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

Request for Information (RFI)
DE-FOA-0001609
on
Novel Power Electronic Systems Enabled by Wide-Bandgap Semiconductors

Objective:

ARPA-E seeks input from the power electronics, electrical engineering, and circuit design communities regarding the development of next-generation advanced circuit topologies for use in power electronics systems that facilitate higher efficiency, more reliable, reduced size and weight, and lower cost devices and/or system architectures. Consistent with the agency's mission, ARPA-E is seeking clearly disruptive, novel technologies, early in the R&D cycle, and not integration strategies for existing technologies.

With advanced circuit topologies, it is possible to envision realizing efficiency gains both directly, by inherently more efficient designs, and indirectly, by facilitating higher levels of adoption for fundamentally higher performing materials. ARPA-E desires input from a broad range of disciplines and fields, including, but not limited to: power electronics, electrical engineering, circuit design, wide-bandgap materials, semiconductor devices, packaging and module design, and others. This includes input from the developers and end-users of such technologies, such as power supplies, LED drivers, data centers, automotive (Electric and Hybrid Electric Vehicles), high-performance computing centers, solar inverters/power conditioners, electric motor driven systems, wind-electric systems, high/medium voltage transmission/distribution, rail/ship propulsion, and emerging new applications not yet categorized. ARPA-E is particularly interested in how next-generation advanced circuit topologies will help to realize the promise of higher efficiency systems.

Please carefully review the REQUEST FOR INFORMATION GUIDELINES below, and note in particular: 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. Respondents shall not include any information in their response to this RFI that might be considered proprietary or confidential.**

Background:

Power electronics are an integral part of many energy systems, including but not limited to power supplies, LED drivers, data centers, automotive, solar inverters, and electric motor drives. By 2030, an estimated 80% of all U.S. electricity is expected to flow through power electronics[1]. Because of this high potential impact, ARPA-E has invested significantly in programs to develop power electronics

[1] Department of Energy Office of Energy Efficiency and Renewable Energy. Power America – Wide-bandgap Semiconductors. [http://energy.gov/eere/amo/power-america]

technologies[2,3,4]. These previous efforts have focused primarily on material and device development where advanced wide-bandgap semiconductor materials, such as silicon carbide and/or gallium nitride, would be substituted for silicon, but mostly without focused consideration and redesign of the circuit topology. Direct replacement of Si devices by wide-bandgap semiconductor devices offers limited improvements in power electronic performance metrics. Thus, there is now an opportunity to build on the successes from earlier programs and aim for both higher performance, as well as increased market penetration of these highly promising technologies.

Given the capabilities of emerging wide-bandgap materials and devices, ARPA-E believes there are new opportunities for innovations in power electronics such as converter circuit topologies and architectures, resonant and soft switching, control techniques, integration and packaging, and system architectures. These innovations can support ARPA-E's mission by leading to higher efficiency power conversion in two different ways: (1) directly, through realization of design that are more efficient and (2) indirectly, by enabling inherently higher efficiency wide-bandgap materials. Recent advances have demonstrated high performance wide-bandgap semiconductor devices, but they have not yet achieved high rates of adoption because power circuits have not been designed that exploit their inherent advantages. Additionally, there are concerns about the cost and reliability of wide-bandgap semiconductor devices. New circuit topologies could be designed to fully extract the potential of wide-bandgap semiconductor devices while addressing the cost and reliability concerns.

ARPA-E believes that the timing is right to leverage recent progress in electronic materials and devices to fully realize their benefits. There are numerous precedents for advances in device technology to require new approaches at the circuit and system level for significant proliferation of the technology. For example, recent programs in compound semiconductors have driven progress in envelope tracking circuits for reducing power (which extends lifetime), as well as performance improvements via heterogeneous integration with other device technologies[5]. Basic materials and device developments (e.g., low-k dielectrics, silicon-on-insulator wafers, Cu interconnect) are typically slow to be adopted often due to reliability concerns and can take 5-10 years until circuit and product teams learn how to make use of the new technology reliably in their designs. This is currently happening with recent progress in 3D memory technology, with designers learning to leverage the new capability[6,7]. Solar inverters provide another example, with circuit designs incorporating distributed inverters throughout solar cells, the overall reliability and performance of the system are improved compared to having one larger inverter farther away from the solar panels. This guidance from the recent history of progress in advanced electronics has generated ARPA-E's interest in a potential effort in novel power electronic systems enabled by wide-bandgap semiconductors to continue to advance the exciting power electronics technologies developed in previous R&D projects.

