FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

FACSIMILE APPEARANCE TO CREATE ENERGY SAVINGS (FACES)

Announcement Type: Initial Announcement
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Funding Opportunity Announcement (FOA) Issue Date:	Thursday, December 8, 2016
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, Friday January 6, 2017
Submission Deadline for Concept Papers:	5 PM ET, Monday January 16, 2017
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 $9.5 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 $9.5 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 of the FOA.

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

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: o Concept Summary o Innovation and Impact o Proposed Work o Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, Monday January 16, 2017
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2017]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2017]	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 to develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector or the applied technology offices within DOE. By contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly lower than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately

become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have the clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

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

B. PROGRAM OVERVIEW

The objective of the FACES Program is to develop advanced information technologies which will dramatically reduce the need to travel for the purpose of communication, thereby reducing travel-related energy consumption and its associated greenhouse gas emissions, as well as increasing the efficiency of energy use and improving economic security.

Telecommunication technology has advanced significantly since the invention of the telegraph, yet we are still far from this ideal. Today's telecommunication technologies still lack essential characteristics demanded by human interaction. ARPA-E believes that extraordinary technological shifts over the past two decades have created an opportunity to dramatically improve the utility of telecommunication technology.

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

This digital form of transportation has the potential to reduce communication-related travel energy consumption by several orders of magnitude because information networks consume substantially less energy than all traditional forms of transportation (such as planes, trains, and automobiles). Travel for the purpose of in-person communication is responsible for roughly 8% of the United States' energy consumption, so the ultimate success of this Program could yield a reduction in energy consumption of several quadrillion BTUs per year in the US alone.

Of essential importance is that an individual would prefer to use the "digital transportation" Technologies developed under the FACES Program rather than the energy-, time-, and cost-intensive status quo of physical travel, thereby providing a substantial incentive for market adoption. If the FACES Program is successful, the United States will benefit from the positive externalities of decreased dependence on petroleum and therefore increased energy security, decreased energy-related emissions, and increased efficiency of communication-related energy expenditure.

To achieve these goals, the FACES Technologies must provide an experience that meets or exceeds the current benefits of in-person interactions. ARPA-E believes that technical advances in computer technology, sensors, displays, computer graphics, and information networks, all of which have changed the world in their own right, will allow this high-quality communication across any distance.

The FACES Program will focus on communication systems employing "Digital Humans". A Digital Human (DH) is a bandwidth-efficient, three-dimensional digital representation of a person that is nearly indistinguishable from the communication partner in real life.

These DH communication systems must provide highly natural and immersive communication that is preferable to physically travelling, and have the potential to be very low cost in their implementation so that the average person can afford to communicate in this way. ARPA-E has identified three critical elements to developing DH communication systems as means of decreasing energy consumption (note: the following is a summary - the Technical Categories of Interest in Subsection E, and Performance Targets in Subsection F, below are controlling for application submissions):

1. ARPA-E seeks advances in real-time motion capture and digitization of the full human form, coupled with the real-time reconstruction and display of the resultant full human likeness at the other end of an information network, yielding an audiovisually-realistic DH-based digital transportation platform.

2. ARPA-E seeks innovative, complementary advances in the requisite Technology components of real-time capture, digitization, reconstruction, and other related hardware and software tools deemed necessary for or conducive to digital transportation.

3. ARPA-E seeks innovative studies of travel-replacement thresholds, new metrics for realism and immersion of telecommunications systems, and for systematic evaluation of DH technologies.

FACES Technologies will be subject to rigorous and quantitative evaluation metrics, and must demonstrate progress towards meeting travel-replacement thresholds. The development and use of the travel-replacement thresholds for digital transportation will be an important contribution of this Program.

(Section IX of the FOA provides an explanation of terms and concepts used in this FOA.)

C. BACKGROUND

Transportation Energy Consumption and Emissions

Over one-quarter of the energy-related emissions in the United States emanate from the activities of the transportation sector,[2] and transportation energy consumption is expected to continue to increase for the foreseeable future (Holtberg 2016).

An unavoidable aspect of nearly all present-day transportation technologies is that the energy source must be carried onboard the vehicle. Gasoline powers most automobiles; diesel powers most heavy-duty trucks; and jet fuel powers most airplanes.[3]

The dominance of these liquid fuels is a result of their enormous energy density and low cost. At 32 MJ/l, the energy density of gasoline is more than an order of magnitude higher than that of lithium-ion batteries and nearly 1000 times higher than uncompressed natural gas.[4]

There is substantial opportunity to improve upon the existing transportation supply chain in order to reduce the energy use in transportation. In its short history, ARPA-E has made several such investments, focusing on electric vehicle batteries, natural gas tanks and compressors, lightweighting, alternative fuel production methods with low lifecycle emissions, and autonomous vehicle powertrains, among others.[5] These Programs sought to create transformative changes within the present paradigm of automobiles and liquid transportation fuels, and have made several important contributions to date.

[2] https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014
[3] http://www.eia.gov/Energyexplained/?page=us_energy_transportation
[4] https://en.wikipedia.org/wiki/Energy_density
[5] If further interested in ARPA-E transportation-related Programs, visit our webpage and search for BEEST, AMPED, MOVE, RANGE, LITECAR, Electrofuels, PETRO, REMOTE, TRANSNET, NEXTCAR or METALS.

Another viable approach is to consider how we could satisfy, with much less energy-intensive technologies, the public's demand for transportation. A high level dichotomy of transportation energy expense is that of moving things versus moving people.

1. Freight transportation results from a demand to have cargo physically exist in a place where it is not presently. This type of transportation is responsible for ~30% or 278 GW (8 quadrillion BTU/yr) of transportation energy expenditures.[6]

2. When people are transported, however, it is their presence that is demanded for one reason or another. Passenger transportation is responsible for ~70% or 568 GW (17 quads/yr) of transportation energy consumption.[5,7]

When presence is demanded it is either psychological or physical presence, or some combination of both. Our psychological perception of presence is the understanding of the environment and people therein that we derive through the eyes, ears, nose, mouth, and dermis. Our physical presence is our ability to use our bodies to interact with the physical environment. Both of these types of presence are very important, and in some cases very difficult to deconvolute.

For purposes of discussing the energy embodied in demand for passenger transportation, we propose a trichotomy based on these high-level objectives of passenger transportation:

1. Communication: We move from one place to another predominantly to convey or consume information, e.g. business trip, drive to office, etc.
2. Labor: We move from one place to another predominantly to interact physically with the environment, e.g. drive to factory, farm or restaurant, etc.
3. Experience: We move from one place to another predominantly to "experience", e.g. trip to the beach, the Pantheon, or a religious gathering.

In an attempt to ascertain how much energy the U.S. uses for each of the objectives outlined above, ARPA-E performed a detailed analysis relying heavily on the National Household Transportation Survey.[8] For more details regarding how this ARPA-E analysis was performed, please refer to the Advanced Telepresence Request for Information from September 29th, 2015 on the ARPA-E website.

Figure 1 shows the breakdown of transportation energy consumption in the United States for 2011. Our analysis indicates that, of United States total energy consumption, roughly:

[6] Freight Facts and Figures 2013. U.S. Department of Transportation. 2011 data. http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/13factsfigures/pdfs/fff2013_highres.pdf

[7] Transportation Energy Data Book: Edition 33-2014

[8] National Household Transportation Survey. U.S. Department of Transportation. 2009 dataset.

8% is associated with passenger transportation for communication (7.5 Q, 251 GW)
5% is associated with passenger transportation to experience (4.9 Q, 164 GW), and
5% is for labor objectives (4.6 Q, 154 GW), with some overlap between categories.

