soil systems, such as root architecture and root physiology, to one another are of particular interest.

Category 1 genetics and environment components should achieve field validation of new phenotypes or identification of genetic markers or causal genes. These genetic markers or key phenotypes could then be transitioned to higher throughput sensors in Category 2 field screening programs to mobilize traits in production settings.

Outcomes of successful projects in this category could be genetic improvement of a carbon sequestration trait by breeding, transgenes, or gene editing methods; development or refinement of a predictive model to identify phenotypes that increase nutrient acquisition efficiency or root biomass; development of a field proxy for a phenotype easily measured in controlled environments; and/or methods that identify phenotypes under high degree of genetic control that require a smaller number of plants and/or predict the impact of field environment variation on trait expression.

Category 2: Field screening platforms – identification of plants in the field that exhibit desired phenotypes via high-throughput and minimally destructive methods

ARPA-E seeks to fund development and validation of systems of sensors and models that enable high-throughput field phenotyping for significant biogeochemical traits. Applicants are expected to provide details on the phenotypes they will characterize and may utilize known varieties with increased rooting depth or other target traits to validate their systems. Applicants should describe details of field studies and collection plans for ground truth and calibration data.

Category 2 sensors should be field deployable in breeding conditions, minimally destructive, and high-throughput. It is expected that sensors developed in Category 2 will generally be lower resolution but higher throughput than those developed in Category 1. For example, aggregate measurements of root mass and structure are expected to be well-suited for Category 2, while measurements of fine root structure are anticipated to be better suited for Category 1.

Category 2 models should accelerate the process of field screening and address the throughput and resolution limitations expected of these sensors. For example, these models may predict below-ground phenotypes from near-surface or above-ground phenotypes and, by establishing these correlations rapidly, promote or discard individual lines. Integration of soil and root modeling might reduce the frequency of measurements needed for accurate prediction of field performance of breeding material.

Category 2 genetic outcomes would be the ability to select individuals with improved root-soil functional characteristics. Category 2 environmental variation should account for a representative range of soil variation, relevant to a significant fraction of the U.S. commercial range of the chosen crop. An example of a potential technology for this category could be the development of a thermoacoustic measurement platform capable of passing over field plots and imaging hundreds of plants per day. A team could utilize this tool on a population of wild accessions originating from drought prone environments over multiple growing seasons to identify a quantitative trait locus (QTL)[47] linked to increased root proliferation.

Dual category submissions

Efforts that link approaches and provide continuity to the process would be highly beneficial, and applicants should not feel constrained to tailor their concepts to fit a specific category, particularly where an Applicant's sensor technology may be applicable to both categories. Certain sensor technologies may be usable for both categories by altering how they were deployed. For example, a Category 1 implementation of magnetic resonance imaging of roots might use a longer averaging time than a Category 2 implementation, or it might involve a soil

[47] A quantitative trait locus is a specific region of DNA in an organism's genome that is statistically correlated with an observed phenotype. Multiple QTLs can be identified throughout a genome to characterize complex, multi-gene traits. Miles, C. & Wayne, M. Quantitative trait locus (QTL) analysis. *Nature Education* **1,** 208-216 (2008)

invasive element in Category 1 and be only used on the surface for Category 2. A dual category project might screen, in its Category 2 element, for the markers identified in its Category 1 element.

E. TECHNICAL PERFORMANCE TARGETS

Table 1: Category 1 Metrics

Category 1 Ideotypes into Phenotypes		
ID	Description	Target
Component A – Sensors		
1A.1	Instrumentation Target	CV < 5% for identification or root or soil characterization R^2 >.75 ground truth value
1A.2	Technical Repeatability	>95%
1A.3	Throughput / Scale	>500 plants, 3 times per season, in translatable conditions
Component B – Models		
1B.1	Improve Throughput	Allows 10-fold reduction in the number of plants to screen for phenotype identification
1B.2	Enhance Translation	Enable correlations between measured values and field performance with $R^2 > 0.6$
Component C - Genetics and Environment		
1C.1	Genetic Basis of Root Traits	Target traits with heritability: > 0.5 *OR* Identify 3 causal genes or linked markers that predict >50% of genetic component of a trait
1C.2	Genetic (G) and Environment (E) Interaction	Quantify GxE influence on traits by measurement in at least 3 environments
1C.3	Quantify Impact	Ideotypes achieve >25% improvement of carbon sequestration, nitrous oxide reduction, or water productivity validated either with field measurement and/or model.

Supplemental Explanation of Category 1 Technical Targets:

- All criteria are under like environmental conditions and best land management practices.
- All genetic improvements must be yield neutral or yield positive, once germplasm is re-optimized.

