FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

ENERGY-EFFICIENT LIGHT-WAVE INTEGRATED TECHNOLOGY ENABLING NETWORKS THAT ENHANCE DATACENTERS (ENLITENED)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001566
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	Friday, June 10, 2016
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, Friday July 15, 2016
Submission Deadline for Concept Papers:	5 PM ET, Monday July 25, 2016
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET,TBD
Submission Deadline for Full Applications:	5 PM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	TBD
Total Amount to Be Awarded	Approximately $25 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

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

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).

- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 of the FOA.

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REQUIRED DOCUMENTS CHECKLIST

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

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

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

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: o Concept Summary o Innovation and Impact o Proposed Work o Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, Monday July 25, 2016
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

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

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

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

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

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

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

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

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

1. SUMMARY

The growing demand for datacenter services across a range of applications has resulted in significant and sustained growth in electrical energy consumption in the Information Communications Technology (ICT) sector. Currently, datacenters consume more than 2.5 % of US electricity and this percentage is projected to double in about 8 years [1-4, 6, 7, 9]. Efficiency improvements due to more efficient cooling, power delivery, and electronic processor chips via Moore's law improve overall efficiency, but do not significantly slow the current growth trend; to do so requires a transformative improvement. The overall objective of the ***ENLITENED*** (***EN***ergy-efficient ***L***ight-wave ***I***ntegrated ***T***echnology ***E***nabling ***N***etworks that ***E***nhance ***D***atacenters) program, therefore, is to provide a transformative change - to achieve an overall doubling in datacenter energy efficiency in 10 years through deployment of novel

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

network topologies enabled by integrated photonics technologies. ARPA-E estimates that if the technical challenges posed by ***ENLITENED*** can be overcome, these alone would reduce projected US energy use by about 1% after 10 years and realize at least twice the number of datacenter transactions with the same amount of energy.

Industry projections show that in order to achieve future datacenter performance requirements, metal interconnects must be increasingly replaced by photonic technologies, yet costs for deployment are often prohibitive and energy efficiency is not necessarily the highest priority in the commercial sector [11, 15, 16]. Though a broad industrial consensus pushes toward further photonic integration in switches and other datacenter components [11,16,18], in some cases, large companies will build another 80 MW datacenter to meet demand, rather than increase efficiency with photonics, due to a combination of reliability risks, cost and limited component supply.

To overcome metal interconnect limitations on future datacenter energy-efficiency performance, ***ENLITENED*** will target the critical packaging and integration challenges needed to exploit the inherent performance advantages of dense photonic interconnects and switching technology at the chip-scale within datacenters. Specifically, ***ENLITENED*** will target packaging and integration of novel and efficient photonics-enabled hardware systems that can demonstrate at least a 2-fold increase in energy efficiency at the datacenter level. To validate hardware solutions, ***ENLITENED*** will also entail modeling and simulation of the new datacenter architectures and data traffic protocols under realistic workloads, to provide quantifiable measures to validate transformative design strategies for future datacenters and retrofits.

2. BACKGROUND AND MOTIVATION

Impact on Datacenters: Energy Consumption and Industrial Trends

The energy consumed by datacenters has been the subject of much study [1-5], reaching 91 TWh in 2013, and increasing at a rate that doubles about every 8 years [1]. Currently, datacenters account for about 2.5% of electricity consumption in the US – while the total annual electricity consumption in the US has remained approximately constant at about 3800 TWh [6] from 2005 to 2012[2].

Datacenters in the US can be divided according to their electricity consumption by market segment as: Small and Medium-Sized (49%), Enterprise/Corporate (27%), Multi-Tenant (19%), Hyper-Scale Cloud Computing (4%), and High Performance Computing (1%) [4] – which shows not only a wide diversity in scale and function, but also highlights the importance of finding energy efficiency solutions that address all market segments. Trends indicate that Multi-Tenant and Cloud services are growing, which may improve efficiencies due to the possibility of

[2] US electrical power generation is projected (EIA reference case) to be 3.9 trillion kWh in 2016, 4.2 in 2026 and 4.7 in 2040. Annual Energy Outlook 2016, early release: http://www.eia.gov/forecasts/aeo/er/index.cfm

virtualizing smaller datacenter functions within larger server farms that allocate resources more efficiently. Nevertheless, the fundamental technologies used, and solutions envisioned are relevant to all datacenters. With growth in all sectors, the importance for reducing energy consumption across the datacenter application domain continues to grow.

Figure 1 depicts the current and projected trends in aggregate power consumption for datacenters in the US (red line). The demands for datacenter services have resulted in an exponential growth rate in the total power requirement. The exponential growth in service demand is actually outpacing the exponential growth in ICT equipment computing efficiency (due in part to Moore's Law scaling of processor performance). Even more concerning is the trend towards an increasing fraction of datacenter power consumed by the internal datacenter network [17]. This pending upswing in the projected power consumption is attributed to anticipated growth in interconnect energy demands with increasing ICT performance, but with existing network technologies it appears unlikely that network energy efficiency will increase proportionally to server performance. Ultimately, the electrical interconnects to the server chips themselves will not be able to keep up with the increasing computing power of those computing elements [14] – which could potentially add to the energy-efficiency burden of datacenters as depicted in Figure 1 for the years beyond approximately 2022.

As depicted with the dashed green line in Figure 1, the ***ENLITENED*** Program seeks to suppress this increasing power consumption trend by enabling energy efficient datacenters with packaged integrated photonic interconnects and switches and associated novel networking architectures. Specifically, ARPA-E sees an opportunity to exploit high-density integrated photonic chip-scale I/O at <1 pJ/bit and lower latency network fabrics enabled by integrated photonic links and switching technology. This combination will make possible significant increases in overall system efficiencies and thereby halt the increasing energy demand, and perhaps even lower the aggregate datacenter energy consumption to manageable levels as depicted in Figure 1.