It is on this basis that ARPA-E considers communication technologies as potential energy-reduction technologies. If we can develop ultra-low energy communications technologies that are preferable to today's practice of driving or flying for the purposes of in-person communication, we could substantially alter the course of increasing passenger transportation and dramatically improve U.S. economic competitiveness and environmental sustainability.

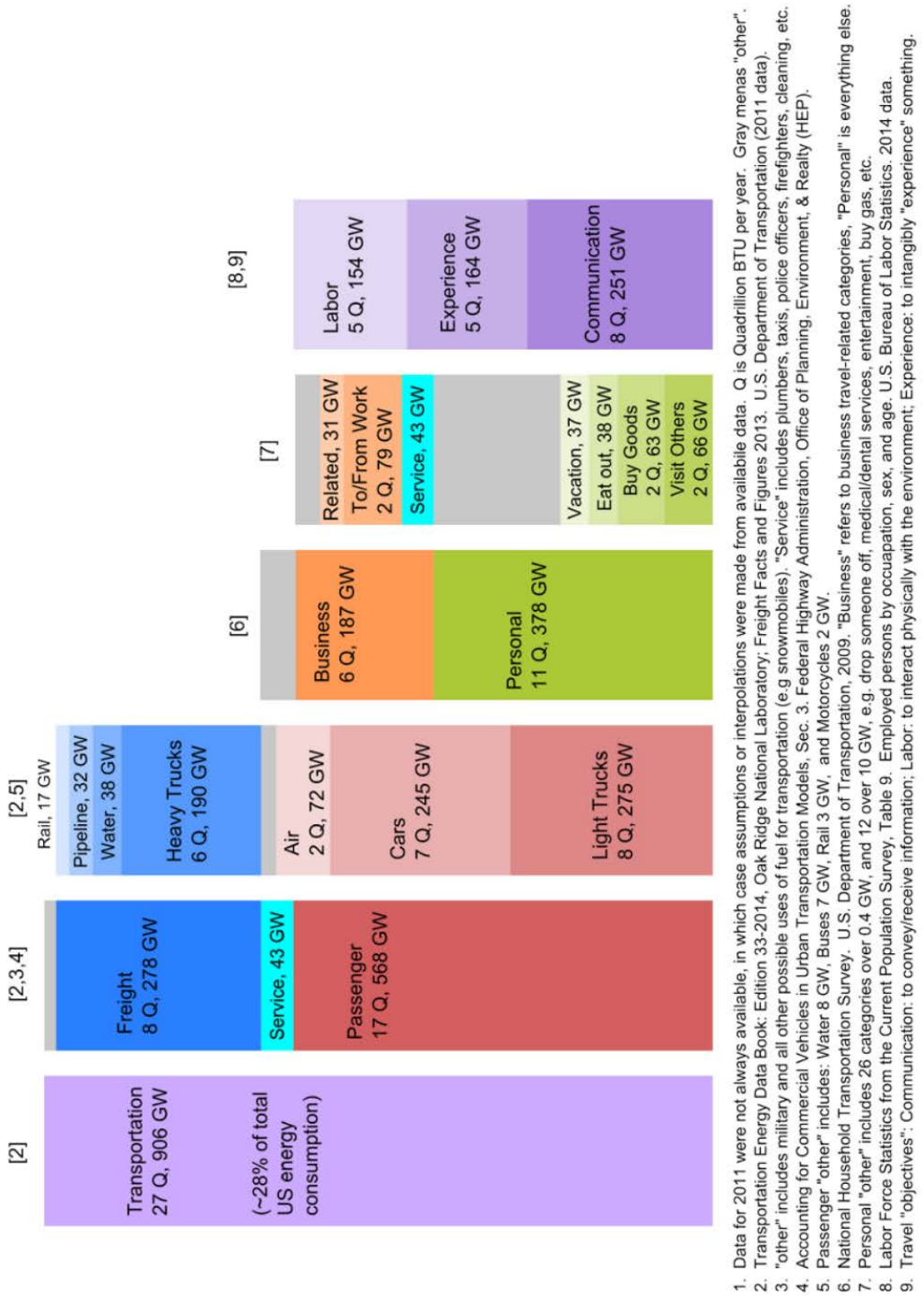

Figure 1. Transportation Energy Consumption, United States 2011

Telecommunications Technologies and Travel Behavior

There has long been the demand to alleviate the burdens of travel. Travel costs time, it costs money, and it is often uncomfortable. Generally speaking, efforts to avoid travel burdens can follow two courses: one may invent ways to make the travel less burdensome, that is, faster, cheaper, or more convenient and comfortable; or one may find ways to avoid it altogether. Telecommunication has long been viewed as holding promise in the latter category.

The electronic telegraph, for example, surely diminished some of the need to take horse and carriage to deliver messages in the late 19th century. But, of course, the telegraph didn't eliminate travel altogether. As telecommunication has improved, with transformational technologies like the telephone, televideo, and the internet, there was increasing enthusiasm regarding the possibility of eliminating face-to-face meetings (Owen 1962; Harkness 1977; Murtishaw et al. 2001; van Wee 2015).

Over the same time period, there was a commensurate transformational improvement in passenger transportation technologies. In the 20th century alone, the world witnessed global proliferation of trains, automobiles, and planes. It is now possible, and frequently practiced, to travel across the United States and back in one day for a business meeting. A similar trip in the early 1800s would have taken several months. As transportation technologies continue to get faster, more comfortable, and more efficient, one would expect them to continue to be used more[9]. And, indeed, history shows as transportation technologies improved, miles traveled per capita and time spent travelling rose dramatically (Mokhtarian 2009).

Telecommunication and transportation technologies can therefore be seen in part as competing technologies, though in part they also augment each other (Mokhtarian 2009). Global commerce, for example, relies heavily on telecommunication to function. It also stands to reason that the additional connections made across the globe by our communication technologies have prompted additional need to travel long distances. In fact, long-distance business travel has grown to 1% of total U.S. energy use.[7]

A fundamental question remains regarding our desire to travel for in-person communication. Could there exist a telecommunication technology that we would prefer to physically travelling in most cases? If so, what minimum technology characteristics would be required to most effectively replace communication-related travel? If there existed a technology that would surpass this postulated travel-replacement threshold in a given circumstance, we would call it a digital transportation technology.

This question has not yet been answered definitively, and ARPA-E hopes to investigate it thoroughly with this Program. We have substantial reason to believe that such future advances

[9] https://en.wikipedia.org/wiki/Jevons's_paradox

in telecommunications could make considerable headway in decreasing passenger transportation.

Digitizing Human Communication

Numerous studies seek to explain the limited ability of telecommunications technologies to replace in-person interactions. In general, they have hypothesized that telecommunications systems lack: 1) a true sense of presence one typically feels when co-located in a physical environment with other individuals; 2) the technical characteristics required to achieve an immersive environment which eliminates distractions from physical reality, thereby achieving the same level of focus one has in a face-to-face meeting; and 3) the fidelity of interaction between participants to achieve the naturalness and ease of conversation inherent to face-to-face communication (Kock 2004; Youngblut 2003).

Achieving presence, the psychological sense of being in an environment, requires that participants "experience the [virtual environment] as the more engaging reality than the surrounding physical world and consider the environment specified by the displays as places visited rather than as images seen." (Slater & Wilbur 1997) To meet this standard of presence, a telecommunications technology must facilitate social presence (awareness of the other person) (Biocca et al. 2003), spatial presence (awareness of the environment) (Steuer 1992), and self-presence (awareness of one's own self). (Cummings et al. 2015; Aymerich-Franch et al. 2012) In particular, social presence requires the ability to build connectedness and intimacy between individuals via sharing both verbal and nonverbal cues. The transference of information through conveyance of facial expressions, body language, vocal cues, gestures, etc. is generally understood to enable the communicating parties to engage in high value communication objectives not readily accomplished using just text or voice-based modalities (Bente 2008). Common scenarios that are difficult to accomplish with current telecommunications systems include building trust, communicating feelings, resolving conflicts, negotiating contracts, and exchanging sensitive information (Standaert et al. 2015).