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[2] Agile Delivery of Electrical Power Technology (ADEPT). 2010.
[http://arpa-e.energy.gov/sites/default/files/documents/files/ADEPT_ProgramOverview.pdf]
[3] Solar Agile Delivery of Electrical Power Technology (Solar ADEPT). 2011.
[http://arpa-e.energy.gov/sites/default/files/documents/files/Solar%20ADEPT_ProgramOverview.pdf]
[4] Strategies for Wide-Bandgap, Inexpensive Transistors for Controlling High-Efficiency System (SWITCHES). 2013
[http://arpa-e.energy.gov/sites/default/files/documents/files/SWITCHES_Program%20Overview.pdf]
[5] Green, Daniel, et al. "Heterogeneous Integration for Revolutionary Microwave Circuits at DARPA." *Microwave Journal* (June 2015).
[6] Courtland, Rachel. "Intel and Micron Move 3-D NAND into Production." *IEEE Spectrum* (April 2015).
[7] Sugiyama, Yusuke, et al. "Application Dependency of 3-D Integrated Hybrid Solid-State Drive System with Through-Silicon Via Technology." International Conference on Electronic Packaging (April 2016).

ARPA-E is thus seeking input from the broad research and development community with regard to developing advanced circuit topologies and systems; in particular, circuits that incorporate advanced wide-bandgap materials that are inherently more efficient, such as SiC or GaN. In addition, we would like to understand all barriers to adoption, whether technical or market-based and any ideas on which might be solved through innovative circuit design. Such insights that leverage the application and adoption of these advanced circuit topologies to well-defined end-use applications are strongly encouraged.

Purpose and Need for Information:

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future programs intended to help create transformative converter circuit topologies that enable innovative higher efficiency power electronics systems. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI on a non-attribution basis. This RFI provides the broad research community with an opportunity to contribute views and opinions regarding the advanced circuit topologies development path, energy use and adoption consideration in relevant end-use applications. Based on the input provided in response to this RFI and other considerations, ARPA-E may decide to issue a Funding Opportunity Announcement (FOA). If a FOA is published, it will be issued under a new FOA number. No FOA exists at this time. ARPA-E reserves the right to not issue a FOA in this area.

REQUEST FOR INFORMATION GUIDELINES:

ARPA-E is not accepting applications for financial assistance or financial incentives under this RFI. Responses to this RFI will not be viewed as any commitment by the respondent to develop or pursue the project or ideas discussed. ARPA-E may decide at a later date to issue a FOA based on consideration of the input received from this RFI. 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 reserves the right to contact a respondent to request clarification or other information relevant to this RFI. All responses provided will be taken into consideration, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that might be considered proprietary or confidential.**

Responses to this RFI should be submitted in PDF or Word format to the email address ARPA-E-RFI@hq.doe.gov by **5:00 PM Eastern Time on Monday, ~~August 29th~~ October 17,** 2016. ARPA-E will not review or consider comments submitted by other means. Emails should conform to the following guidelines:

- Please insert "Responses for RFI Number DE-FOA-0001609" 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 10 pages in length (12 point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential methodologies. However, do **not include any information in a response to this RFI that might be considered proprietary or confidential**

- **Questions:** ARPA-E encourages responses that address any subset of the following questions of relevance to the respondent and encourages the inclusion of references to important supplementary information.

1) Envisioning what is possible when barriers are removed.
   a) What are the system challenges that can be addressed with new circuit topologies in the application areas below? Why would each of these application areas be (or not be) an attractive target for early application of new circuit topologies? How should prioritizing or targeting different application areas be deliberated? To what extent would targeting each of these applications advance ARPA-E's mission?