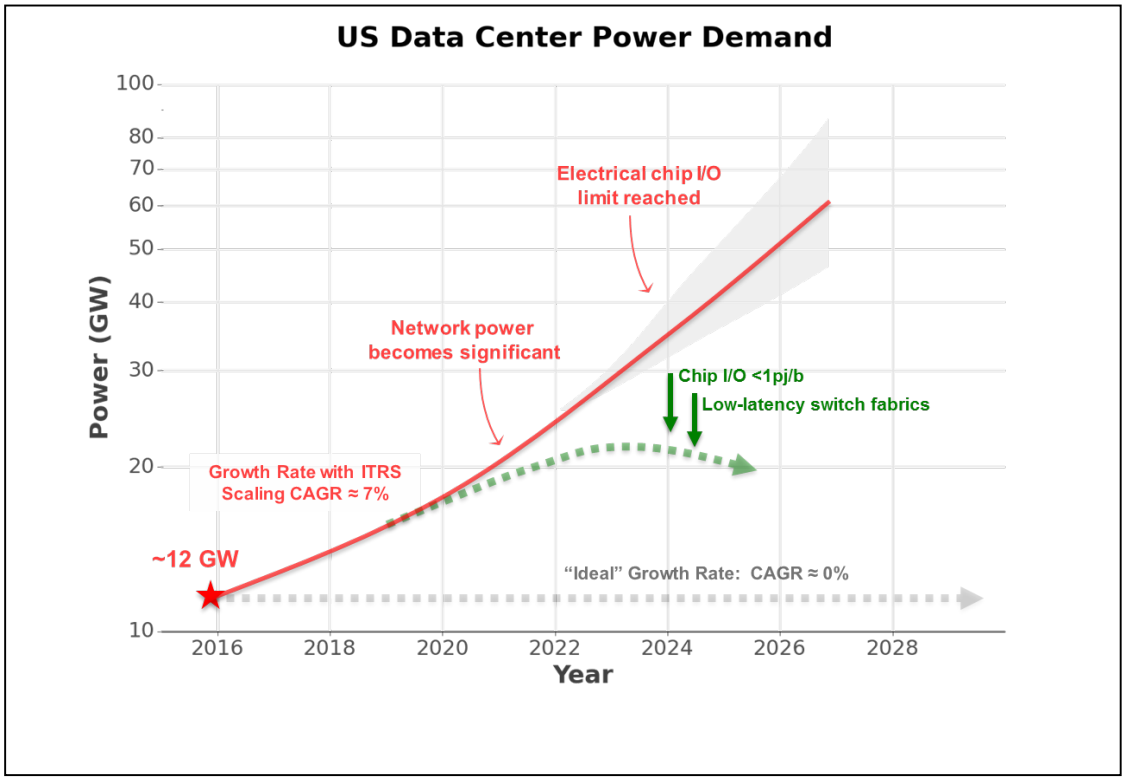

Figure 1. Aggregated power consumption of US datacenters as a function of time. The red line shows current trends and anticipates further electrical power growth due to the network becoming more significant and reaching the limits of metal interconnects. The green dotted line indicates the ***ENLITENED*** objective enabled by low-energy photonic interconnects and switching technology.[3]

Rationale for targeting IT Infrastructure vs. other sources of datacenter inefficiency

Opportunities for improving datacenter efficiency abound through potential improvements in Information Technology (IT) components, software, cooling techniques, electrical power delivery, and computing chip advances. As depicted in Figure 2, to analyze the energy consumed by a datacenter, it is useful to break up its energy efficiency into components, for example: electrical power delivery and conversion efficiency, cooling efficiency, and IT efficiency. Currently, power delivery, power down-conversion, and cooling are the subject of

[3] The estimated total electrical load of ~12 GW for 2016 is extrapolated from trends for data from 2000, 2005 and 2010 [1], and assumes a Cumulative Average Growth Rate (CAGR) of approximately 7%. The value obtained for 2016 is consistent with the prediction by the DatacenterDynamics (DCD) of 13.25 GW also for 2016. The extrapolation from 2016 to 2020 with the same CAGR yields 16.8 GW. The portion of the graph from 2020 to about 2023 assumes that network becomes a bigger percentage of energy utilization reaching as much as 50%, as predicted in [8], leading to an approximately 50% additional growth to 30 GW for 2023. After 2022, the effects of reaching the limits of metal interconnects for delivering the required throughput to the anticipated many-core chips is added. As an illustration of this last point, in [14] we observe that by 2022, assuming a constant IO B/FLOP, the metal interconnects fail to deliver the required I/O throughput to the future server chip – resulting in a further limitation of energy efficiency growth in datacenters. The shaded region indicates the uncertainty in predicting future demand.

much interest and research. For example, companies operating very large datacenters are reporting cooling efficiencies approaching optimal values. Due, in part, to the existing strong level of investments in the infrastructure components, these elements are not considered under this FOA.

It is anticipated that future datacenter performance limits will stem from the inability of the datacenter network to keep pace with increased data loads to/from future server chip technology. Therefore, one opportunity for transformative improvement comes from enabling new network topologies and data management protocols through advanced integrated photonics systems. ***ENLITENED*** is targeting the efficiency of the IT elements of datacenters – and specifically the networking elements (interconnects and switching elements) of the datacenter.