Required for presence is a high degree of immersion facilitated by the technological characteristics of the communications modality (e.g. cell phone, monitors, commercial 3D displays, etc.). Achieving immersion requires eliminating distractions from the surrounding physical environment (Slater & Wilbur 1997) by enhancing specific technological aspects. Such characteristics include: field of view, scale, and resolution of the display; sound quality; update rate; user perspective; stereoscopic vision; tracking-level of the users, etc., and are easily measured by quantitative analysis (Cummings et al. 2015).

In contrast to the independent quantitative and psychological definitions of immersion and presence, naturalness aims to combine the features into a comprehensive, unifying theory. Inherent to achieving a natural telecommunications experience are 5 key features which can be directly mapped to technology characteristics (Kock 2004): 1) colocation, requiring spatial

audio, realistic interpersonal distance, agency of the user; 2) synchronicity, the quick or immediate exchange of communicative information, requiring low latency communication; 3) conveyance and observance of facial expressions, requiring shared gaze and high fidelity microexpressions; 4) conveyance and observance of body language, requiring posture, hand movement & expressions; and 5) conveyance and interpretation of speech, requiring high sound clarity, accurate voice timbre.

While presence, immersion, and naturalness are interconnected, each is necessary to comprehensively capture the required components of telecommunications.

The wealth of literature on these topics is consistent with efforts in the telecommunications industries to meet these requirements. For instance, audio quality has steadily improved with high-definition (aka 'wideband', 'superwideband', and 'fullband') audio now available on some networks and devices. Higher sampling rates and bit depths encompassing a wider range of speech frequencies have advanced sound quality beyond the 8 kHz sample rate and 8-bit depth commonly used for landline telecommunication (ITU-T G.711), reducing overlapping conversation and the cognitive load associated with differentiating between similar sounds (Cox et al. 2009). Enhanced video capabilities have been incorporated to convey the verbal and nonverbal cues thought necessary for intimate communication. State-of-the-art videoconferencing, such as the CISCO™ IX5000 Telepresence system[10] (first announced in 2014), can now transmit verbal and nonverbal cues using high-quality, 1080p60 video transmitted at data transmission rates of greater than 10,800 kbps, compared to 128 kbps required for low-quality video conferencing. Larger screen sizes also depict users as life-size, and additional functionality enables eye contact between participants. The enhanced presence and naturalness enabled by larger displays and higher quality video was shown to move the efficacy of the system closer to face-to-face communication in some instances (Standaert 2015). However, significant limitations still prohibit a truly natural experience: depiction of individuals is limited to the waist-up, other participants are displayed only in 2D, and the environment is only that portrayed on the screen. Despite increased utilization of more advanced videoconferencing systems, the required capital investment, high bandwidth connections, and dedicated infrastructure limits more wide-scale adoption.

Virtual environments, such as Linden Lab's Second Life™[11], have also enabled digital communication. These platforms require much less bandwidth than videoconferencing by representing the users as digital, animated characters. The effects on communication (attention, trust, collaboration, etc.) influenced by incorporating digital representations of users has been widely studied with varying results. We direct the reader to the numerous review articles citing and cited by Bente et al. (Bente 2008). However, a key limitation of virtual

[10] ARPA-E has included the names of products and companies in this FOA to illustrate the current state of the art in this field. Inclusion of these trademarks is not a government endorsement of the trademarked products or company names, and trademark owners have not endorsed the purpose of the FACES FOA.
[11] http://secondlife.com/

environments is the absence of realistic representations of the user and other communicating participants, limiting the ability to achieve true self- and social presence.

More recently, similar systems have been developed using head mounted displays, enabling higher degrees of presence and immersion in a 3D environment (Bailenson 2016). Higher immersion is attributed to the increased ability of 3D systems to eliminate distractions from the surrounding physical environment. Enhanced social presence is facilitated by the ability to see a full individual in 3D, interact collaboratively, and manipulate the 3D environment. In fact, the recent "Dell and Intel Future Workforce Global Study" found that 66% of global employees would be willing to use virtual or augmented reality in their professional lives (PBS Research 2016).

To merge the level of immersion capable in 3D environments with the visual fidelity of information transferred by high-quality video, we look towards developing a DH with the necessary qualities of photorealism, human-like representation, and behavior consistent with the levels of fidelity expected from in-person interactions. In a 3D environment, developing a realistic DH enables higher degrees of naturalness by more realistically conveying body language, facial expressions, and hand motions. Also allowed is interaction between participants, achieving necessary abilities like variation of interpersonal distance, eye contact, collaboration on challenging tasks, etc. In a 2D environment like a digital display, the DH inherently requires less bandwidth than 4k video.

Fully digitizing all aspects of the animated communicative human form could yield tremendous progress towards replacing travel with digital transportation technologies.

State of the Art of Digital Human Construction and Animation

Tremendous strides have been made in the art of performance capture and digitization of humans in the gaming and film industries over the last two decades. Gamemakers and filmmakers who employ digital graphics characters have pushed the boundary of what is technically feasible in realism, naturalness, and rendering of humans to achieve better entertainment experiences for their audiences. It is important to note that these industries are not bound by the constraint of real time visualization or operation in the same way a communication technology is, as their goal is primarily to produce entertaining content that is consumed with at most minimal interaction (for example, through a game controller). Therefore much of their graphics work is done ex situ by graphics engineers and rendering farms out of convenience.

Research towards a true DH has yielded compelling prototypes, which have demonstrated the ability to capture the state of a performer with very high fidelity, both statically and dynamically. Generally, the performer is detected by some array of sensors, digitized as a set of blendshapes corresponding to a prefabricated, high-fidelity rig of the performer, and then later

reconstructed in a digital environment for display. Modern graphics cards have demonstrated the ability to reconstruct and display a DH in real time[12].

For example, the Digital Ira project, developed by The Institute for Creative Technologies at the University of Southern California in conjunction with NVIDIA™ and Activision™, serves as one of the most photorealistic DH models demonstrated to date (Figure 2). Numerous research groups have built on this realism by developing effective wrinkle modelers (Cao et al. 2015, Nagano et al. 2015), gaze trackers and compensators (Kuster et al. 2012), and hair modelers (Luo et al. 2013).

Challenges remain in translating these DH prototypes into a digital transportation platform. Capture methods sometimes require cumbersome sensor configurations or markers, digitization is sometimes done ex situ from the performance capture data, hair is often omitted, only select parts of the body are captured in high fidelity, precise mouth movements are lacking, and details around the eyes and mouth during expressions leaves something to be desired. Advances in all of these areas are required to achieve a DH-based digital transportation technology.

Figure 2. Digital Ira represents the state of the art for extremely high quality digital human representation. For more information see http://ict.usc.edu/prototypes/digital-ira/.

[12] NVIDIA GTC 2013 Keyonte: https://www.youtube.com/watch?v=5d1ZOYU4gpo

The principle behind using DHs in a communication platform follows a generic workflow that applies to all telepresence platforms. Figure 3 shows this workflow schematically. This 7-step process consists of capture, digitization, network upload, server-side operations, network download, reconstruction, and display. The network upload and download steps are assumed to follow internet protocols and will not be discussed or investigated as part of this FOA.

Experts in a variety of industries have made tremendous progress in each of the remaining steps. The following is an attempt to describe the state of the art of each as it pertains to the objective of creating a DH-based digital transportation platform. This summary does not capture all of the salient work that has been done in this space. ARPA-E expects Applicants to familiarize themselves with all prior art relevant to their submission, and requires submissions to represent substantial contributions to advancing the state of the art, not merely incremental improvements.

