U.S. Department of Energy
Advanced Research Projects Agency – Energy

Request for Information (RFI)
DE-FOA-0002134
on
Energy Efficient Integrated Photonic Networking Technologies

Objective:

The Advanced Research Projects Agency – Energy (ARPA-E) of the United States Department of Energy is seeking information concerning the current state of development of energy efficient photonic technologies for communication networks within datacenter and high-performance computing (HPC) systems. ARPA-E is interested in technologies which have the potential to enable a transformative improvement in performance and efficiency of datacenter and HPC systems as compared to the state of the art. Specifically, ARPA-E is interested in learning of technologies that can meet the technical metrics originally outlined in the *ENLITENED* FOA DE-FOA-0001566, but that are not currently funded under the portfolio of projects in the ARPA-E *ENLITENED* program.

ARPA-E is seeking information on technologies at an advanced level of development, albeit prior to commercialization and full-scale production. ARPA-E is not interested in early stage technologies which are unproven or not yet reduced to practice in the form of an operational device/component/subsystem. Depending on the responses to this RFI, ARPA-E may consider the rapid initiation of a competition that would result in one or more funded collaborative research projects to advance the state of the art in integrated photonic networking technologies.

Please carefully review the REQUEST FOR INFORMATION GUIDELINES below. Please note, in particular, that the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

Background:

Data centers in aggregate use a significant fraction of the United States' total energy output, with the latest estimates suggesting 70 TWh, or approximately 2% of the total US annual consumption.[1] At the same time, the continued exponential growth of internet and datacenter traffic is expected to fuel data center expansion/scale-up, and therefore total power consumption.

ARPA-E's founding principles include funding R&D to reduce US energy imports, to reduce the emissions associated with the production and consumption of energy, to improve the energy efficiency of energy production, storage, transmission distribution and end usage, and to improve US competitiveness. Improving the energy efficiency of domestic datacenters to manage their future energy usage is thus of interest to ARPA-E. Given the overlap in underlying networking needs, it is expected that certain technologies will find dual-use for HPC applications as well, which is another mission critical area of

[1] Arman, S., Smith, S. J., Sartor, D. A., Brown, R. E., Herrlin, M., Koomey, J. G., Masanet, E. R., Horner, N., Azevedo, I. L., Lintner, W. *United States Data Center Energy Usage Report*. LBNL-1005775. Lawrence Berkeley National Laboratory, 2016.

interest for the Department of Energy.

Efficiency improvements in the supporting infrastructure of a datacenter or HPC system such as the cooling infrastructure and power delivery systems, as well as efficiency improvements to individual server/node-level technologies such as compute chip performance as derived from compute core design/scaling may contribute to overall datacenter/HPC efficiency. These research areas are addressed in various other research efforts and are not of direct interest here. ARPA-E specifically seeks to learn of networking technologies and associated topologies which can provide a multiplicative enhancement in overall system level efficiency by unlocking network bound performance boosts.

ARPA-E launched the *ENLITENED* program two years ago (https://arpa-e.energy.gov/?q=arpa-e-programs/enlitened), which is currently funding the development of a diverse portfolio of solutions to enable future high-performance, low-latency networking fabrics exploiting high-density integrated photonic chip-scale I/O and switching technologies. Accomplishments to date have realized strong progress towards program goals. Specifically, teams have demonstrated link energy within 2 pJ/bit of the *ENLITENED* metrics and novel packaging approaches have been implemented with aggregate bandwidth densities surpassing the FOA metrics. Also, initial modeling and simulation efforts have validated significant total system architecture efficiency improvements on relevant datacenter and HPC workloads enabled through the innovative network architectures. For the purposes of this RFI, ARPA-E is interested in learning of technologies and solutions currently not funded under *ENLITENED*, but that are within scope of the original FOA, have a credible path towards achieving the original FOA metrics, and have not yet reached commercialization.

Purpose and Need for Information:

The purpose of this RFI is solely to solicit input for ARPA-E's consideration, to inform the possible formulation of future ARPA-E projects or programs intended to further the research and development of energy efficient integrated photonic networking technologies for datacenters and HPC. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI. This RFI provides the broader community with an opportunity to contribute facts, data, information, and projections regarding the current state of the art integrated photonic networking technologies and the potential for transformative energy efficient system performance scaling as enabled by the former.

REQUEST FOR INFORMATION GUIDELINES:

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents should not include any information in the response to this RFI that might be considered proprietary or confidential.** However, respondents should indicate in their responses if additional confidential or proprietary information exists that would be helpful to ARPA-E in assessing respondents' technologies. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI.