      (i) Industrial electric motor driven systems
      (ii) Data centers / High-performance computing centers
      (iii) Automotive (electric and hybrid electric vehicles)
      (iv) Power supplies
      (v) Solar inverters/power conditioners
      (vi) Wind-electric systems
      (vii) LED drivers
      (viii) High/medium voltage transmission/distribution electronics (e.g. power flow controllers)
      (ix) Rail and ship propulsion

   b) Are there any other existing or emerging application areas that ARPA-E should be interested in because of their high energy impact and potential for improvement via novel circuit topologies?

   c) Are there challenges across multiple applications that can be addressed by new advanced power circuits to help drive significant adoption of GaN / SiC electronics? Examples could include reliability, lifetime, and cost. Which areas share common challenges, allowing for common performance targets/objectives?

2) Evaluating success and setting attainable stretch goals

   a) For each of the application categories, how should a novel power electronic circuit be evaluated? How should the focus on peak efficiency be balanced versus some other metric that captures efficiency across typical operating conditions? In what applications would peak efficiency be less important than partial load efficiency?
   b) How would the novel power electronic circuit advance ARPA-E's mission to decrease our nation's dependence on foreign energy sources, reduce greenhouse gas emissions, improve energy efficiency across the board, and maintain or reestablish U.S. technological leadership in the energy sector?
   c) What would a convincing demonstration of the novel power electronic circuit be and at what scale (power or otherwise) to make a compelling case?
   d) What should the success metric(s) be for the power electronic circuit? An example table with strawman metrics for some potential application areas is shown in Table 1, and feedback is sought on metrics and target values for all application areas previously identified and emerging applications. Define the application specific metrics in as much detail as possible. In your opinion, what can be realistically achieved in 3, 5, 10 years?

e) For other potential application areas of interest, how should novel power electronic circuits be evaluated and what are potential metrics to motivate development, evaluation, and market adoption?

Table 1: Example performance targets for four application areas of potential interest

Application	Metric	State of the Art	Target
Data Centers	Efficiency (%) at UPS power, cost, lifetime of interest	92.5%[8]	
Solar Inverters	Efficiency (%) at weight, power, cost, lifetime of interest	94%[9]	
Electric Vehicles	Power Density (kW/L) of a) electric drives b) other power electronics (inverter, converter, controller)	a) 2.6 kW/L[10] b) 12 kW/L	
LED Drivers	LED efficacy (lumens / Watt)	200 lm/W[11]	

3) What other new technology development should ARPA-E consider with the goal of enabling advanced power electronic circuits? Possibilities could include:

a) New packaging and module technologies would likely result in more compact systems, which would give designers more options in their power electronics circuits.
b) Advanced thermal management technologies could also allow higher density functionality and extended device lifetimes or operating modes for power electronics.
c) Technologies that also enable power electronics to be integrated into systems or places where that is not possible today. For example, the need for liquid cooling or fans is a major impediment to the adoption of power electronics in grid applications. If efficiency improved to the point where a novel thermal management approach with no moving parts could be used that field would change entirely.
d) New passive device capabilities would also give designers more degrees of freedom due to miniaturization and/or performance improvements.
e) Novel methods for reducing or eliminating electromagnetic interference (EMI) and realization of circuits that achieve electromagnetic compliance (EMC) by design.
f) Others?

4) What else besides cost issues might prevent adoption of a novel power electronic circuit in the various application categories? Are there technical and market barriers to wide spread adoption? How could these barriers be overcome?

[8] Zhabelova, Gulnara et al. "Data Center Energy Efficiency and Power Quality: An Alternative Approach with Solid State Transformer." IEEE Industrial Electronics Society Conference (2015).
[9] Amirabadi, Mahsid. "A New Class of High-Power-Density Universal Power Converters." Energy Conversion Congress and Exposition (2015).
[10] Rogers, Susan et al. "Overview of the DOE Advanced Power Electronics and Electric Motor R&D Program." US DOE (June 2014).
[11] "Energy Efficiency of LEDs." Building Technologies Program, US DOE.