Capture

Static capture of a subject and rigging of a DH is mature art with many methods available. The Digital Ira project is one example (Alexander et al., 2013) of high quality capture and construction of a DH from a Lightstage™[13]. Other lower fidelity examples, which still require improvement, include using multiple low-quality photographs from a camera phone (Cao et al., 2016) and using 2D video footage (Ichim et. al, 2015). ARPA-E will focus primarily on motion capture (mocap) for this FOA.

The entertainment industry has a number of solutions for capturing the movements, gestures, and general state of a performer. Commonly used body-mounted capture devices require a number of fiducial markers to be placed on the face and body, e.g. those from Vicon™[14], PhaseSpace™[15], OptiTrack™[16], etc. Rooms can be fully instrumented with mocap sensors, offering large performance areas and the potential for tracking several people concurrently. While these mocap systems have matured and yield excellent precision, structured environments and fiducial markers present a challenge for wide proliferation of DH communication platforms. The ideal mocap system would not require any structuring of the environment or modification of the performer. Markerless mocap systems have been demonstrated with reasonable quality, for example researchers have used commodity-grade digital cameras employing machine vision, Microsoft Kinect™, and Intel RealSense™ to capture motion information for digitization. Purpose-built mocap sensors have been made to capture hand movements, e.g. Leap Motion™. Eye gaze tracking sensors have successfully been demonstrated inside head mounted displays by Fove and others. Markerless mocap still requires substantial improvement to yield the accuracy and precision ARPA-E believes is necessary.

[13] https://home.otoy.com/capture/lightstage/
[14] https://www.vicon.com/
[15] http://www.phasespace.com/
[16] http://optitrack.com/

1. Capture	2. Digitization	3. Network Upload	4. Server-Side Operations	5. Network Download	6. Reconstruction	7. Display

Figure 3: The Digital Transportation workflow requires these seven steps to be performed in series. The capture-to-display latency must be below values that make humans uncomfortable when communicating, which have been shown to be around 150 ms (International Telecommunication Union, 2003).

Digitization

The digitization step takes raw captured data and turns it into sensible instructions for a computer on the other end of an information network to reconstruct the DH. Some methods for static digitization of a person are well developed, such as those used in the Digital Ira project. The most mature methods employ deep knowledge of human facial expressions, e.g. the Facial Action Coding System (FACS) poses (Hjortsjo, 1970; Ekman and Friesen, 1978) to generate a "basis set" of blendshapes that can be weighted to construct any facial geometry in combination. Simply transmitting blendshape weights for reconstruction dramatically reduces bandwidth requirements of high quality visual information transmission. Other methods employ a musculoskeletal model of the head anatomy to yield high quality static digital representations of people, such as those used in the BabyX project (Sagar et al, 2014) and to reconstruct faces for forensic analysis (Wilkinson 2004). These methods may have the advantage of more natural facial expression and the capacity for predictive modeling of dynamic facial physics to smooth out short network disruptions.

Digitization of motion capture information is less advanced. Digital Ira, for example, used 6 video feeds for markerless mocap, yet calculated blendshape weights ex situ. Calculating optimal blendshape weights in real time has proved to be challenging computationally, and diminishing returns on communication experience in relation to the tradeoff between blendshape-weight accuracy and digitization latency have not been explored. Additional digitization methods to increase realism and naturalness include wrinkle modeling, skin modeling, and hair modeling. ARPA-E expects substantial improvements to the state of the art in real time digitization will be required to achieve the levels of realism and naturalness called for by the FACES Program.

Server-side operations

The backbone of a functional end-to-end DH communication system is the server that manages the digitized information flowing to and from various clients. Information can be simply "passed through", as is primarily the case with 2D televideo codec transmission services like Skype™, Facetime™, Hangouts™, etc. In more complicated communication environments, such as those developed by SecondLife™, AltspaceVR™, and HighFidelity™, more operations are performed on the server. These include reconciling virtual physics, adding virtual effects or objects,

correcting gaze and other virtual "fixes", and yield customizable, highly interactive, server-hosted virtual environments for communication.

Reconstruction

When digitized information is received over an information network, it must be reconstructed into a DH that is real and natural enough to provide a high quality communicative experience. This step is intimately tied to the digitization step, as they must cooperate to display the captured information in an agreeable form to an observer. Graphics processing is essential for effective reconstruction of the real-time DH model, which requires substantial computing power. Modern graphics processing has demonstrated the ability to reconstruct characters based on digitized instructions in extremely high detail in real time on consumer hardware. Graphics processing is now cheaper and more efficient than ever before; the average cost per gigaflop of computing power has continued its exponential decrease for the last 70 years (Nordhaus, 2007), and energy required for this computation has continued to decrease exponentially over this same period (Koomey et al, 2011). For this reason, we believe that graphics computational power per watt will proceed to levels necessary for future digital transportation systems without ARPA-E investment.

Display

The display of audiovisual information to an observer using a digital transportation platform should be, to a large extent, consistent with the display of entertainment content. Display technology is advancing at a rapid pace, and ARPA-E expects that all commercially available display technologies are on a development path that does not need further government investment. These include, but are not limited to, high definition 2D displays used for monitors, cell phones, and televisions, consumer 3D displays, closed-view head mounted displays like the Oculus Rift™ and the HTC Vive™, open-view augmented reality displays like the Microsoft Hololens™, virtual reality cave and projector technologies, and several others. ARPA-E believes there are underfunded display categories that are not currently commercially available, such as true holographic displays, direct retinal projection, true light field displays, and displays that have features such as the ability to occlude bright real-world objects in an augmented reality display scenario. Future display concepts are expected to be necessary to solve inherent problems or inconveniences associated with commercially available display technologies, such as the vergence-accommodation conflict (Hoffman et al., 2008) or the necessity to wear a display as is the case with all modern head mounted displays.

D. PROGRAM OBJECTIVES

The FACES Program aims to accelerate the development of photorealistic, low cost, natural and immersive DH communication systems that people would prefer to use rather than physically traveling for communication purposes, thereby obviating the energy and emissions associated with travel for in-person communication and improving U.S. energy and economic security.

ARPA-E believes that significant energy and emissions reductions via digital transportation are within reach given recent advances in energy efficiency of information networks; cost reductions in computer hardware and dramatic increases in processing and computational power; decreasing display costs and increasing display quality; and an increased understanding of how computer graphics technology can create lifelike digital representations of humans in natural motion.

The FACES Program will focus solely on communication systems employing DH, as opposed to high-resolution 2- or 3D video transmission. The potential advantages of DH-based communication systems are as follows:

1. **High bandwidth efficiency:** only minimal data detailing how to move the DH is required to convey communicative information
2. **Eye contact, gaze**: effectively simulate gaze angle and shared gaze, allow for communication through the eyes
3. **Convey detailed facial expressions**: detailed facial reconstruction in real-time will allow for accurate communication through facial expressions and microexpressions
4. **Posture:** full-body reconstruction will enable greater use of postural communication
5. **Body language**: full body motion capture will enable communication through gestures and other body language
6. **User agency**: users gain the ability to move themselves in a virtual space and change viewing perspective or location
7. **Interpersonal distance**: ability to choose interpersonal distance with DH is communicative
8. **Scalable display resolution**: the DH reconstruction can be scaled to arbitrarily high display resolution without increasing transmission bandwidth
9. **Inherently a 3D object**: a DH by definition exists in the same dimensionality as real life
10. **Immersive display**: 3D digital representations are conducive to immersive audiovisual displays
11. **Cross-platform compatibility**: a DH can be immersed in a 3D virtual space (e.g. a conference room) or displayed on a 2D screen like traditional televideo
12. **True-to-life representation**: viewing angles and lighting can be rendered digitally so one is not constrained to specific view angles or poor lighting that can lead to unflattering representations

The DH-based communication systems to be developed in the FACES Program must provide highly natural and immersive communication, be preferable to physically travelling, and have the potential to be very low cost so that average people could conceivably afford to communicate this way.