1A.1 Target refers to the CV and R^2 for the chosen soil or phenotype from Table 3. Sensor metrics are specified in Table 3.
R^2 is defined as the sample coefficient of determination, which represents the proportion of the variation of the data in question as explained by the regression, and coefficient of variation (CV) is defined as the root mean squared error, divided by the *y*-value for the data point, expressed as a percentage.[48]
Ground truth is defined as relative to state of the art in measuring the indicated property.

1A.2 Technical Repeatability is defined as precision under repeatability conditions, where repeatability conditions are defined as conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. Definition from ISO 5725-1:1994.

1B.2 Correlation, as quantified by the correlation coefficient, measures the strength of a relationship between two variables.[48]

1C.1 Heritability is a measure of the phenotypic variation of a population observed in an environment that is due to genetic variation within the population. Broad sense heritability can be represented by the ratio $H^2 = Var(G)/Var(P)$. [49]

[48] Chapters 11 and 12 of Walpole, Myers, Myers, Ye. Probability and Statistics for Engineers and Scientists. 8th edition. Pearson Education International. 2007.
[49] Principles of Population Genetics, 4th Ed. Hartl and Clark, 2007

Table 2: Category 2 Metrics

Category 2 Field Screening Crop Root Systems		
Component A – Sensors		
2A.1	Instrumentation Target	Instrumentation Target: CV< 10% of root or soil property R^2 >.6 ground truth value
2A.2	Technical Repeatability	>90%
2A.3	Throughput / Coverage	2 hectares with 2000 plant accessions each measured 3 times during growing season
Component B – Models		
2B.1	Improve Throughput	25%-50% improvement of throughput in field breeding.
Component C - Genetics and Environment		
2C.1	Genetic Basis of Root Traits	Target traits with heritability: > 0.4, or establish predictive models (e.g. Genomic Selection) accounting for >50% of heritable variation
2C.2	Genetic (G) and Environment (E) Interaction	Quantification of GxE influence on cultivar, by measurement in at least 3 environments with maximum coverage of relevant commercial crop growth
2C.3	Quantify Impact	Cultivar with wide deployment that achieves >25% improvement of carbon sequestration, nitrous oxide reduction, or water productivity validated either with field measurement and/or model.

Supplemental Explanation of Category 2 Technical Targets:

- All criteria are under like environmental conditions and best land management practices.
- All genetic improvements must be yield neutral or yield positive, once germplasm is re-optimized.

2A.1 Target refers to the CV and R^2 for the chosen soil or phenotype from Table 3. Sensor metrics are specified in Table 3.
R^2 is defined as the sample coefficient of determination, which represents the proportion of the variation of the data in question as explained by the regression, and CV is defined as the coefficient of variation is defined as the root mean squared error, divided by the *y*-value for the data point, expressed as a percentage.[48]
Ground truth is defined as relative to state of the art in measuring the indicated property.

2A.2 Technical Repeatability is defined as precision under repeatability conditions, where repeatability conditions are defined as conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. Definition from ISO 5725-1:1994.

2B.1 Throughput increased is defined by a decrease the breeding cycle time or the number of required plots and locations to discriminate breeding population performance.

2B.2 Correlation, as quantified by the correlation coefficient, measures the strength of a relationship between two variables.[48]

2C.1 Heritability is a measure of the phenotypic variation of a population observed in an environment that is due to genetic variation within the population. Broad sense heritability can be represented by the ratio $H^2 = Var(G)/Var(P)$.[49]

Additional Requirements

All projects—Category 1 and/or Category 2—are expected to demonstrate commercial utility via:

(1) Crop choice of an annual or perennial crop that has a robust fine root system, well-characterized genetic resources, a sequenced genome, and access to existing breeding pipelines with commercial potential. If perennial crops are chosen, proposer must have access to established crop sites in multiple environments. Sensors with broad crop applicability are encouraged.

(2) Development of technology capable of achieving cost targets and throughput levels (at full deployment) relevant to commercial breeding.

Table 3 includes a list of particularly interesting phenotypes and soil characteristics, and metrics for measuring those phenotypes. All submissions must address at least one of the listed phenotypes or soil characteristics. Submissions with only Component A must develop a sensor capable of achieving the corresponding metrics. Submissions with all three Components are recommended to address a sensor metric in Table 3, but may argue for a different metric if applicants' proposed sensor technology is not well described by the sensor metrics below; or applicants are combining sensors and/or models that can achieve program goals without meeting the specific metrics below.