Depending on the responses to this RFI, ARPA-E may consider the rapid initiation of a competition that would result in one or more funded collaborative research projects to advance the state of the art in integrated photonic networking technologies with the potential to enable >2x improvements in the average "wall-plug" efficiency of the entire ICT system of a datacenter or HPC. This may manifest in, for

example, reduced overall task execution time, increase in the number of tasks completed per unit time, improved resource utilization improvement, or another metric which may be proposed in the RFI response.

Responses to this RFI should be submitted in PDF format to the email address ARPA-E-RFI@hq.doe.gov by **5:00 PM Eastern Time on June 14th, 2019**. Emails should conform to the following guidelines:

- Please insert "Responses for Energy Efficient Integrated Photonic Networking Technologies" in the subject line of your email, and include your name, title, organization, type of organization (e.g. university, non-governmental organization, small business, large business, federally funded research and development center (FFRDC), government-owned/government-operated (GOGO), etc.), email address, telephone number, and area of expertise in the body of your email.
- Responses to this RFI are limited to no more than 8 pages in length (12 point font size, 1 inch margins).
- Respondents should include non-proprietary results, data, information and figures that describe their current technology (that meets the target requirements of this RFI), the current state of development of the technology, as well as any plans they have for the further development of the technology.

ARPA-E encourages responses to the following. ARPA-E is interested in both technology solutions as well as relevant application areas where the technology can be applied. Please provide answers and information about any of the following questions to the fullest extent; citations are encouraged as appropriate. For the questions below, ARPA-E is specifically interested in application areas which are of relevance for hyperscale datacenters and HPC:

- As stated in the original FOA, "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... via the incorporation of advanced integrated chip-scale photonic interconnects and switching technologies." ARPA-E is interested in learning of technologies and solutions not currently funded under *ENLITENED*, but that have a credible path towards achieving the original FOA metrics, have not yet reached commercialization, and are applicable to either datacenters and/or HPC.
- ARPA-E is interested in descriptions of vertically integrated end-to-end solutions comprising enabling component technology such as high density photonic I/O integrated with switching elements forming and/or enabling a novel network fabric. Please describe in detail the integrated technology platform (including interconnects, switching elements, integration scheme, 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 for future datacenters and HPC systems. Further describe the network structure enabled by the technology presented, and articulate how that would lead to a transformative energy efficiency and/or performance improvements.
    - Interconnect technology
        - End-to-end signaling energy in pJ/bit including electronic overhead and all system losses
        - Bandwidth density as measured by the linear chip-edge
    - Switching scheme and characteristics – either:
        - Photonically-enabled electronic switches, or
        - Optical switches, or
        - A hybrid solution of both
    - Network topology

        - Control scheme
        - Latency characteristics (e.g. average latency, end-to-end latency, average hop count)
    - System level impact and projections
        - What is the expected enhancement in application performance over state of the art when the described solution is deployed at scale?
    - Application drivers: Describe a class of applications or workloads which are currently network bound and may benefit from the technology solution described. Identify the scale of the application (cluster scale, datacenter scale), and how the performance might scale with increased network bandwidth and/or the novel network concept proposed.

- For the aforementioned solutions described, please also address the following questions below**:**
    A. Current status: Describe the current status of development of their technology.
    B. Future development plans: Describe the potential future status of development of their technology. Include data, information, and descriptions as required to indicate the potential of attaining the technical metrics and targets listed in Table 1 below. In particular, respondents should provide information about the readiness of their technology for transition into the market place in the 2022 timeframe, and the pathway anticipated for that transition.
    C. Team and Capabilities: Briefly describe their organization's capabilities in this field, including areas of expertise in design, fabrication, packaging, and simulation/emulation.

Topics Not of Interest:

ARPA-E is not interested in technologies which have yet to be developed, demonstrated, or reduced to practice. For the purposes of this RFI, ARPA-E is not interested in evolutionary technologies that provide an incremental advance against the state of the art. For the purposes of this RFI, ARPA-E is not interested in receiving information not related to networking technology for datacenters and HPC.

Reference:
Original *ENLITENED* FOA metrics provided here for reference. The respondent is also encouraged to read through Section I of the original *ENLITENED* FOA for context.

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.

1.3	BW Density Demo: Chip or Chip carrier I/O	> 1TB/s/cm*	• The proposed packaging approach enables 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

***Note, BW density requirement is 8x that stated in the original FOA. The original target in the FOA had a capitalization typo which misstated "TB/s/cm" as 'Tb/s/cm".**