Specific objectives of the FACES Program are:

- **Increase realism of digital humans**: ARPA-E seeks to increase the extent to which a DH-based communications platform can reproduce the interactions inherent in face-to-face

communication. A critical component is the development of a photorealistic DH, captured, digitized, and rendered in real-time. Technologies proposed in FACES should have the ability to capture and display a full human that is perceived as true-to-life.

- **Ensure decreased transportation energy and emissions**: Of essential importance is that users would prefer the FACES method of telecommunication over physically travelling. Adoption of such communications platforms requires a substantial increase in the naturalness of DHs to nearly perfect levels, though a quantitative description of diminishing returns on perceived quality does not exist. Parallel evaluation of FACES Technologies is necessary to assess likelihood of adoption and likelihood, if adopted, to replace travel. The FACES Program will explore individual communication Technology characteristics to correlate levels of realism, immersion, and naturalness to the likelihood of user adoption and travel replacement.
- **Enable real-time motion capture and digitization of digital humans**: ARPA-E expects motion capture and digitization to be done in real-time with extremely high quality and accuracy. For interpersonal communication, there exists an expectation of simultaneity which requires digitization computations to be performed extremely quickly. The motion capture technologies are expected to have the ability to be integrated into a display, and the performance area must be commensurate with the display viewing area. For instance, while it is not uncommon to have a conversation while sitting at one's desk, the Technology should consider the possibility that the sitting person may stand or move around during the course of such a conversation while still in view of the display.
- **Increase immersion of digital transportation systems**: The DH communication Technologies developed under the FACES Program should enable a sense of presence or of "being there" in a digital environment in a fashion that "shuts out physical reality" (Lombard & Ditton 1997). FACES seeks to advance these specific technical components which include, but are not limited to, tracking-level, field of view, sound quality, update rate, user perspective, resolution, and stereoscopic vision.
- **Increase presence in digital systems**: The DH communication Technologies should enable a sense of presence in the digital environment, presence with other users of the environment, and self-presence, maintaining awareness of oneself within the environment. Achieving the multiple dimensions of presence is predicated on the fidelity of the DH and the immersion characteristics of the platform.
- **Develop quantitative "travel-replacement thresholds"**: ARPA-E is interested in developing a set of quantitative travel-replacement criteria which a DH communication platform must meet in order for people to choose it over traveling for communication purposes. These thresholds will serve as guidance for FACES Technology developers to focus their efforts in the second year of the Program.
- **Decrease system cost**: Adoption of digital communication Technologies requires that the commercial cost must be able to be equal to or less than today's widely adopted consumer telecommunications technologies if they were to reach high-volume production scale (e.g. personal computers, home televisions, cell phones, etc.).

- **Ensure interoperability**: The Technologies funded under FACES must be portable across current or anticipated hardware and software. This includes, but is not limited to, commercially available displays, head-mounted displays, graphics cards, operating systems, computer chipsets, virtual world platforms, gaming engines, etc.

E. TECHNICAL CATEGORIES OF INTEREST

ARPA-E seeks to fund innovative approaches to generate low-cost, natural and immersive DH communication systems that obviate the need for travel-related energy use in a substantial number of cases. In order to achieve this goal, ARPA-E has identified three Technical Categories of Interest:

1. Real-time capture, digitization, and reconstruction of a human
2. Complementary digital transportation Technologies
3. Travel-replacement Thresholds and Technology Evaluation

Category 1: Real-time capture, digitization, and reconstruction of a human

General description: Advances in real-time markerless capture, digitization, and reconstruction of a full human in motion are essential to decrease transportation-related energy usage. We expect solutions will need to meet or exceed the naturalness and immersion of in-person communication in order to displace travel. Applicants applying to Category 1 may propose either a technology demonstration project with a period of performance up to 36 months or an initial proof of concept demonstration project with a period of performance of up to 18 months. Projects that demonstrate significant success may have the potential to receive follow-on funding, subject to the availability of funds..

Category 1 requires:

- Markerless capture and digitization of a participant's physical likeness and movement, with strong emphasis on capturing and accurately reproducing the face in live motion
- Network upload, transmission, and download
- Reconstruction and display of a participant's likeness maintaining a high level of naturalness at high display resolution, in real time

Solutions proposed in Category 1 are expected to incorporate, at a minimum:

- Real-time markerless capture of nonverbal behavior: e.g. facial expressions (including microexpressions), head and body movement, posture, gestures, etc.
- Gaze direction and shared gaze
- Potential for display-integration of capture technology in future displays
- Capability to capture under variable lighting with moving subject in defined space

- Accurate mouth and tongue movement
- Real-time reconstruction of all non-occluded body parts relevant to verbal and nonverbal communication
- Real-time reconstruction and display of high-resolution facial features (e.g. wrinkles, hair, pores, mouth, and accurate tongue behaviors)
- Ability to immerse a DH in any lighting environment, to include skin translucence effects based on subsurface scattering, accurate diffuse and specular lighting interactions for multilayer skin structure
- Ability to port into environments with a large number of participants
- Portability across multiple display modalities – e.g. two-dimensional displays of various sizes, stereoscopic displays, light field displays, etc.
- Ability to integrate into virtual environments
- Highly bandwidth-efficient transmission

Applicants may consider a priori capture and building of a digital model; if so, approaches to generating and updating these models should be discussed.

Testing of Category 1 Technologies will require:

- Demonstration of high quality, real-time, bidirectional communication between two people through DHs using several different display modalities
- Demonstration of high quality, real-time, bidirectional communication for a group of five DHs using several different display modalities
- Evaluation of DH Technologies using in-house capabilities or those of an independent third party
- Demonstration of progress towards meeting the travel-replacement thresholds determined by ARPA-E, which may be determined based on research outcomes performed by Category 3 Awardees
- Initial hypothesis for commercialization strategy, including target customer, value proposition, barriers to adoption, and required partner ecosystem for productization and adoption

Category 2: Complementary digital transportation Technologies

General description: Additional Technologies may be beneficial or necessary to the ultimate success of digital transportation displacing physical travel. Category 2 seeks Technologies that will complement developments from Category 1, which the applicant argues will substantially increase the likelihood of technology adoption and associated travel reduction. Submissions to Category 2 must represent dramatic and unequivocal advances to the state of the art. Applicants applying to Category 2 may only propose an initial proof of concept demonstration project with a period of performance of up to 18 months and a budget of less than $1M.

Projects that demonstrate significant success may have the potential to receive follow-on funding, subject to the availability of funds.

Of specific interest in Category 2 are Technologies which accelerate the development of digital transportation and realize the objectives of FACES. ARPA-E will consider complementary component-level advances in the digital transportation workflow (i.e. one, or a combination of: capture, digitization, server-side operations, reconstruction and display).

Examples of such Technologies of interest in Category 2 may include and are not limited to:

- **Capture**: Advanced markerless capture of the body's state, such as technologies and interfaces to recognize and convey extra-sensory information (pulse, tone, level of interest, attentiveness, etc.), non-visual means of capturing body state (e.g. audio extraction of facial features)
- **Digitization**: Novel methods for data reduction or augmentation of the captured content
- **Server-side operations**: physics models of interaction, 3D or 360 degree immersive video transmission-based communications solutions with extremely low bandwidth usage
- **Reconstruction**: occlusion solutions, optimized apportioning of server-side machines for increased DH-based communications performance, predictive modelers for expressive facial behavior, high fidelity skin, hair and clothing modeling
- **Display**: holographic displays, technologies to avoid vergence-accommodation conflict or other display inadequacies (e.g. lightfield displays), incorporation of local surroundings
- **System integration and usability**: technologies for translating additional senses (e.g. scent); technologies for easily creating and manipulating extremely high quality DHs, worlds, or objects with minimal cost and effort

N.B. The examples provided above are purely illustrative and not meant to prescribe or limit the scope of proposed advances. ARPA-E may make one, multiple, or no awards that qualify as complementary advances to digital transportation objectives.