In addition to requirements in Table 3, novel sensors must be at least as accurate as the corresponding state of the art, to which they should be compared to ground-truth during the project.

TABLE 3: Phenotypes and Sensor Metrics

Phenotypes	**Sensor Metrics**
Carbon Flux and Nitrogen Flux Characteristics	
Root or Microbe Mass	Precision and repeatability within 10% on total mass of roots or microbial community. Alternatively, the team can provide 10% precision and repeatability relative to another quantity, such as soil mass or volumes. Methods capable of distinguishing root mass from residue are of interest.
Photosynthate or Exudate Flux	10% precision and repeatability on total photosynthate or exudate flux, or per a defined mass of soil.
C:N Ratio Or Lignin:Cellulose Ratio	10% precision and repeatability for C:N ratio or lignin:cellulose ratio.
Root Spatial Characteristics	
Root System Architecture	Must show significant improvement relative to state of the art in identification of root system architecture, including differentiation among roots, soil and plant litter. Examples of parameters relevant to root system architectures may include root angle, branching, depth, surface area, or length.
Root Physiology / Growth Rate	Must show significant improvement relative to state of the art. Obtaining information about carbon partitioning or composition may be considered synergistic.
Root Morphology / Anatomy	Must show significant improvement in ability to measure aspects of root anatomy, such as root hairs, rhizosheaths, or root cortical arenchyma, relative to the state of the art.
Soil Characteristics	
Bulk Density	Precision and repeatability < 3%
Nitrate Concentration	Precision and repeatability of 2 ppm.
Soil Carbon Content	Specify 0.1% precision on total soil mass or volume over an area of 10 m^2

Nitrous Oxide Concentration	Specify 10% precision over an area of 10 m^2, integrated on a weekly basis
Soil Porosity (Compaction)	Precision and Repeatability < 3% over proposed soil volume.
Soil Water Content (including water holding capacity and plant-available water)	Provide soil water content at a spatial resolution of 10 cm of depth. Precision and Repeatability < 3% over proposed soil volume.
Soil Respiration Rate	Precision and repeatability < 10% over a time interval of one day.
Soil Water Potential	Provide soil water potential at a spatial resolution of 10 cm of depth. Precision and Repeatability < 3%.
Fraction of Nitrogen Microbially-Fixed	Specify 10% precision over an area of 10 m^2, integrated on a weekly basis

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 8-12 awards under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

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

The period of performance for funding agreements may not exceed 48 months. ARPA-E expects the start date for funding agreements to be February 2017, or as negotiated.

ARPA-E encourages applications stemming from ideas that still require proof-of-concept R&D efforts as well as those for which some proof-of-concept demonstration already exists.

Applications requiring proof-of-concept R&D can propose a project with the goal of delivering on the program metric at the conclusion of the period of performance. These submissions should contain an appropriate cost and project duration plan that is described in sufficient technical detail to allow reviewers to meaningfully evaluate the proposed project. If awarded, such projects should expect a rigorous go/no-go milestone early in the project associated with the proof-of-concept demonstration. Alternatively, applications requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, the Applicants are required to provide a convincing vision how these partial solutions can enable the realization of the program metrics with further development.

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

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

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

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

B. ARPA-E FUNDING AGREEMENTS

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

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[50] Accordingly, ARPA-E has substantial involvement in the direction of every project, as described in Section II.C below.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[51]

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.

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

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

2. Funding Agreements with FFRDCs/DOE Labs, GOGOs, and Federal Instrumentalities

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

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

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

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs (including NETL), and Federal instrumentalities (e.g., Tennessee Valley Authority) will be consistent with the sponsoring agreement between the U.S. Government and the Laboratory. Any funding agreement with a FFRDC or GOGO will have similar terms and conditions as ARPA-E's Model Cooperative Agreement (http://arpa-e.energy.gov/arpa-e-site-page/award-guidance).

Non-DOE GOGOs and Federal agencies may be proposed to provide support to the project team members on an applicant's project, through a Cooperative Research and Development Agreement (CRADA) or similar agreement.

3. Technology Investment Agreements

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

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

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

C. STATEMENT OF SUBSTANTIAL INVOLVEMENT

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

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.338 and 200.339.
- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

III. Eligibility Information

A. Eligible Applicants

1. Individuals

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[52] as the lead for a Project Team,[53] or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. Domestic Entities

For-profit entities, educational institutions, and nonprofits[54] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

FFRDCs/DOE Labs are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team that includes institutions of higher education, companies, research foundations, or trade and industry research collaborations, but not as a Standalone Applicant.