A commonly-used measure of datacenter efficiency is PUE (Power Usage Effectiveness). PUE is defined as the ratio of total energy consumed by the datacenter (E_{total}) to that consumed by the IT equipment (E_{IT}). The total energy used by a datacenter can therefore be expressed as:

$$E_{total} = PUE \cdot E_{IT}$$

Often, the "PUE" factor lumps in all other factors such as cooling, power conditioning and delivery. Other smaller facilities-related consumption, such as lighting, is also added in certain estimations. Many companies report decreasing PUE values, yet this number does not reveal the amount of energy consumed. In most cases, the majority of the energy is consumed by IT equipment and the proportion is growing, due in part, to lower PUE achievements. It is also true that if IT energy consumption is reduced, this results in less energy consumed by cooling and power delivery in roughly the same proportion, because both are directly driven by IT energy use. It is this IT energy that is the target of the ***ENLITENED*** program.

A number of studies suggest that the IT network is an increasing fraction of the total IT power, in some case over 50% [12, 15, 18, 19]. Innovation in networking components and topologies can reduce the power consumed by the IT network, and further increase system efficiency in other ways, such as enabling a reduced percent of idle time of processor chips that consume significant energy while not being utilized [8,13] via higher overall network bandwidth and lower network latency. For example, for the datacenter schematic depicted in the bottom portion of Figure 2, higher bandwidth components could enable fewer switch nodes with higher port count per switch, in turn reducing the number of "hops" and idle time between servers, resulting in less energy consumed for the same transaction.

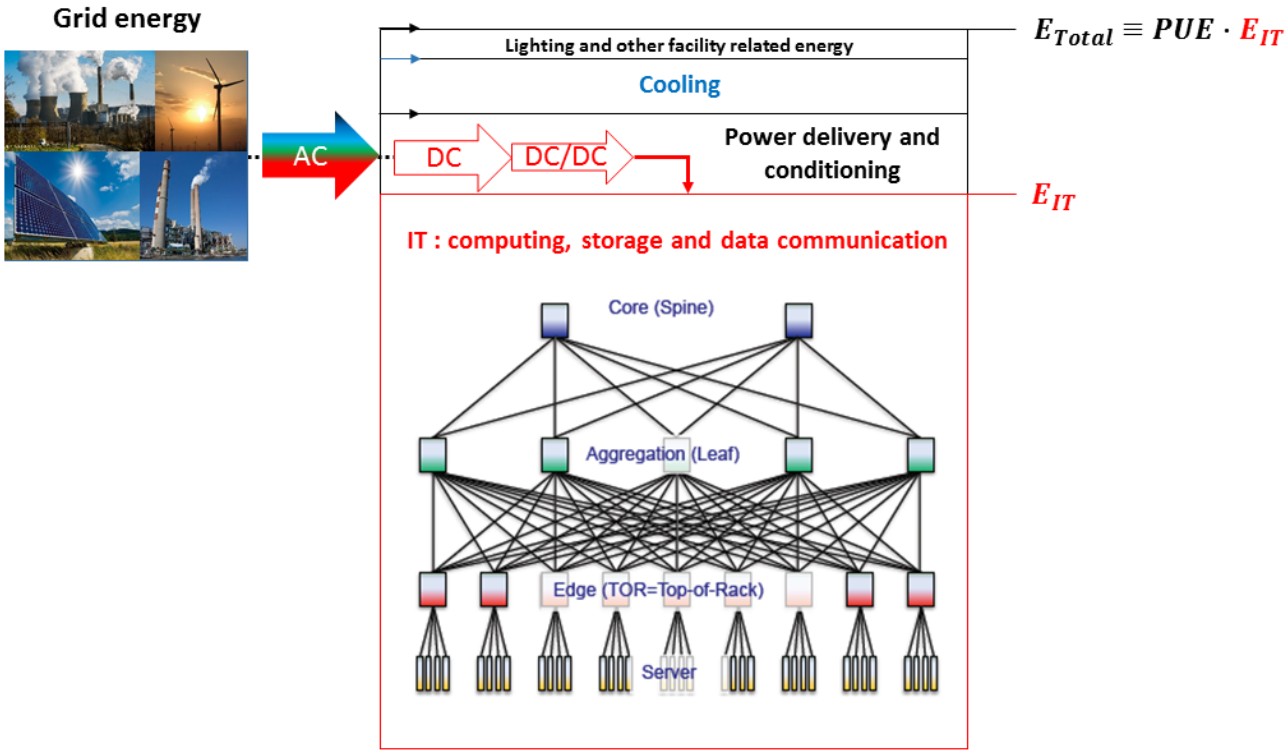

Figure 2. Schematic depiction of a datacenter and sources of energy consumption, the primary being IT, followed by cooling and power delivery and conditioning. The schematic at the bottom represents a datacenter network with servers as the bottom thin yellow boxes and switches as red, green and blue boxes.

The datacenter depicted in Figure 2 is one with a "Fat-Tree" network topology, with lines representing data interconnects between switches and servers – the lines and nodes in the diagram are "the network." Typically, switches receive, store and forward data, and play a role in data routing decisions. Within each server are central processor and memory chips mounted on printed circuit boards that perform the majority of calculations and data storage. The first level of hierarchy for data communications outside of the server is called the "Top-of-Rack" (TOR) switch, which usually has the largest number of connections compared to all other network switches. Data communication at the level of the TOR and above is commonly referred to as "east-west" and from the TOR to the processor and memory chips within server boards as "north-south." Although the "network" is often considered to be all data transactions outside of a server, in fact a large amount of data communication occurs "on-board", right up to the edge of the memory and processor chips inside server boards. ***ENLITENED*** seeks to invest in technologies that can be integrated right up to the edge of the chip (i.e., integrated directly with the chip carrier) to enable both increased performance as well as transformative gains in energy efficiency.