Applicants in Category 2 are required to describe:

- The potential impact that the proposed project would have on the FACES objectives
- The proposed Technology, including its basic operating principles, how it is unique and innovative, and why it represents a substantial improvement over the state of the art.
- The proposed Technology's target level of performance (Applicants should provide technical data or other support to show how the proposed target will be met)
- A path towards integration with Category 1 efforts for bidirectional communication
- The current state-of-the-art in the relevant field and application, including key shortcomings, limitations, and challenges

- How the proposed Technology will overcome the shortcomings, limitations, and challenges in the relevant field and application
- The key technical risks/issues associated with the proposed Technology development plan
- Why ARPA-E funding is needed for the success of the proposed project
- Initial hypothesis for commercialization strategy, including target customer, value proposition, barriers to adoption, and required partner ecosystem for productization and adoption

Category 3: Travel-replacement Thresholds and Technology Evaluation

General description: Despite the expanse of literature examining how interpersonal interaction varies in digital environments and what characteristics are necessary to achieve communicative levels which meet those of face-to-face communications, no studies have systematically evaluated how to achieve reduction of travel. In fact, as more immersive telecommunications technologies have achieved higher market penetration, U.S. travel per capita has continued to rise. Thus, ARPA-E aims to determine what qualities are necessary to reduce travel per capita, not purely sustain user adoption. Applicants applying to Category 3 may propose a technology demonstration project with a period of performance up to 36 months. Projects that demonstrate significant success may have the potential to receive follow-on funding, subject to the availability of funds.

Reducing travel is dependent on the ability of a communications technology to achieve the types of communications that still necessitate face-to-face interactions. While text-based and video-based modes currently allow participants to accomplish tasks, routinely exchange information, and find solutions to problems, these technologies are limited in their ability to facilitate building trust, communicating feelings, resolving conflicts, negotiating contracts, and exchanging sensitive information (Standaert et al. 2015). Furthermore, conversations between groups of people necessitate sharing of communicative information in ways that may differ from requirements of one-on-one communication.

ARPA-E seeks submissions which leverage state-of-the-art digital communications and travel behavior research. Category 3 Awardees' research may independently and objectively inform the Technology development paths of Category 1 and Category 2. Specifically, ARPA-E is interested in determining which technical aspects of a digital communications system are most strongly correlated to likelihood of adoption, sustained utilization, and resulting reduction of travel. Category 3 Awardees will be expected to assess technical and communicative aspects of interaction between 2 - 5 users of a digital communications system.

The aims of the Technology evaluation are to:

1. Define travel-replacement thresholds by identifying the minimum set of characteristics digital communications technologies must exhibit to replace face-to-face communication to satisfy various communication objectives
2. Quantify the realism of the DH and immersion of the communications modalities against characteristics defined by the travel-replacement threshold(s)
3. Assess likelihood of sustained user adoption and correlated impact on travel behavior via real-world longitudinal user acceptance studies

1. Travel-Replacement Thresholds:
ARPA-E aims to develop a system with a path to reduce travel in business environments by 25% (for instance: 1 week/month travel replaced by digital communications or 25% of employees exclusively using digital transportation). Reduction of travel-related energy and emissions to this extent requires defining the characteristics necessary to increase the likelihood of a participant to use DH Technologies in such a manner.

Examples of relevant questions that may require further research include:

- What limits adoption and use of current telecommunications technologies?
    - e.g. Why do individuals prefer to face-to-face communication and the qualities inherent to such communication?
- Why don't current telecommunications technologies reduce travel?
- What is necessary in a telecommunications technology to replace at least 25% of communication-related business travel?
    - How do specific characteristics differ based on the communications objective, related to the specific task, number of people, etc.?
- How can DH Technologies meet these requirements?
- What are key Technology characteristics and limitations correlated to participant adoption?
    - e.g. How necessary is conveyance of microexpressions, hand gestures; body language, etc. in building trust and having difficult conversations?

2. Naturalness assessment of DH communication system:
Achieving a quantitative threshold to replace travel is predicated on a realistic DH appearing and behaving in a natural manner and the communications system achieving a sense of immersion such that the participant is unaware that the immediate environment is mediated by a Technology platform.

To date, no group has achieved a fully realistic DH to enable an understanding of its impact on telecommunication. To evaluate progress towards the levels of realism defined in Category 1, new methodologies of realism evaluation are expected. These include qualitative studies such as self-report and quantitative procedures using measurable cognitive and physiological parameters. Quantitative evaluation can provide more nuanced information on user interaction and relative efficacy of the telecommunications system. For instance, one can imagine

systematically varying DH realism to evaluate user trust based on cognitive processing and physiological measures.

Immersion and presence studies have been more widely implemented to study the ability of a communications platform to achieve the fidelity of face-to-face communications. We direct the Applicant to references in this FOA for state-of-the-art studies and meta analyses assessing these areas. Over the course of the project, Awardees will be expected to evaluate DH Technologies using systematic evaluation of Technology characteristics such as tracking-level, field of view, sound quality, update rate, user perspective, resolution, stereoscopic vision, etc. Similar incorporation of quantitative and qualitative measures is expected when evaluating such characteristics.

Over the project period, Awardees are expected to:

- Define a baseline comparison utilizing state-of-the-art technologies and well-defined communications evaluation methods
- Systematically evaluate state-of-the-art DH realism and identify limitations and requirements to achieve full realism
- Provide independently and objectively determined metrics to ARPA-E to guide realism evaluation
- Provide independently and objectively determined metrics to ARPA-E to guide naturalness and immersion evaluation of the digital communications systems
- Assess viability of metrics across different communications objectives (e.g. communicating information, giving instructions, building trust, carrying out tasks, etc.) and different-sized user groups (2 - 5 users)

3. Ensure Progress towards Travel Replacement:

As Technologies advance to meet the Program goals set forth in Category 1 and 2, real-world evaluation and longitudinal studies are required to assess the impact of virtual environments on users, fidelity of the communications, and the ability of the platform to achieve 25% travel reduction. Evaluation of Category 1 and 2 Technologies may be offered by Category 3 Awardees in real-world environments (e.g. university, corporate, government offices, etc.) with a user base indicative of potential future adopters.

F. TECHNICAL PERFORMANCE TARGETS

Only Technologies with the potential to be transformational and eventually meet or exceed the FACES Program objectives will be considered for funding.

Category 1: Real-time capture, digitization, and reconstruction of a human

Submissions for Category 1 funding should constitute complete DH-based communication systems built upon substantial advances to the state of the art in real-time motion capture, digitization, and reconstruction of DHs.