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

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

3. Foreign Entities

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or

[52] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[53] 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.
[54] Nonprofit organizations described in section 501(c)(4) of the Internal Revenue Code of 1986 that engaged in lobbying activities after December 31, 1995 are not eligible to apply for funding as a Prime Recipient or Subrecipient.

otherwise formed or to be formed) under the laws of a State or territory of the United States to receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application and can be found at https://arpa-e-foa.energy.gov/. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. CONSORTIUM ENTITIES

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

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

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

B. COST SHARING[55]

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

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

1. Base Cost Share Requirement

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.B.1 of the FOA). Under a Cooperative Agreement, the Prime Recipient must provide at least 20% of the Total Project Cost[56] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[57]

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").[58] 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

[56] 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.
[57] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.
[58] Small businesses are generally defined as domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards). Applicants that are small businesses will be required to certify in the Business Assurances & Disclosures Form that their organization meets the SBA's definition of a small business under at least one NAICS code.

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.[59]

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

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

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

4. Legal Responsibility

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

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

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.

[59] See the information provided in previous footnote.

6. COST SHARE TYPES AND ALLOWABILITY

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

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

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

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

In addition, Project Teams may not use independent research and development (IR&D) funds[60] 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.

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

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

7. Cost Share Contributions by FFRDCs and GOGOs

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

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

8. Cost Share Verification

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

C. Other

1. Compliant Criteria

Concept Papers are deemed compliant if:

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

Concept Papers found to be noncompliant will not be merit reviewed or considered for award. ARPA-E will not review or consider noncompliant Concept Papers, including Concept Papers submitted through other means, Concept Papers submitted after the applicable deadline, and incomplete Concept Papers. A Concept Paper is incomplete if it does not include required information. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Full Applications are deemed compliant if:

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

Full Applications found to be noncompliant will not be merit reviewed or considered for award. ARPA-E will not review or consider noncompliant Full Applications, including Full Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Replies to Reviewer Comments are deemed compliant if:

- The Applicant successfully uploads its response to ARPA-E eXCHANGE by the deadline stated in the FOA.
- The Replies to Reviewer Comments comply with the content and form requirements of Section IV.E of the FOA.

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

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Concept Papers and Full Applications. The following types of submissions may be deemed nonresponsive and may not be merit reviewed or considered:

- Submissions that fall outside the technical parameters specified in Section I.E of the FOA

- Submissions that have been submitted in response to other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from those submitted in response to other currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.
- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA.
- Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Submissions that are not scientifically distinct from existing funded activities supported elsewhere, including within the Department of Energy.
- Submissions that describe a technology but do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- Submissions with significant technical overlap with the ARPA-E MONITOR and TERRA programs. Specifically:
  - Submissions that solely include significant development of novel trace gas sensors, especially focused on mid infrared sensing, such that they overlap with technologies being developing under ARPA-E's MONITOR program. Submissions that include canopy flux sensing are still considered of interest.
  - Submissions that solely include development of above-ground, advanced automated robotic platforms and genome-phenotype linkage algorithms in sorghum, such that they overlap with technologies being developing under ARPA-E's TERRA program.
- Submissions that advance a breeding outcome without significant improvement in throughput over state of the art in measurement for selection.
- Predictive models that cannot be advanced meaningfully with the data to be measured in the project.
- Submissions proposing to work with crops that don't have the following characteristics:
  - Existing infrastructure and grower expertise.

    - At least one published and annotated genome sequence.
- Submissions that primarily focus on early stage fundamental microbiome research, microbial genomics, systems biology on the roles of microbial communities and metabolic activities specific to particular microbes.

4. LIMITATION ON NUMBER OF APPLICATIONS

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

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E eXCHANGE

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

2. CONCEPT PAPERS

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

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Concept Papers found to be noncompliant or nonresponsive will not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria in Section V.A.1 of the FOA.

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

3. Full Applications

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

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Full Applications found to be noncompliant or nonresponsive will not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria in Section V.A.2 of the FOA.

4. Reply to Reviewer Comments

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

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

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

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

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

6. Selection for Award Negotiations

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA. The Selection Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

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

7. Mandatory Webinar

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

B. Application Forms

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

C. Content and Form of Concept Papers

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

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

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

- The Concept Paper must be written in English.

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

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

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

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

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

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

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

1. Concept Paper

a. Concept Summary

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

b. Innovation and Impact

- Clearly identify the problem to be solved with the proposed technology concept.

- Describe how the proposed effort represents an innovative and potentially transformational solution to the technical challenges posed by the FOA. Address the difficulties of translation and field applicability of Category 1 submissions and limitations on throughput and resolution of Category 2 submissions.