Meeting Future Datacenter Needs: Overcoming the Bandwidth Bottleneck

There are two areas of concern that will limit future datacenter system performance. Chip-scale metal interconnects limit the scalability of silicon-chip-based electrical switches and therefore, are a fundamental source of future datacenter inefficiency [15]. Similarly, the metal interconnects connecting server chips and memory units to each other and the network interface will not be able to keep pace in an energy-efficient way with the bandwidth demands [14]. As bandwidth and capacity requirements of datacenters grow, the limitations of electrical interconnects will become further exaggerated when compared to integrated photonics technologies that are inherently more energy-efficient and capable of having far greater bandwidth-per-channel and bandwidth density at the chip scale [14]. There is an ever-increasing fraction of datacenter power requirements and costs dedicated to the intra-datacenter network, with projections suggesting further increases [12, 13].

Although integrated photonics technologies have been shown to achieve much lower link and switch energies than metal and electronic technologies, wide-spread deployment (such as in future datacenters) must overcome significant fabrication cost barriers to replace metal interconnects on server boards and to switching elements. Consequently, ***ENLITENED*** specifically targets the development of fabrication/manufacturing techniques that address the integration and packaging of photonic data-com technologies within server environments and the development of novel networking architectures that take advantage of these photonic technologies.

Figure 3 is a comparative schematic depiction of chip-scale integrated electronic and photonic interconnects which highlights the key issues for metallic interconnects and the key challenges that must be overcome in next-generation integrated photonics technologies. State-of-the-art server or switch chips (depicted as orange squares) are mounted on chip-carriers (depicted as blue squares with black dots indicating metal connection points to the underlying board) that provide the metal trace interface to the underlying circuit board. Two key attributes determine the I/O capability of the system: the “escape bandwidth density” for the chip package and the energy-per-bit (E/b) consumed for each link. The escape bandwidth density is defined as the linear bandwidth density around the periphery of the chip or chip package and is limited by the geometric and physical constraints of the chip-carrier on pin density, number of wiring layers, cross-talk, line termination requirements, etc. Traditional multi-layer chip-carrier techniques approaches are limited to approximately 1 Tb/s/cm in escape bandwidth density [20]. Furthermore, due to the fundamental loss mechanisms in high-bandwidth electrical transport, energy requirements for high-density integrated metallic links are approximately proportional to the length of the link. State-of-the-art metal links can achieve approximately 0.5 pJ/b/cm and therefore the length of required inter-chip links is a critical concern. As server and switch chip technology continues to scale, the ability of metal interconnects to keep pace is projected to be limited [14].

In contrast to integrated metallic interconnects, integrated photonic interconnects offer the potential to provide much higher escape bandwidth and E/b performance that is essentially independent of the chip-scale interconnect distance, as depicted in the lower half of Figure 3. At the inter-chip distances considered here, waveguide and fiber transport is essentially lossless. E/b performance for optical links have been demonstrated at approximately 1 pJ/b [14] and projected performance for integrated photonic links may achieve even much lower levels of E/b [14]. What's more, due to the ability of waveguides to carry highly multiplexed signals, and be packed in high density with little crosstalk, the potential escape bandwidth of integrated photonic interconnects far exceeds that of metal interconnects.

As depicted in Figure 3, the critical implementation challenge for integrated photonic links is the transduction from the electronic to optical domains (E→O) at the transmitter and the inverse (O→E) at the receiver. Integrated photonic technologies may achieve this through direct modulation of a laser diode (LD) and then detection of the photonic signal with a photodiode (PD) at the receiving end, as depicted, or other types of photonic modulation and detection of laser signals may be employed. In any integrated photonic scheme, the electronic/photonic transductions present the critical integration and packaging challenges for efficiently interfacing to the server or switch chip and the waveguide structure that comprises to actual interconnect fabric.