Table 1: Category 1 Technical Performance Targets

Metric	Description	Target
Capture and Digitization		
1.1	Motion capture	• Full body, including detailed face, mouth, hands, and limb tracking • No mocap dropouts or hanging (may require multiple sensors, predictive models, etc.)
1.2	High tracking accuracy	• Near perfect capture of position and orientation of head, arms, torso, legs, feet, hands and fingers, to be accurate enough to convey all communicative information and not feel uncanny • No applied or worn markers allowed for operation
1.3	Ease of use	• Potential for future integration of fundamental capture technology into future display unit • Capability to perform without wearables, tracking aids, or controllers
Reconstruction and Display		
1.4	Reconstruction resolution	• Real time rendering capability for 1 arcminute resolution display at up to 120 Hz (intended to be beyond perceptual limits, cf. Messina 2006)
1.5	DH Realism	• Behavioral, anthropomorphic, and photorealism traits nearly identical to face-to-face communication, specific to each individual participant

		• Appropriate response to display environment lighting (subsurface scattering, specular/diffuse maps, light bounce behavior)
1.6	Cross-platform compatibility	Demonstrated integration with at least 3 of: • monitor or television (4k or higher resolution) • tablet or smartphone • head-mounted stereoscopic display • novel display device
1.7	DH integration	Must develop an installer for each display modality, including any necessary dependencies, such that users are able to conveniently use the communication system without having to purchase licensed software.
System Constraints		
1.8	Commercial integration	• Power or charge from US 110 V AC power supply • Compatibility with enterprise operating systems for each display modality (Windows 7 or greater / Mac OS X or greater for PCs, iOS 9 or greater / Android 5.0 or greater for mobile devices, as appropriate for other modalities)
1.9	System Capture-to-display latency	• < 150 ms for transmission of one DH across continental US from coast to coast (each direction, including 'last mile' communications) ○ 50 ms budget for data transmission ○ Applicants should explain the breakdown of the remaining 100 ms (including capture, digitization, server-side operations, reconstruction, and display)
1.10	Bandwidth	• < 1 Mbps (megabit / sec) for transmission of one fully audiovisually-encoded DH during runtime ○ high definition spatialized audio budgeted at about 0.5 Mbps
1.11	System Cost	• Consistent with comparable consumer electronics products costs at scale • Anticipated commercial or specialized component costs should be provided
1.12	Platform Capabilities	• Demonstration of natural communication between 2-5 users, represented as individualized DHs

Category 2: Complementary digital transportation Technologies

Submissions to Category 2 may reflect numerous complementary advances in component Technologies or new paradigms in digital communication identified as necessary to realize the travel reduction objectives of FACES. Submission to Category 2 must represent dramatic and unequivocal advances to the state of the art. Successful Applicants will provide a detailed description of their proposed Technology, arguments as to why this Technology is necessary and why it will matter if successfully developed, and specific Technical Performance Targets they aim to achieve over the project award period. ARPA-E Technologies must represent substantial improvements over state of the art, and cannot be merely incremental advances.

In addition to proposing specific Technical Performance Targets, Applicants must also address these Technology features:

Table 2: Category 2 Technical Performance Targets

Metric	Description	Target
2.1	System Cost	Provide the expected cost at scale of a fully installed system with justification
2.2	Interoperability	Describe how the Technology integrates with other hardware and software components of a digital communications platform
2.3	Energy Reduction	Provide an argument as to why one would expect a reduction in travel as a result of achieving the proposed innovation
2.4	Immersion, Presence, Realism, Naturalness	Describe relevant Technology characteristics that will achieve a higher sense of immersion, presence, realism, and naturalness and an argument as to why the proposed Technology will provide for a better communicative experience and enhanced adoption.

Category 3: Travel-replacement Thresholds and Technology Evaluation

In Category 3, multidisciplinary Applicants will be required to assess the efficacy and impact of DH Technologies throughout the life of the Program, to include developing an Evaluation methodology. .

1. Travel-Replacement Thresholds:
Progress towards travel replacement requires developing a deep understanding of why individuals travel and what telecommunications characteristics are required to meet each of those needs. Based on state-of-the-art technologies, Category 3 Applicants should propose how they will provide actionable feedback to ARPA-E on Technology characteristics necessary to improve likelihood of travel replacement. Category 3 awardees may also assist Category 1 and 2 awardees in testing that demonstrates increase of usability, preference, and adoption over time. A specific methodology must be proposed regarding how the travel-replacement threshold will be studied and defined, both qualitatively and quantitatively.

2. Naturalness assessment of DH communication system:
Immersion and realism evaluation by Category 3 Awardees will assess the degree to which DH Technologies achieve the travel-replacement threshold by obtaining sustained utilization.

Category 3 Applicants should provide details regarding:

1. Procedures for evaluating DH Technologies, either previously developed or a literature-supported approach to new development of new procedures
2. Acquisition of a statistically significant and diverse participant group
3. Method to correlate qualitative and quantitative realism studies
4. (Optional) Mechanisms to collaborate with Category 1 and Category 2 Awardees on a voluntary basis to achieve rapid Technology iteration based on quantitative information regarding specific Technology and DH characteristics

Examples of subjective Evaluation of DH Technologies might include assessment using the following techniques: Presence Questionnaire; iGroup PW; ITC-Sense of Presence Inventory; MEC-spatial Presence Questionnaire; Temple Presence Inventory; Networked Minds Theory; Psychobiological method of communication; or new methods suggested by Applicants.

Examples of objective Evaluation of DH Technologies might include the assessment of: heart rate; skin temperature; eye-movement; eye-gaze; neural activity; task-based performance; or new methods suggested by Applicants.

N.B. The above examples are purely illustrative and do not comprise a comprehensive list.

3. Ensure Progress Towards Travel Replacement:
Real world testing to ensure travel replacement requires:

- Statistically significant longitudinal studies to determine sustained adoption
- Communication between 2 - 5 individuals implemented in a real working environment
- Hardware and infrastructure capable of implementing DH Technologies, such as those developed in Categories 1 and 2
- Facilities for conducting evaluations
- Quantitative measurement of use over time and correlation with travel behavior

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $9.5 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 2-3 awards in Category 1, 0-5 awards in Category 2, and 1 to 3 awards in Category 3 under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

Individual awards may vary between $250,000 and $9.5 million.

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects the start date for funding agreements to be November 2017, or as negotiated.

ARPA-E encourages submissions 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.

Submissions 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 must 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, submissions 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 submissions with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

ARPA-E will accept only new submissions 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."[17] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, 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.[18]

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

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

2. FUNDING AGREEMENTS WITH FFRDCS/DOE LABS, GOGOS, AND FEDERAL INSTRUMENTALITIES

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

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

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,[19] as the lead for a Project Team,[20] 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[21] 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 otherwise formed or to be formed) under the laws of a State or territory of the United States to

[19] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[20] 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.
[21] 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.

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[22]

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

1. BASE COST SHARE REQUIREMENT

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.B.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime

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

Recipient must provide at least 20% of the Total Project Cost[23] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[24]

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

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80%, but less than 100%, of the total work under the funding agreement (as measured by the Total Project Cost) the Project Team are entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.[26]

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[23] 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.

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

[25] 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.

[26] See the information provided in previous footnote.

- 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.

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[27] to meet their cost share obligations under cooperative agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under Technology investment Agreements.

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

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

Applicants may wish to refer to 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.

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

7. COST SHARE CONTRIBUTIONS BY FFRDCS AND GOGOS

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

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

8. COST SHARE VERIFICATION

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

C. OTHER

1. COMPLIANT CRITERIA

Concept Papers are deemed compliant if:

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

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

Full Applications are deemed compliant if:

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

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

Replies to Reviewer Comments are deemed compliant if:

- The Applicant successfully uploads its response to ARPA-E eXCHANGE by the deadline stated in the FOA.

- The Replies to Reviewer Comments comply with the content and form requirements of Section IV.E of the FOA.

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

2. RESPONSIVENESS CRITERIA

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

- Submissions that fall outside the technical parameters specified in this FOA.
- Submissions that have been submitted in response to other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to other currently issued ARPA-E FOAs.

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

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- Development of display technologies that are not compatible with the display of high-quality, natural DHs.
- Technologies related to physical manipulation in a remote environment.
- Technologies related to providing or employing haptic feedback.
- Technologies related to physical mobility of a telepresence system in a remote space.
- Technologies related to processing unit advances.
- Improvements to internet and networking technologies related to data transmission.
- Collaborative workspaces such as shared documents and other forms of written media
- Incremental development to head mounted displays.
- Motion capture technologies requiring the use of any markers, suits, or other applied, carried, or worn tracking aids.