- 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. At the concept paper stage focus on the direct impacts of sensors and other immediate innovations, rather than estimating potential environmental impacts that occur over time.

- To the extent possible, provide quantitative metrics in a table that compares the proposed technology concept to current and emerging technologies and to the technical performance targets in Section I.E of the FOA for the appropriate Technology Category in Section I.D of the FOA.

c. Proposed Work

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

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

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

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

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

d. Team Organization and Capabilities

- Indicate the roles and responsibilities of the organizations and key personnel that comprise the Project Team.
- Provide the name, position, and institution of each key team member and describe in 1-2 sentences the skills and experience that he/she brings to the team.
- Identify key capabilities provided by the organizations comprising the Project Team and how those key capabilities will be used in the proposed effort.
- Identify (if applicable) previous collaborative efforts among team members relevant to the proposed effort.

D. Content and Form of Full Applications

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

E. Content and Form of Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

F. Intergovernmental Review

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

G. Funding Restrictions

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

H. Other Submission Requirements

1. Use of ARPA-E eXCHANGE

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

E eXCHANGE, please refer to the “ARPA-E eXCHANGE User Guide” (https://arpa-e-foa.energy.gov/Manuals.aspx).

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

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

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

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

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

- Failing to comply with the form and content requirements in Section IV of the FOA;
- Failing to enter required information in ARPA-E eXCHANGE;
- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Failing to click the “Submit” button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and

- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

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

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

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

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

1. CRITERIA FOR CONCEPT PAPERS

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

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;

- Achievement of the technical performance targets defined in Section I.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and

- Demonstration of awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

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

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

- Sufficiency of technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;

- Clearly defined project outcomes and final deliverables;

- Identification of techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and

- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

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

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

2. Criteria for Full Applications

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

3. Criteria for Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

B. Review and Selection Process

1. Program Policy Factors

In addition to the above criteria, ARPA-E may consider the following program policy factors in determining which Concept Papers to encourage to submit a Full Application and which Full Applications to select for award negotiations:

I. **ARPA-E Portfolio Balance**. Project balances ARPA-E portfolio in one or more of the following areas:
   a. Diversity (including gender) of technical personnel in the proposed Project Team;
   b. Technological diversity;
   c. Organizational diversity;
   d. Geographic diversity;

e. Technical or commercialization risk; or
f. Stage of technology development.

II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
   a. Reduction of US dependence on foreign energy sources;
   b. Stimulation of domestic manufacturing;
   c. Reduction of energy-related emissions;
   d. Increase in U.S. energy efficiency;
   e. Enhancement of U.S. economic and energy security; or
   f. Promotion of U.S. advanced energy technologies competitiveness.

III. **Synergy of Public and Private Efforts**.
   a. Avoids duplication and overlap with other publicly or privately funded projects;
   b. Promotes increased coordination with nongovernmental entities for demonstration of technologies and research applications to facilitate technology transfer; or
   c. Increases unique research collaborations.

IV. **Low likelihood of other sources of funding.** High technical and/or financial uncertainty that results in the non-availability of other public, private or internal funding or resources to support the project.

V. **High-Leveraging of Federal Funds**. Project leverages Federal funds to optimize advancement of programmatic goals by proposing cost share above the required minimum or otherwise accessing scarce or unique resources.

VI. **High Project Impact Relative to Project Cost.**

2. ARPA-E REVIEWERS

By submitting an application to ARPA-E, Applicants consent to ARPA-E's use of Federal employees, contractors, and experts from educational institutions, nonprofits, industry, and governmental and intergovernmental entities as reviewers. ARPA-E selects reviewers based on their knowledge and understanding of the relevant field and application, their experience and skills, and their ability to provide constructive feedback on applications.

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments. In addition, ARPA-E trains its reviewers in proper evaluation techniques and procedures.

Applicants are not permitted to nominate reviewers for their applications. Applicants may contact the Contracting Officer by email (ARPA-E-CO@hq.doe.gov) if they have knowledge of a potential conflict of interest or a reasonable belief that a potential conflict exists.

3. ARPA-E SUPPORT CONTRACTOR

ARPA-E utilizes contractors to assist with the evaluation of applications and project management. To avoid actual and apparent conflicts of interest, ARPA-E prohibits its support contractors from submitting or participating in the preparation of applications to ARPA-E.