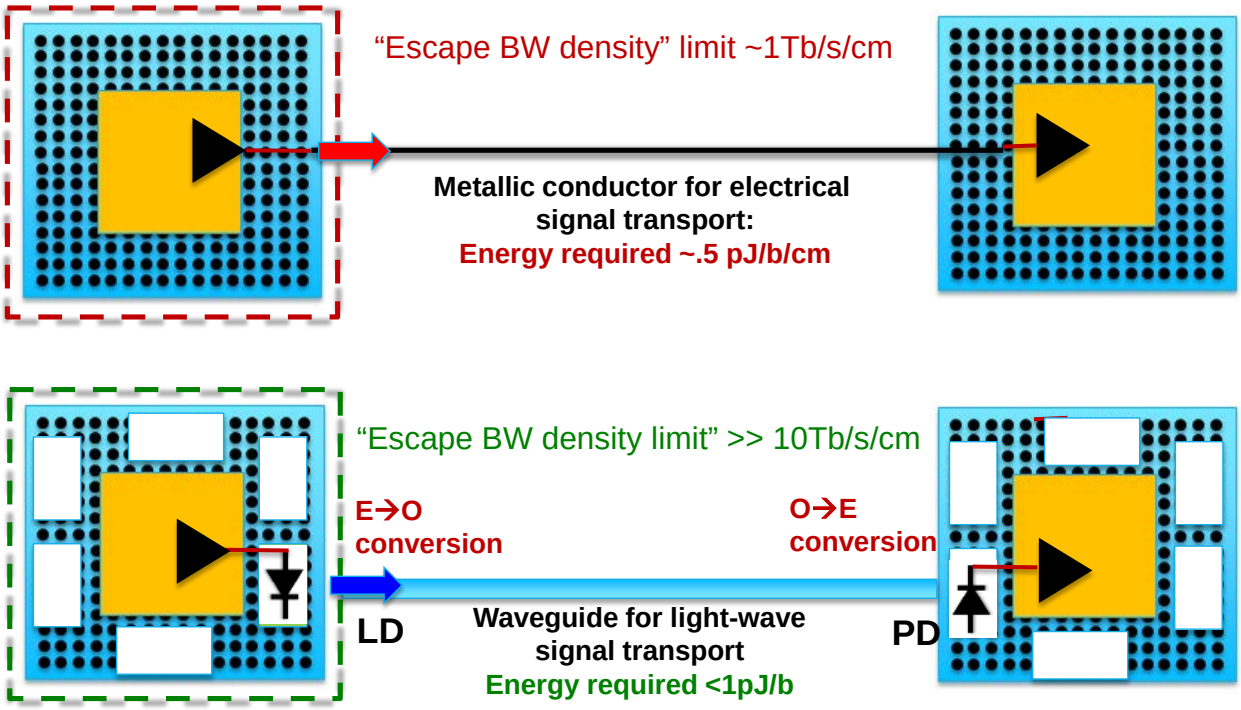

Figure 3. Schematic demonstrating an "interconnect" between processor chips and limitations using electrical metal links (above) and optical waveguide (below) interconnection technologies. Due to practical and dimensional design limitations of about ~200 W/processor chip and other

physical constraints of metal wires [14] , data transfer rates into and out of processor chips are limited and distances over which electrical signals can travel are limited due to signal loss (~0.5 pJ/b/cm). Optical interconnects are virtually lossless as a function of distance and enable a much greater "escape bandwidth" to increase the chip input/output data rates, however, E/O and O/E (O= optical, E = electrical) conversion steps must be efficient to minimize heating and achieve higher overall efficiency.

C. PROGRAM OBJECTIVES

The overall objective of the ***ENLITENED*** Program is to create new technology platforms, components, and evaluation methods to enable a > 2-fold improvement in the energy efficiency of datacenter ICT infrastructure.

Although the energy needs and functions of datacenters vary, ARPA-E posits that efficiency can be improved across all datacenter applications via the incorporation of advanced integrated chip-scale photonic interconnects and switching technologies. Although no one universal metric for datacenter efficiency may be applied to all cases, ARPA-E considers a doubling of the average "Transactions/Joule" (interpreted as a "wall-plug" efficiency for the entire ICT system of the datacenter) to be a plausible general target. One objective of ***ENLITENED*** is to tie different use-cases and data loads to a standard system-level metric: "Transactions" in the numerator and energy consumed by the entire datacenter (E_{IT} in Figure 2) during those transactions in the denominator. This would enable greater clarity for innovation to optimize for energy at the system level and evaluate other performance trade-offs. Examples of intermediate system-level metrics from which "Transaction" units can be derived could be measures such as FLOPS/Joule and bytes/FLOP for a series of queries, the number of intermediate switch hops and overall time for a given byte or data packet to travel between servers, and so forth. Such analysis will enable objective measures of datacenter energy-efficiency and easier comparison across computational models and hardware sub-systems.

ARPA-E anticipates that this level of datacenter system efficiency improvement will stem in part from the fundamentally lower energy-per-bit achievable with integrated photonic links. The remaining significant efficiency improvements will stem from changes in network architecture enabled by the ultra-high bandwidth density of photonics and low latency photonic switch fabrics. The closer integration of switching and computational elements that will emerge from ***ENLITENED*** will potentially blur the distinctions now made in techno-economic analyses of server, switch, and transceiver costs for datacenters. Nevertheless, ARPA-E estimates that an effective cost structure is needed to bring ***ENLITENED*** technologies to market by putting packaged technologies on a path to < 10 cents/Gb/s for integrated transceivers and aggregate switch bandwidths > 50 Tb/s, capable of radix > 128 [18]. Early market insertion opportunities may be possible in other areas such as high-performance computing (HPC), where performance and energy efficiency are prioritized over market cost metrics.

At the end of the program, ARPA-E expects datacenter sub-systems and architectures, supported by detailed modeling and simulation that achieve a 2-fold or greater average improvement in energy efficiency as well as a path to commercialization.

D. PROGRAM STRUCTURE AND TECHNICAL CATEGORIES OF INTEREST

ARPA-E anticipates a 2-phase, 4-year program for ***ENLITENED***, however the initial period of performance for awards resulting from this FOA will be for Phase I and will not exceed two years. Phase 2, also a maximum of 2 years, may only be awarded contingent upon successful completion of Phase 1 and will be subject to the availability of appropriated funds. The program objective is a packaged hardware solution consistent with a computational datacenter model and/or calculations that demonstrate the potential to achieve an average 2-fold improvement in energy efficiency for a broad range of use cases.

Applicants are encouraged to have vertically-integrated teams that bring together technology, packaging and integration, and network architecture expertise. ARPA-E may also consider partial solutions, for example, of a component that has a critical path to being packaged and integrated into datacenter sub-systems, a new integration and packaging approach that could have broad impact, or a computational modeling approach that can be used, together with realistic hardware specifications and datacenter constraints, to design solutions that meet the program metrics.

Full Solutions

Vertically-integrated teams are expected to develop the integration and packaging concepts needed to enable chip-scale ultra-high-density photonic link and switching technologies within future datacenters. It is anticipated that, depending on the integrated photonic technologies proposed, potential solutions will have differing levels of hybridization/integration between electronic and photonic elements. Applicants must propose, and articulate a rationale for, an integrated technology platform (that includes links, transceivers, switching elements, control strategies, and all interfacing technologies and techniques) needed to couple the photonic elements to the anticipated electronic computing elements at the chip, chip package, board and intra-rack-levels, as appropriate in future datacenters. Applicants must present a network structure enabled by the integrated technologies that would lead to transformative energy-efficiency improvements.

