

ADEPT Program Overview

B.1. BACKGROUND

In the U.S., about 40% of the primary energy consumed is used to produce electricity. Electricity is projected to supply an increasing share of the world's total energy demand and is the fastest-growing form of end-use energy worldwide. Deploying advanced power electronics could provide as much as a 25-30% reduction in electricity consumption, representing 12% of the total U.S. energy consumption. Further, innovations in power electronics could lead to significant reduction in costs, promoting U.S. businesses through our technological leadership.

The ADEPT program considers the following sectors:

- **Industrial** Two-thirds of the world's industrial energy runs electric motors and only 5% of these use variable speed drives, which consume 1/8th the energy of a constant speed drive. It is estimated that industrial applications of new energy saving power electronics could improve energy efficiency by up to 88%.
- **Automotive** Power electronics are a key technology for hybrid vehicles and represent 20% of the material costs; this percentage is even larger for electric vehicles (EVs). As cars rely more on electric drives, the motor power increases beyond 100 kW with voltages approaching the voltage and temperature limits of conventional switch technology.
- **Lighting** 19% of total U.S. energy consumption is for lighting in residential and commercial buildings. Solid-state lighting offers the potential for 80% reduction in this consumption. However, commercial LED drivers (for incandescent lamp replacement) today have efficiencies of only 60-85%. High-efficiency power electronics with small form factors and low material utilization that can also be scaled to high-volume production are necessary to realize the full cost savings of solid-state lighting (SSL) systems.
- **Utility - Electricity Delivery** Presently, 30% of all electric power generated uses power electronics somewhere between the point of generation and end use. By 2030, 80% of all electric power will flow through power electronics. Power electronics are used in many forms to control electric power flow or serve as grid interfaces to convert electric power to meet specific needs. Lower costs of semiconductor switches, along with higher efficiency, reliability, switching frequency, and temperature operation are needed for electric utility applications.
- **Photovoltaics** The DOE Solar Energy Technologies Program's Multi-Year Technical Plan establishes a goal of reducing the Levelized Energy Cost for photovoltaic (PV) systems to approximately \$0.10/kWh by 2020. The Multi-Year Technical Plan estimates that in order to meet the PV system goal, PV inverter prices will need to decline by a factor of 3 to approximately \$0.01/kWh by 2020.¹

Conventional power electronics are limited by:

- the loss and voltage breakdown in the semiconductor switches;
- the loss, size, and cost of the magnetic elements such as ferrite inductors and transformers; and
- the reliability, size, and energy density of the charge storage elements such as electrolytic capacitors.

When these individual components are assembled into systems, further losses due to thermal and electrical parasitics as well as new failure mechanisms from board interconnections are introduced. Balancing the limitations of individual components has resulted in systems that trade off efficiency, power density, and cost. Today, these trade-offs are made

¹ Navigant Consulting Inc. for DOE, "A Review of PV Inverter Technology Cost and Performance Projections," January 2006

within the constraints of silicon switch technology (>90% of all switches being Silicon MOSFETs, IGBTs, and thyristors for the various application voltages) and manganese zinc ferrite magnetics.

The goal of the ADEPT program is to invest in technologies that can leapfrog over today's approaches and create the technologies to enable a 25-30% reduction in electricity consumption and significant reductions in cost and form factor for power electronics.

B.2. OBJECTIVES

This FOA is primarily focused on the development of advanced component technologies, converter architectures, and packaging and manufacturing processes with the potential to improve the performance and lower the cost of power converters and power management systems. Specifically, three categories of performance and integration level will be considered.

Category 1 seeks to broaden the application space for *fully-integrated, chip-scale power converters* from mobile applications to applications including, but not limited to, dimmable SSL drivers, distributed micro-inverters, and computer power supplies. To address these broader applications, the performance of integrated converters must scale from today's 1W class chips to 10W and 50W class converters supporting voltages beyond 100 V or currents beyond 10A. Technologies for chip-scale converters at line-voltages is of particular interest.

Category 2 seeks to broaden the application space for *package integrated power converters* by reducing the size and improving component and package performance enabling applications such as inverters for grid-tied photovoltaics and variable speed motors. To address these applications, the performance of package integrated converters must scale from 10A (current state of the art) to the 40A range, and/or voltage levels beyond 600V, and power levels beyond 3 kW.

Category 3 addresses *lightweight, solid-state, medium voltage* energy conversion for high power applications such as solid-state substations and wind turbine generators. To address these applications, new solid-state switch technology at voltages exceeding 13kV and advanced magnetics technology supporting MW scale power converters with multi-kilohertz frequencies are of particular interest.