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. ANTICIPATED ANNOUNCEMENT AND AWARD DATES

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

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

2. CONCEPT PAPER NOTIFICATIONS

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

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

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

3. Full Application Notifications

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

B. Administrative and National Policy Requirements

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

C. Reporting

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

VII. Agency Contacts

A. Communications with ARPA-E

Upon the issuance of a FOA, only the Contracting Officer may communicate with Applicants. ARPA-E personnel and our support contractors are prohibited from communicating (in writing or otherwise) with Applicants regarding the FOA. This "quiet period" remains in effect until ARPA-E's public announcement of its project selections.

During the "quiet period," Applicants are required to submit all questions regarding this FOA to ARPA-E-CO@hq.doe.gov. Questions and Answers (Q&As) about ARPA-E and the FOA are available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, please send an email with the FOA name and number in the subject line to ARPA-E-CO@hq.doe.gov. Due to the volume of questions received, ARPA-E will only answer pertinent questions that have not yet been answered and posted at the above link.

- ARPA-E will post responses on a weekly basis to any questions that are received. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- ARPA-E will cease to accept questions approximately 5 business days in advance of each submission deadline. Responses to questions received before the cutoff will be posted approximately one business day in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- Responses are posted to "Questions and Answers" on ARPA-E's website (http://arpa-e.energy.gov/faq).

Applicants may submit questions regarding ARPA-E eXCHANGE, ARPA-E's online application portal, to ExchangeHelp@hq.doe.gov. ARPA-E will promptly respond to emails that raise legitimate, technical issues with ARPA-E eXCHANGE. ARPA-E will refer any questions regarding the FOA to ARPA-E-CO@hq.doe.gov.

ARPA-E will not accept or respond to communications received by other means (e.g., fax, telephone, mail, hand delivery). Emails sent to other email addresses will be disregarded.

During the "quiet period," only the Contracting Officer may authorize communications between ARPA-E personnel and Applicants. The Contracting Officer may communicate with Applicants as necessary and appropriate. As described in Section IV.A of the FOA, the Contracting Officer may arrange pre-selection meetings and/or site visits during the "quiet period."

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings. ARPA-E provides Applicants with a notification encouraging or discouraging the submission of a Full Application based on ARPA-E's assessment of the Concept Paper. In addition, ARPA-E provides Applicants with reviewer comments on Full Applications before the submission deadline for Replies to Reviewer Comments.

VIII. OTHER INFORMATION

A. FOAS AND FOA MODIFICATIONS

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA are also posted to these websites. You can receive an e-mail when a modification is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

B. OBLIGATION OF PUBLIC FUNDS

The Contracting Officer is the only individual who can make awards on behalf of ARPA-E or obligate ARPA-E to the expenditure of public funds. A commitment or obligation by any individual other than the Contracting Officer, either explicit or implied, is invalid.

ARPA-E awards may not be transferred, assigned, or assumed without the prior written consent of a Contracting Officer.

C. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

Applicants are required to make a full and complete disclosure of the information requested in the Business Assurances & Disclosures Form. Disclosure of the requested information is mandatory. Any failure to make a full and complete disclosure of the requested information may result in:

- The rejection of a Concept Paper, Full Application, and/or Reply to Reviewer Comments;
- The termination of award negotiations;
- The modification, suspension, and/or termination of a funding agreement;
- The initiation of debarment proceedings, debarment, and/or a declaration of ineligibility for receipt of Federal contracts, subcontracts, and financial assistance and benefits; and
- Civil and/or criminal penalties.

D. Retention of Submissions

ARPA-E expects to retain copies of all Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions. No submissions will be returned. By applying to ARPA-E for funding, Applicants consent to ARPA-E's retention of their submissions.

E. Marking of Confidential Information

ARPA-E will use data and other information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments strictly for evaluation purposes.

Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions containing confidential, proprietary, or privileged information must be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

The cover sheet of the Concept Paper, Full Application, Reply to Reviewer Comments, or other submission must be marked as follows and identify the specific pages containing confidential, proprietary, or privileged information:

> Notice of Restriction on Disclosure and Use of Data:
>
> Pages [___] of this document may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

The header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure." In addition, every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

F. Title to Subject Inventions

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

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

- All other parties: The Federal Non-Nuclear Energy Act of 1974, 42. U.S.C. 5908, provides that the Government obtains title to new inventions unless a waiver is granted (*see below)*.

- Class Waiver: Under 42 U.S.C. § 5908, title to subject inventions vests in the U.S. Government and large businesses and foreign entities do not have the automatic right to elect to retain title to subject inventions. However, ARPA-E typically issues "class patent waivers" under which large businesses and foreign entities that meet certain stated requirements, such as cost sharing of at least 20% may elect to retain title to their subject inventions. If a large business or foreign entity elects to retain title to its subject invention, it must file a patent application in a timely fashion. If the class waiver does not apply, a party may request a waiver in accordance with 10 C.F.R. §784.