Implementation of Phase 2 for the ***ENLITENED*** program will depend on satisfactory progress across the program during Phase 1, subject to the availability of appropriated funds and other factors. Project teams will be expected to deliver analyses, perform sub-system experiments (as detailed below), and refine a Phase 2 project plan that will enable ARPA-E to make informed selections for the second phase. If ARPA-E selects a project to continue to Phase 2, the team will develop more significant experimental validations of their concept that culminates with

critical analyses, simulation, and hardware-in-the-loop experiments that will enable valid assessment of the technologies and progress towards commercialization.

An expectation of Phase 2 success is demonstration of the concept at a minimal system level. For example, a new transceiver or switch architecture must take into account all system elements that consume energy such as clock and data recovery, re-timing circuitry, and other system level inefficiencies. Applicants pursuing full solutions should propose goals that are ambitious and exceed the current goals of other commercial efforts in terms of energy efficiency, such as those of the Consortium of On-Board Optics (COBO) [11].

Partial Solutions

ARPA-E anticipates that some teams may not be fully "vertically integrated" or "full solution" as described above, but may provide a valuable partial solution that could contribute significantly to achieving the program objectives. Such projects may have a hardware solution that is significantly less than a full system, for example a laser or modulator array that is to be packaged into a transceiver or switch. Others may have novel datacenter network architectural notions that promise to take full advantage of emerging photonics technologies in future datacenters using realistic components and show a clear commercial path to achieving the program metrics, yet not currently be part of a team that has the matching hardware solutions.

ARPA-E anticipates that partial solutions may be more suited to Phase 1, but a Phase 2 path must at least be addressed, albeit in less detail than vertically integrated teams. As listed in Section IV.C "Content and Form of Concept Papers," and in the Concept Paper template document, teams pursuing partial solutions are expected to submit Concept Papers of no more than 4 pages in length. For certain common components that have well-demonstrated performance, for example, high efficiency/bandwidth lasers, modulators, couplers, etc.; a two-year window may be critical for integration and packaging into existing product lines.

For teams pursuing partial solutions to design and simulate novel network architectures only, Concept Papers must explain how their proposed network design will leverage projected performance advantages of photonics-enabled sub-systems. Teams must use realistic [10] component technology specifications and techno-economic analyses and address all technical performance targets, even though they may not have experimental measurements as part of their Phase 1 project plan.

E. TECHNICAL PERFORMANCE TARGETS AND DELIVERABLES

The ***ENLITENED*** technical performance targets are designed to demonstrate the ability of any proposed solution to meet the transformative energy efficiency objective described in this FOA when compared to *anticipated* state-of-the-art electrical interconnect and networking technologies. In other words, the benefits of the proposed solution must be in addition to any

future improvements in CPU, memory, or other datacenter electrical components or architectural efficiency enhancements (e.g., anticipated silicon CMOS scaling, or energy-proportional computing strategies).[4]

Applicants must address the overall 2x average system efficiency improvement target in the context of datacenters at all scales (large, small, multi-tenant etc.), and diverse distributions of data loads. The justification of the efficiency improvement should include, in addition to datacenter diversity and data loads, the effects of format conversion between single-mode and multi-mode for North-South and East-West communications, number of E-O-E (or O-E-O) conversions, etc., if appropriate. Table 1 provides targets for Program Metrics. **The target in Metric 1.1 is the overall program objective and must be addressed in all submissions. If an applicant is going to meet the target in Metric 1.1 without meeting the targets in Metrics 1.2-1.5, the applicant must provide alternative targets for Metrics 1.2-1.5 and provide a rationale showing how the target in Metric 1.1 will nevertheless be met.** Comprehensive simulation results are not expected in concept papers, but a quantifiable argument for how the 2x efficiency improvement (excluding cooling and power down conversion effects) will be reached must be presented. Metric 1.6 refers to the technology economic assessment.

Applicants should identify the specific datacenter structures targeted for innovation. Examples of this would be creating a switch architecture that combines many top of rack and core switches into one and meeting the FOA metrics by reducing the number of "hops" for the majority of data packets, while increasing bandwidth and processor utilization. This example may include both "short" and "long reach" hardware elements that could be addressed by both VCSELs over multi-mode fiber as well as Silicon photonics, for example. Another example would be targeting the infrastructure "below the Top of Rack", which would likely be dealing with mostly "short reach" communications that take place between CPUs and memory elements inside the "server unit" of current datacenter designs. Of interest are approaches that aim to disaggregate datacenter elements and blur boundaries between servers, as such architectures are predicted to have advantages in performance and energy efficiency and potentially maintenance and reliability.

Table 1: Program Metrics

ID	Metric	Target	Description
1.1	System Energy Efficiency	>2x "Transactions /Joule"	• Applicants must show how their proposed integrated photonics and new switch network provides a credible path to >2x efficiency.
1.2	Link Demo	< 2 pJ/bit	• Must show a path to <1 pJ/bit for inter-chip board-level links of length 1 to 100 cm.

[4] For example the system efficiency improvement could be shown by exhibiting simulations with and without the photonic technologies but both including other future improvements

1.3	BW Density Demo: Chip or Chip carrier I/O	> 1Tb/s/cm	• The proposed packaging approach should enable aggregate bandwidths of 10 Tb/s or greater for future server or switch chips.
1.4	Board Level I/O	Applicant-provided	• Board-level I/O will be determined by specifics of proposed network architecture.
1.5	Switch Concept	Applicant-provided	• Must show how integrated photonics enables an efficient architecture (> 2x efficiency from item 1) • Specify required switch metrics (e.g., radix > 128, end-to-end Energy/bit, etc.) • Define how store and forward steps, latency affect overall system performance and energy • Switch concepts must show path to > 50 Tb/s aggregate bandwidth per switch
1.6	Technology Economic Assessment	Applicant-provided	• Show cost effective packaging compatible with server/communication equipment • IP enables path to < $0.10/Gb/s at inter board level • Network cost: Applicants must provide TEA to eventual wide scale deployment of the proposed IP –architecture