B.3. AREAS OF INTEREST

Any technology able to meet or exceed the "Primary Technical Requirements" and to meet or exceed the majority of the "Secondary Technical Targets" stated below will be considered for award under this FOA. However, areas of particular interest for this FOA include, but are not limited to, the following:

- Magnetic materials with high operating flux densities exceeding 0.5T at frequencies greater than 1 MHz for a power loss of 300 kW/m³ (15x greater than MnZn ferrites) while achieving electrical resistivity exceeding 1mOhm-cm (5-10x greater than MnZn ferrites) and exhibiting high thermal conductivity. The magnetics should exhibit stable performance to temperatures exceeding 125 °C. Examples include but are not limited to:
 - Air core magnetics with low winding loss and low electromagnetic interference
 - The design and manufacturing processes for thin film magnetic components with the above magnetic properties that can be integrated on to electronic switching devices.
 - Bulk materials (e.g. ceramic nanocomposites) with the above properties for package integrated converters.
 - Quantitative modeling of advanced soft magnetic materials.
- Advanced solid-state switch technologies to support miniaturization of power converters in all System Categories. Specifically, components that achieve higher switching frequencies and higher breakdown voltages with low switch losses (low on resistance). Technologies to be considered include advanced Silicon switches as well as wide-bandgap devices (examples include but are not limited to SiC, GaN, GaN on Si, diamond, ZnO).

- Fully integrated power switches with 10x higher operating voltages and switching frequencies than conventional Silicon.
- Switches (thyristors, IGBTs, etc) with operating voltages exceeding 13kV. First in class demonstration of bipolar switches in wide-bandgap semiconductor technology. Optically controlled medium to high voltage switches.
- Advanced circuit topologies and converter architectures that support higher reliability, lower costs, and/or miniaturization. Topologies that mitigate/manage the limitations of passive components. Examples include but are not limited to:
 - Transformer-less medium (600-15kV) voltage converters
 - High efficiency line-voltage converters without electrolytic capacitors
 - Integrated, high-efficiency switched capacitor converters
 - Advanced arc-fault detection and self-diagnostics
- Advanced charge storage devices with power densities approaching electrolytic capacitors. High energy density supporting 10ms pulse times.
 - High speed and higher voltage ultracapacitors
 - Improved energy density thin film capacitors

B.4. TECHNICAL REQUIREMENTS

This FOA is focused around supporting power converter technology research and development projects that are able to address the specific quantitative target performance metrics described below. Proposed technology development plans must have well justified, realistic potential to meet or exceed the stated “Primary Technical Requirements” by the end of the period of performance of the proposed project in order to be considered for award. Proposed technologies will secondarily be evaluated against their well justified, realistic potential to approach the “Secondary Technical Targets” by the end of the period of performance of the proposed project. Proposed technologies may still be considered for award if they fall short of one or more of the Secondary Technical Targets below, but will be evaluated and compared to one another according to their ability to address these targets.

The general expectation is that applicants will be proposing to develop technologies at the component and system level. Relevant system level metrics are defined below. Component level metrics may be estimated using reasonable assumptions, which must be clearly stated. The discussion of component performance should include a presentation of the development status of the existing approach and a detailed plan to realize the component performance required to meet the FOA goals presented in the tables below. For example:

- A proposal seeking to develop GaN-on-Si switches must clearly state the metrics (such as conduction losses, leakage currents, breakdown voltages, thermal performance) achievable at the start of the program and the end of the program. A research plan in terms of novel materials growth, device processing, and/or device design to achieve the necessary performance should be presented.
- Similarly, a proposal seeking to advance the state-of-the-art for SiC bipolar switches must clearly state the metrics achievable at the start of the program and the end of the program. A research plan in terms of novel materials growth, device processing, and/or device design to achieve the necessary performance should be presented.
- A proposal seeking to advance the state-of-the-art for magnetics must clearly state the metrics (such as core loss at a particular switching frequency, including electrical conductivity and hysteresis loss, magnetic permeability, and thermal performance) achievable at the start of the program and the end of the program. A research plan in terms of novel materials growth, device processing, and/or device design to achieve the necessary performance should be presented.

For all of the above, full proposals should include preliminary data to support claims of material characteristics, component performance, and converter design.

The Primary Technical Requirements and Secondary Technical Targets for this FOA are clearly stated in the two tables below.

PRIMARY TECHNICAL REQUIREMENTS:

System Categories	Voltage & Power	Efficiency	Switching Frequency	Function	Size
Category 1	>100V 10-50W	>93%	>5 MHz	DC/DC AC/DC DC/AC	single-chip converter (including magnetics, capacitors, switches)
Category 2	>600 V 3- 10kW	>95%	>1 MHz	AC/DC DC/AC	multichip module package integrated converter
Category 3	13 kV 1 MW	>98%	>50 kHz	DC/DC AC/DC	NA

SECONDARY TARGET REQUIREMENTS:

System Categories	Temperature	Controller Electronics	Volume Efficiency
Category 1	>100 °C	On-chip integration Fault monitoring & detection	>300 W/in ³
Category 2	> 100 °C	In-package integration Fault monitoring & detection	>150 W/in ³
Category 3	>150 °C	Fault monitoring & detection	NA

In addition to the Primary Technical Requirements and Secondary Technical Targets detailed above, applicants must address the following key technical requirements.

1) **Manufacturability of Proposed Technology at Scale**

The applicant must describe the manufacturing approach(es) that will most likely ultimately be used to scale up the proposed converter technology to be prototyped in the proposed research and development project and must discuss the ability of this/these manufacturing approach(es) to scale at sufficiently low cost to address the target application. The applicant is also encouraged to describe whether or not the proposed component or converter technology offers an opportunity for the U.S. to take a leadership role in manufacturing and to provide justification.