- GOGOs are subject to the requirements of 37 CFR Part 501.

G. Government Rights in Subject Inventions

Where Prime Recipients and Subrecipients retain title to subject inventions, the U.S. Government retains certain rights.

1. Government Use License

The U.S. Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world. This license extends to contractors doing work on behalf of the Government.

2. March-In Rights

The U.S. Government retains march-in rights with respect to all subject inventions. Through "march-in rights," the Government may require a Prime Recipient or Subrecipient who has elected to retain title to a subject invention (or their assignees or exclusive licensees), to grant a license for use of the invention. In addition, the Government may grant licenses for use of the subject invention when Prime Recipients, Subrecipients, or their assignees and exclusive licensees refuse to do so.

The U.S. Government may exercise its march-in rights if it determines that such action is necessary under any of the four following conditions:

- The owner or licensee has not taken or is not expected to take effective steps to achieve practical application of the invention within a reasonable time;
- The owner or licensee has not taken action to alleviate health or safety needs in a reasonably satisfactory manner;
- The owner has not met public use requirements specified by Federal statutes in a reasonably satisfactory manner; or
- The U.S. Manufacturing requirement has not been met.

3. U.S. Manufacturing Requirement

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

H. Rights in Technical Data

Data rights differ based on whether data is first produced under an award or instead was developed at private expense outside the award.

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to five years in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

I. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

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

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

J. COMPLIANCE AUDIT REQUIREMENT

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

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

IX. GLOSSARY

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

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

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

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

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

DOE: U.S. Department of Energy.

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

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

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

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

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

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

PI: Principal Investigator.

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

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

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

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

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

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

X. APPENDIX: OVERVIEW OF ROOT AND SOIL PROPERTIES

Roots are the hierarchically structured below-ground portion of a plant responsible for nutrient and water collection. Due to the difficulty of root phenotyping most improvements to roots have been incidental to selection for yield. Like above-ground traits, there is tremendous variety of root form and function, satisfying the breeders' need for phenotypic diversity for selection and optimization.[61] Coarse roots, which contain the majority of the biomass and are responsible for nutrient transport, are defined as those with diameter above 2 mm. Fine roots, which are responsible from nutrient uptake from the soil, are those with diameter below 2 mm.

The challenges of root phenotyping revolve around the complex root-soil interaction and the difficulties associated with making observations in soil. Soils also strongly attenuate many forms of electromagnetic radiation and vary widely in composition, making observation of roots extremely challenging. Although highly variable, some generalizations of physiochemical characteristics of soils are included below to indicate likely conditions where certain types of novel sensors will perform.

Soil is the biologically activated surface layer of the earth. It is divided into distinct physiochemical strata, known as horizons. The top two horizons are often referred to as "topsoil" and its depth is canonically taken as 30 cm, though the actually depth of topsoil is variable. Soil contains an organic carbon fraction that typically falls between 0.5 percent and four percent. The total depth of the soil, defined as that which is root accessible, varies significantly, but the general scale is about 2 meters. That depth contains the vast majority of root biomass.

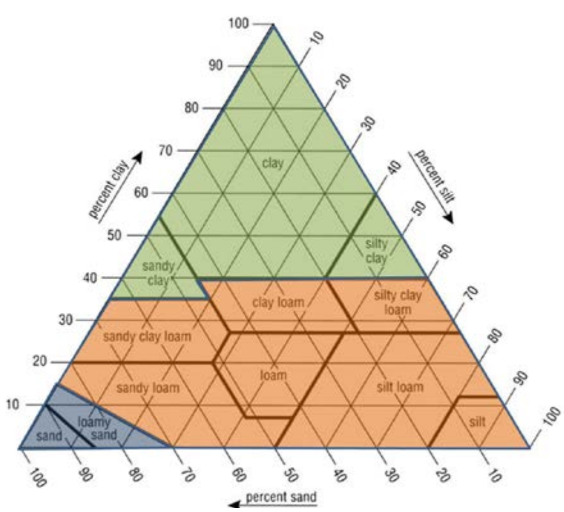

Figure 9: Soil particle composition pyramid used to define bulk soil properties and classification.