Deliverables

"Full solutions" applicants must experimentally validate the listed program metrics in Table 1. These deliverables must make a convincing case for commercial transition. Applicants must provide a technical approach and milestone plan for achieving the deliverables. Full solution Applicants must propose the following five deliverables for Phase 1:

1. Laboratory demonstration of a chip-level integrated photonic link with a clear path to < 1 pJ/b for 1-100 cm link lengths and an integrated interconnect demonstration that shows a path to 10 Tb/s for future server and switch chips.
2. Laboratory demonstration of an integrated switching concept that exploits the proposed photonic link concept and enables the proposed networking architecture.
3. Network architecture and datacenter simulations that are consistent with the experimentally-measured results from 1 and 2 and show a path to at least a 2-fold improvement in average energy efficiency.
4. A technical plan for the packaging and integration of all system components considered and methods of manufacturing identified with accompanying techno-economic analysis.
5. Submission, at the end of Phase 1, of a detailed Phase 2 plan that builds upon the Phase I deliverables and refined simulations and proposes prototype integrated packaged sub-

systems with sufficient numbers of links and switching elements to validate the proposed concept.

"Partial solutions" applicants must specify their own quantifiable milestones and deliverables as appropriate, but consistent with showing well-defined paths to the overall program objective via detailed simulations.

Additional Clarifications for Partial Solutions

Applicants developing partial hardware solutions must address all of the above metrics during the ***ENLITENED*** program, even though the metrics may not be directly measured as part of proposed project plans. Applicants must provide intermediate metrics and relate those to system level performance. For example, if a partial solution that involves the packaging and integration of a laser array into an existing series product line were proposed, other additional metrics would be expected such as modulation rate, total wall-plug power per port, coupling efficiency, error-free bit-rate per port, inside of a prototype packaged system.

Similarly, for partial solutions consisting of modeling and simulation (not experimental work) , teams must demonstrate the ability to communicate and understand what industry customers require, as well as the inner workings of both enterprise scale and hyper-scale cloud datacenters. Teams must be technically competent to perform state-of-the-art simulations to evaluate experimental results from hardware developers and simulate datacenter operation by varying the size of the datacenter (number of servers and switches), the topology of the datacenter (Clos-type, HyperX, All-to-All, Fat-Tree, etc.) and software-defined datacenter algorithms.

Additional Clarifications for Computational Modeling

All Concept Papers that include network architecture/system modeling, whether vertically integrated teams, or partial solutions (without experiments), must:

- Develop models that show innovative ways to reach a global energy efficiency improvement > 2 x Transactions/Joule. This universal metric must be related across datacenter sizes, with different data load size distributions, activity patterns and computational metrics. Other measures such as FLOPS/Watt, FLOPS/Joule, bytes/FLOP must be related to expected global gains.
- Specify topologies and compare to the state-of-the-art.
- Specify data loads, where the data will be obtained and how relevant these data sets and traffic patterns are to evolving datacenter trends.
- Have models that use realistic system components, including the most advanced and anticipated integrated photonics capabilities being developed by other teams in the ***ENLITENED*** program and enable modularity to evaluate how the global metric is affected by changes in components and topologies. Physics-based constraints must be

taken into account as well, such as the trade-offs in bandwidth density per area, heat generated per area, etc.

- Provide a techno-economic justification for the computational model to evaluate the feasibility of adoption. This must take into account realistic models of CAPEX and OPEX and creative ways of how new datacenters could be manufactured or retrofit with emerging technologies in a cost effective way. Thought leadership for creative ways that industry can adapt to limitations of power, real-estate and other constraints are welcome.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $25 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 12-15 awards under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

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

The period of performance for funding agreements may not exceed 24 months. ARPA-E anticipates a 2-phase, 4-year program for ***ENLITENED***, however the initial period of performance for awards resulting from this FOA will be for Phase I and will not exceed 24 months. Phase 2, also a maximum of 2 years, may only be awarded contingent upon successful completion of Phase 1 and will be subject to the availability of appropriated funds. ARPA-E expects the start date for funding agreements to be June 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 Phase 1 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."[5] 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.[6]

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

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

Project Team must provide the information requested in the "FFRDC Lab Authorization" and "Field Work Proposal" section of the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

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

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

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

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

3. TECHNOLOGY INVESTMENT AGREEMENTS

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

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

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

C. STATEMENT OF SUBSTANTIAL INVOLVEMENT

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

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

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

1. INDIVIDUALS

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[7] as the lead for a Project Team,[8] 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[9] 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

[7] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[8] 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.
[9] 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[10]

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

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

1. BASE COST SHARE REQUIREMENT

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.B.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime Recipient must provide at least 20% of the Total Project Cost[11] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[12]

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").[13] 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

[11] 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.
[12] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.
[13] Small businesses are generally defined as domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards). Applicants that are small businesses will be required to certify in the Business Assurances & Disclosures Form that their organization meets the SBA's definition of a small business under at least one NAICS code.

the funding agreement (as measured by the Total Project Cost) the Project Team are entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.[14]

- 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.

[14] See the information provided in previous footnote.

6. COST SHARE TYPES AND ALLOWABILITY

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

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

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

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

In addition, Project Teams may not use independent research and development (IR&D) funds[15] 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.