2) **Technical Strength of the Performance Team**

The applicant should describe the unique elements/background/skills of the proposed technical team that make the team uniquely suited to successfully execute the proposed research and development plan. The teams should be able to demonstrate specific expertise on magnetic materials, advanced switch technologies, thermal management, and packaging.

B.5. CONCEPT PAPER STRUCTURE

Applicants are required to first submit a Concept Paper describing the essence and novelty of their new technology concept in order to be considered for award under this FOA. The purpose of the Concept Paper phase of this FOA is to allow applicants to communicate their technology concept to ARPA-E, with a minimal level of investment in time and resources, and receive feedback on ARPA-E's level of interest in the concept before ARPA-E requests the submission of a more time and resource intensive Full Application.

General Concept Paper requirements can be found in Section IV.B.2 of this FOA. Specific requirements and key elements that each Concept Paper must address are found in this section (Section I.B.5) and in the rest of Section I.B.

As stated in Section IV.B.2, Concept Papers will consist of a body not exceeding five (5) pages in length containing the following sections: 1.) Abstract and 2.) Technical Section. The Concept Paper will also include a one page "Cost Summary" (described in Section IV.B.2) that should be included in a single Concept Paper file, but will not count toward the five (5) page Concept Paper body limit.

TECHNICAL SECTION

Specific issues/questions that should be considered and addressed in the Technical Section include the following:

- Identification of whether the applicant is applying for an award under the "Proof of Concept" category or the "Advanced Device Prototyping" category. Please see definitions on in section B.7 on page 12 of this document.
- The applicant should clearly identify the System Category being addressed. The applicant must identify a specific application (for example but not limited to solid-state lighting, hybrid vehicles, PV microinverters, wind turbines) that is being addressed in the proposal. Application specific metrics for the power converter must be stated and justified. A detailed description of the state-of-the-art in that technology as well as the impact of the proposed power converter technology on the chosen application area must be provided.
- A detailed description of the novel technology approach to be developed in the proposed project, including a description of its basic operating principles of how the proposed approach is unique and innovative.
- A description of the current state-of-the-art in the proposed technology area, including key shortcomings/limitations/challenges, and how the proposed project will seek to significantly improve upon the current state-of-the-art performance and overcome current key shortcomings/limitations. A discussion on how it could significantly reduce costs, when relevant, should be provided.
- The applicant should provide a brief paragraph addressing the following issues for each of the Primary Technical Requirements and Secondary Technical Targets:
 - What is the current state-of-the-art performance level for the proposed technology area for the specified requirement/target?
 - What level of performance will the project proposed here target for the specified requirement/target?
 - What are the specific technical issues that have limited performance of this technology to date for the specified requirement or target?
 - How does the project proposed here address these specific technical issues to provide enhanced performance relative to the specified requirement or target? The applicant should provide technical justification for why this proposed target can credibly be met.
 - What are the key technical risks/issues associated with the technology development plan related to the specified requirement or target?
- A brief description of the manufacturing approach by which the proposed technology would most likely be scaled and the scalability/cost issues related to this approach.
- A brief description of how the project, if successful, would impact U.S. leadership in technology development and manufacturing.

- A brief description of the project team and why they are uniquely suited to successfully execute the proposed research and development plan.
- A brief description of the impact ARPA-E funding of the proposed project would have relative to other previous or existing funding sources the project team has secured.

B.6. CONCEPT PAPER EVALUATION CRITERIA

General Concept Paper Evaluation Criteria are found in Section V.A. of this FOA. More specific Concept Paper Evaluation Criteria are described in this section.

Concept Papers will be evaluated against the following evaluation criteria in decreasing order of importance:

- To what degree does the Concept Paper present a power converter technology development plan that demonstrates credible and well-justified technical potential to meet or exceed each of the Primary Technical Requirements of this FOA. Technology approaches will be evaluated in a quantitative fashion, with technology approaches rated according to the degree to which they fall short of, meet, or exceed each quantitative Primary Technical Requirement.
- To what degree does the Concept Paper present a technology development plan that demonstrates credible and well-justified technical potential to meet or exceed each of the Secondary Technical Targets of this FOA. Technology approaches will be evaluated in a quantitative fashion, with technology approaches rated according to the degree to which they fall short of, meet, or exceed each quantitative Secondary Technical Target.
- To what degree does the Concept Paper present a unique and innovative technical approach to significantly improve power converter performance over the current state-of-the-art.
- To what degree does the Concept Paper present a clearly demonstrated understanding of the current state-of-the-art and technical limitations of the current state-of-the-art in the relevant technology area.
- To what degree does the technology proposed in the Concept Paper hold potential to enable U.S. manufacturing leadership in advanced components and power conversion systems.
- To what degree does the proposed technical team have the skills and knowledge to successfully execute the project plan.
- To what degree will ARPA-E funding have a leveraged impact on the development of the proposed technology relative to other funding sources for the project team.