The composition of soil is about 50% porous and 50% solid. The porous fraction varies between water-filled and air-filled, depending on weather and climate. Soils are classified by particle size and mineral composition ranging from sub-micron clays, to intermediate sized silt, and >1 mm sands with the relative fractions of each particle type giving rise to soil properties that are classes as sands, clays, silts, loams, etc. The varying particle sizes result in significant differences in pH, dielectric properties, water holding capacity and drainage, cation exchange capacity, and others. Some of the best agricultural soils are loams, but all soil types can

[61] National Geographic Magazine: http://proof.nationalgeographic.com/2015/10/15/digging-deep-reveals-the-intricate-world-of-roots/ Accessed 2/27/2016

be productive and are relevant to agriculture. The bulk density of soil is between 1 and 1.6 g/cm^3.

In addition to mineral components, there is a great variety of fungi, bacteria, and viruses that live in the soil, and many of these form symbiotic relationships with plants. Roots interact with the soil microbiome via exudation of chemicals that enable chemical adaptation, sustain symbiotic microbes, and kill parasitic ones. Though the effects of the soil microbiome on plants is substantial, interactions between the microbial communities and plants are complex and have proven difficult to manipulate through breeding—although this also represents a technologic horizon in need of further development. Certain types of microbial growth in the rhizosphere are associated with improved plant health, soil quality, and soil organic matter turnover and carbon mineralization making these alterations a field of high-potential opportunity. However, given the current challenges related to microbial manipulation and transferability, this is not the focus of ROOTS.

Root traits have a major role in modifying ecosystem processes, such as carbon and nutrient cycling, and the formation and structural stability of soil, see Figure 10. The interactions in the rhizosphere operate via a variety of mechanisms. Modification of root traits and the soil environment could have far-reaching implications on ecosystem processes.[62]

[62] Bardgett, R. D., Mommer, L. & De Vries, F. T. Going underground: root traits as drivers of ecosystem processes. *Trends in Ecology & Evolution* **29**, 692-699 (2014)

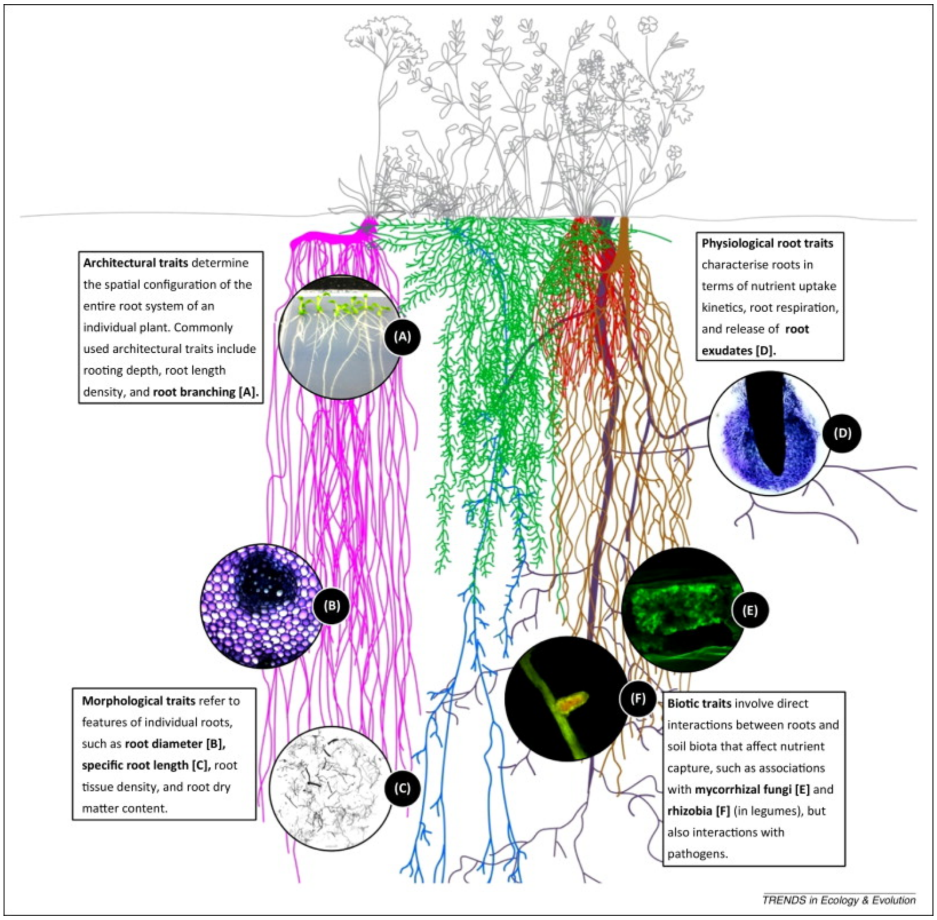

Figure 10: Definition of root traits and their interaction with environmental properties.