4. LIMITATION ON NUMBER OF SUBMISSIONS

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

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E eXCHANGE

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

2. CONCEPT PAPERS

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

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

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

3. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 45 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

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

4. REPLY TO REVIEWER COMMENTS

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

ARPA-E performs a preliminary review of Replies to determine whether they are compliant, as described in Section III.C 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 or site visits, nor will these costs be eligible for reimbursement as pre-award costs.

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

6. SELECTION FOR AWARD NEGOTIATIONS

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

Applicants are promptly notified of ARPA-E's selection determination. ARPA-E may stagger its selection determinations. As a result, some Applicants may receive their notification letter in

advance of other Applicants. Please refer to Section VI.A of the FOA for guidance on award notifications.

7. MANDATORY WEBINAR

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

B. APPLICATION FORMS

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

C. CONTENT AND FORM OF CONCEPT PAPERS

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

- The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables.
- The Concept Paper must be submitted in Adobe PDF format.
- The Concept Paper must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right

corner of the header of every page. Page numbers must be included in the footer of every page.

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

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

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

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

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

1. CONCEPT PAPER

a. CONCEPT SUMMARY

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

b. INNOVATION AND IMPACT

- Clearly identify the problem to be solved with the proposed technology concept.
- Describe how the proposed effort represents an innovative and potentially transformational solution to the technical challenges posed by the FOA.
- Explain the concept's potential to be disruptive compared to existing or emerging technologies.
- To the extent possible, provide quantitative metrics in a table that compares the proposed technology concept to current and emerging technologies and to the Technical Performance Targets in Section I.F of the FOA for the appropriate Technology Category in Section I.E 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.

- Estimated federal funds requested; total project cost including cost sharing. Include breakdown of labor, travel, and other direct charges (hardware, software, etc.).

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 MARCH 2017]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2017]

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 MARCH 2017]

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.F of the FOA for the appropriate technology Category in Section I.E of the FOA;
- Identification of techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; 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; 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 MARCH 2017]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2017]

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/U.S. Manufacturing Plan;
   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 MARCH 2017]

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 MARCH 2017]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2017]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN MARCH 2017]

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.

- Determination of Exceptional Circumstances (DEC): Each Applicant is required to submit a U.S. Manufacturing Plan as part of its Full Application. The U.S. manufacture provision included in Attachment 2 of an award is included as part of the U.S. Manufacturing Plan. If selected, the U.S. Manufacturing Plan may be incorporated into the award terms and conditions for domestic small businesses and nonprofit organizations. DOE has determined that exceptional circumstances exist that warrants the modification of the standard patent rights clause for small businesses and non-profit awardees under Bayh-Dole to the extent necessary to implement and enforce the U.S. Manufacturing Plan. For example, the commitments and enforcement of a U.S. Manufacturing Plan may be tied to subject inventions. Any Bayh-Dole entity (domestic small business or nonprofit organization) affected by this DEC has the right to appeal it. The DEC is dated September 9, 2013 and is available at the following link: http://energy.gov/gc/downloads/determination-exceptional-circumstances-under-bayh-dole-act-energy-efficiency-renewable.

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.

Asynchronous communication: the deliberate transmission of communications data intermittently, rather than as a continuous stream when a conversation is happening in real-time. An example of commonly used asynchronous communications is text messaging.

Bidirectional communication: the sharing of information in which parties are both speaking and listening in real-time, involving the transmission of information in both directions.

Blendshape: the basis for a method of 3D digital animation where a surface is stored as a set of vertex positions (a "blendshape") and new shapes may be computed by combining individual blendshapes with relative deformation weights.

Capture: the process of recording the dynamic state (i.e. body pose, including facial features) of a conversation participant.

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.

Digital transportation: the use of digital information networks, such as the internet or wireless communications, to transport information across any distances to achieve the same objective for which one would now physical travel (*e.g.* drive, ride, fly).

Digital communications: the transfer of information between two or more participants using a digital information network.

Digital human (DH): a photorealistic and life-like animated digital representation of a human that is nearly indistinguishable audiovisually from a person perceived directly in real life.

Digitization: the process of encoding the captured state of a conversation participant into an information stream that can be transmitted over a data network.

Display: the device at the end of a communication platform that presents information, usually audiovisual, to viewers or listeners of a conversation, e.g. a desktop monitor or headphones.
DOE: U.S. Department of Energy.

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

Face-to-face: in-person, co-located interaction between two or more individuals. Video conferencing, such as Skype®, is *not* considered a face-to-face interaction.

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.

Immersion: the technical characteristics of a telepresence system which lead to a sense of presence [Bailenson 2015, Slater 1997]. Such characteristics include tracking level, field of view,

sound quality, update rate, user perspective, resolution, stereoscopic vision, and scale of display.

'Last mile' communications: the final leg of data sent over a telecommunications network, specifically over enterprise and home networks, originating at the internet service provider's terminus and ending at the objective computing system (navigating through any networking routers, switches, etc.).

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

Motion capture: the process of capturing the dynamic physical state of a person in live motion.

Naturalness: the similarity between a digital communication platform and face-to-face communication, based on the *medium naturalness* (i.e. the degree by which digital communication incorporates the elements of face-to-face interaction) and *cognitive effort* required utilize the digital communication platform (Kock 2004).

Network Upload: the process of sending digitized information from the conversational speaker's computer or device out to all listener's devices.

Network Download: the process of receiving digitized information from the conversational speaker's computer or device at all listener's devices.

Nonverbal communication: the multidimensional and multifunctional system utilizing *discourse functions* (pointing, illustrative and beat gestures that accompany speech production)*, dialogue functions* (head nods, eye contact, etc.)*, and socioemotional functions* (conveyance of emotion and interpersonal attitudes). It is well-acknowledged that nonverbal communication is paramount to conveying information, forming initial impressions, and building trust. (Bente 2008)

Presence: a participant's sensation of "being there" or "the (suspension of dis-) belief of being located in world other than the physical one." (Slater 1994) In the context of FACES, the "other" world is any digital environment in which the DH is being viewed and can range from a mobile device to a head mounted display.

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.

Realism: the degree by which the DH represents the captured human and the ability of the communication platform to achieve true presence.

Reconstruction: the process of converting a digital information stream to an appropriate representation for subsequent display on the listener's end of the telecommunication.

Rig, Rigging: in skeletal animation, the rig is the underlying structure supporting the surface mesh that is responsible for posing or coarse movements.

Server-side operations: robust server tools for managing a high volume of digital transportation connections and generally any combination or modification of data streams to facilitate a communicative experience.

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.

Telepresence: is commonly defined as "the use of technology to establish a sense of shared presence of shared space among geographically separated members of a group" (Buxton 1991).

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.

Travel-replacement threshold: The state of the technology in digital transportation which meets a traveler's extrinsic (*e.g.* reduce spatial separation) and/or intrinsic (*e.g* interest in or enjoyment of travel) requirements for physical travel. The importance of intrinsic and extrinsic travel motivators are discussed in detail by Mokhtarian et al. (2015).

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

Verbal communication: the spoken dialogue used to transfer information between two or more participants.

Vergence Accommodation Conflict: the inability for your eye direction to converge or diverge on a near-field or far-field object that is projected onto an arbitrary visual plane in front of the eye, and then focus on (accommodate) that object in a digital environment. In a head-mounted

display, for instance, your eyes will converge on far-field object, but accommodate the screen at the distance it is displaced from your face. The resulting decoupling causes fatigue, discomfort, and potential motion sickness.

Virtual environment: a network-based digital communication environment which enables interaction between two or more individuals, and sometimes interaction with elements within digital space which they occupy. Examples of commonly used virtual environments are Second Life, FaceTime, and Skype.

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