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

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

7. COST SHARE CONTRIBUTIONS BY FFRDCS AND GOGOS

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

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

8. COST SHARE VERIFICATION

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

C. OTHER

1. COMPLIANT CRITERIA

Concept Papers are deemed compliant if:

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

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

Full Applications are deemed compliant if:

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

Full Applications found to be noncompliant 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 do not address the required technical information (i.e. information that "must" be included), as specified in Sections I.D and I.E of the FOA.
- Submissions that have been submitted in response to other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from 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:

- Solutions that address thermal management issues in datacenters.
- Solutions to electrical energy conditioning distribution within datacenters.
- Solutions that address power delivery to datacenters.
- Electronic logic gate advances.
- Integrated circuit (server, switching, memory) advances.
- Datacenter networking or network element advances not directly related to the incorporation of integrated photonic interconnects and switching technologies.
- Submissions that do not explain how the proposed network design will leverage projected performance advantages of photonics-enabled sub-systems.
- Submissions for which the efficiency gains derive solely from future improvements in CPU, memory, or other datacenter electrical components or architectural efficiency enhancements (e.g., anticipated silicon CMOS scaling, or energy-proportional computing strategies).

- Optical computing concepts.

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 30 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

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

5. PRE-SELECTION CLARIFICATIONS AND "DOWN-SELECT" PROCESS

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

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

6. SELECTION FOR AWARD NEGOTIATIONS

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

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

7. MANDATORY WEBINAR

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

B. APPLICATION FORMS

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

C. CONTENT AND FORM OF CONCEPT PAPERS

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

- The Concept Paper must not exceed 4 pages in length for partial solutions, or 6 pages in length for full solutions, including graphics, figures, tables, and/or references.
- 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.
- Specify if you are submitting a full solution or partial solution.
- Partial solutions are limited to 4 pages, full solutions are limited to 6 pages.
- All Concept Papers must describe Phase 1 and Phase 2 work, with Phase 1 in more detail.

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.E of the FOA for the appropriate Technology Category in Section I.D of the FOA.

c. PROPOSED WORK

- Describe the final deliverable(s) for the project and the overall technical approach used to achieve project objectives. Applicants must address the deliverables listed in Section I.E of the FOA.

- 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.

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 SEPTEMBER 2016]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

F. INTERGOVERNMENTAL REVIEW

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

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

H. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

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

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

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

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Concept Paper, or Full

Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

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

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

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

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

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

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

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

1. CRITERIA FOR CONCEPT PAPERS

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

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- Achievement of the technical performance targets defined in Section I.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and
- Demonstration of awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

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

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;
- Sufficiency of technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;
- Clearly defined project outcomes and final deliverables;
- Identification of techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and
- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

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

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

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

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

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

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

III. **Synergy of Public and Private Efforts**.
   a. Avoids duplication and overlap with other publicly or privately funded projects;

b. Promotes increased coordination with nongovernmental entities for demonstration of technologies and research applications to facilitate technology transfer; or
c. Increases unique research collaborations.

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

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

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

2. ARPA-E REVIEWERS

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

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

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

3. ARPA-E SUPPORT CONTRACTOR

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

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of

ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. ANTICIPATED ANNOUNCEMENT AND AWARD DATES

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

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

2. CONCEPT PAPER NOTIFICATIONS

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

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

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

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN SEPTEMBER 2016]

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

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

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

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

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

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

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

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

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

B. DEBRIEFINGS

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

VIII. OTHER INFORMATION

A. FOAS AND FOA MODIFICATIONS

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

B. OBLIGATION OF PUBLIC FUNDS

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

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

C. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

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

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

D. RETENTION OF SUBMISSIONS

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

E. MARKING OF CONFIDENTIAL INFORMATION

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

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

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

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

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

F. TITLE TO SUBJECT INVENTIONS

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and

Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

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

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

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

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

G. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

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

1. GOVERNMENT USE LICENSE

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

2. MARCH-IN RIGHTS

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

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

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

3. U.S. MANUFACTURING REQUIREMENT

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

H. RIGHTS IN TECHNICAL DATA

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

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

I. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

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

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

J. COMPLIANCE AUDIT REQUIREMENT

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

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

IX. REFERENCES

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X. GLOSSARY

b: bit

B: Byte = 8 bits

b/s: bits/second

Tb/s: 10^{12} bits/second

Bandwidth density: the amount of bits/second per unit length along the perimeter edge of an electrical processor chip, such as a CPU or memory chip, subject to practical constraints of size and design that is embedded on a server board

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

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

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

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

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

DOE: U.S. Department of Energy.

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

Electrical interconnect: all associated circuitry and components needed to send data between electrical processor or memory chips

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

FLOPs: Floating Point Operations per second

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

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

Interconnect: data link between devices

ITRS: International Technology Roadmap for Semiconductors

Long Reach: Over 1 km

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

Network: All of the IT infrastructure required to move data in a datacenter, aside from electronic processor and memory chips in servers

Network architecture: the topology of connections between switches and servers and their interconnects in datacenters

North-South and East-West communications: Data communications at the level of the TOR and above is commonly referred to as "east-west" and from the TOR to the processor and memory chips within server boards as "north-south".

OE / EO: optical to electrical data conversion / electrical to optical data conversion

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.

Radix: the number of ports in a switch, for example if a switch has an aggregate bandwidth of 1 Tb/s and a radix (in other words , port count) of 10, that means that the switch has 10 ports at 100 Gb/s each, or a radix = 10 with 100 Gb/s per port.

Silicon Photonics: study and application of photonic systems which use silicon as an optical medium

Single mode fiber: is optical fiber that is designed for the transmission of a single ray or mode of light as a carrier

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

Store-and-forward: telecommunications technique in which information is sent to an intermediate station where it is kept and sent at a later time to the final destination or to another intermediate station.

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

Switch: computer networking device that connects devices together on a computer network, by using packet switching to receive, process and forward data to the destination device.

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.

Top of the Rack: portion of the network interconnect above the server racks

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.

Transceiver: device comprising both a transmitter and a receiver which are combined and share common circuitry or a single housing

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

VCSEL: vertical-cavity surface-emitting laser