Solar ADEPT Program Overview

B. PROGRAM OVERVIEW

The U.S. Department of Energy (DOE) estimates that a $1/Watt (peak) installed photovoltaic solar energy system – equivalent to 5-6 cents/kWh – would make solar without additional subsidies competitive with electric generating systems using fossil fuels, nearly everywhere in the US. Power electronics is required to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited to the load. The power electronics (1) are the dominant point of failure for the installed system and are a major component of maintenance, (2) are responsible for a loss of approximately 4% of all of the electricity generated, and (3) are a major factor in balance of system costs (wiring, siting, labor).

1. Background

Today, power electronics contribute $0.2-0.22/Watt (peak) to the cost of a utility-scale photovoltaic installation. State of the art module integrated inverters – so called microinverters – are approximately $2/Watt (peak). Achieving grid-parity without subsidy in each of the critical markets for photovoltaics will require dramatic cost reductions in the cost of PV modules, power electronics, and system installation. Clearly reducing the cost of power electronics will directly contribute to the $1/W goal. Furthermore, power electronics has the potential to improve the energy yield of the module as well as mitigate many of the balance-of-system costs.

For example, we can consider the following architectures for photovoltaics in three different markets:

- Utility-scale photovoltaics with string-level DC/DC converters with high output voltages, feeding light-weight 5 MW inverters with direct (without a line transformer) grid connection. High DC distribution within the installation supports lower wiring loss allowing consolidation of multiple 1 MW inverters into a single large inverter. Direct grid connection removes the direct cost of the line transformer and the cost associated with site preparation and installation of 10,000 lbs of equipment.
- Lightweight 100kW inverters that can be placed within equipment rooms or roof-tops for commercial photovoltaic installations. Flexible siting of the inverters can reduce the expense associated with running DC wiring through or around an existing building.
- Residential photovoltaic modules that have direct AC 120V or 240V output compatible with home wiring. These microinverters should add little to the weight of the module and would ideally fit within the frame of the module for easy transport.

At any of these scales, there are opportunities for sub-module ultra-low cost microinverters that replace existing bypass diodes while provide maximum power point-tracking and fault management at the sub-module scale.

For each of these sample architectures, conventional power electronics are limited by:

1. The loss and voltage breakdown in the semiconductor switches
2. The loss, size, and cost of the magnetic elements such as ferrite or steel inductors and transformers
3. 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 within the constraints of silicon switch technology (>90% of all switches being Silicon MOSFETs and IGBTs), manganese zinc ferrite magnetics for low-power inverters and Si-rich steel for high power inverters, soldered joints in either surface mount or through-hole packages.

The goal of this Funding Opportunity Announcement (FOA) is to invest in technologies that can leapfrog over today's approaches and create the technologies to support $1/W (peak) target for fully installed photovoltaic solar energy.

2. Program 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 photovoltaic systems. Specifically, four categories of performance and integration level will be considered.

Category 1 seeks to broaden the application space for *fully-integrated, chip-scale power converters* for sub-module integrated applications. The performance of integrated converters must scale from today's 1W class chips to 10-80W class converters. Technologies for chip-scale DC/DC converter with Maximum Power Point Tracking (MPPT) that can be integrated during module assembly are of particular interest.

Category 2 seeks to broaden the application space for *package integrated microconverters* by reducing the size and improving component and package performance. The existing state-of-the-art for microinverters requires large (as high as 500) numbers of discrete components to achieve high efficiency over the full-operating range as defined by California Energy Commission (CEC). Highly integrated DC/AC converters with total part-counts less than 10 are required.

Category 3 addresses *lightweight inverter* for commercial roof-top and wall-mount application. State-of-the-art inverters weigh in excess of 250 lbs for 100kW. Reducing the inverter weight simplifies siting of inverters for small to medium sized commercial buildings – allowing the inverters to be rooftop mounted or wall-mounted within an instrument room. High performance component and circuit architectures will be required to realize dramatic (> 6x) improvements in power densities.

Category 4 addresses *lightweight, solid-state, medium voltage* energy conversion for high power applications such as utility-scale inverters with direct grid connection. 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.

3. Areas of Interest

Any technology able to meet or exceed the "Primary 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:

- **Areas of Particular Interest:**
  - Magnetic materials with high operating flux densities exceeding 0.5T at frequencies greater than 1 MHz for a power loss of 300 kW/m^3 (15x greater than MnZn ferrites) while achieving electrical resistivity exceeding 1mOhm-cm and exhibiting high thermal conductivity. The magnetics should exhibit stable performance to temperatures exceeding 125^{o}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.
  - Small-footprint AC (four quadrant) switches that enable reduction in part count and overall cost savings
- 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:
  - High efficiency line-voltage converters without electrolytic capacitors
  - Integrated, high-efficiency switched capacitor converters
  - Advanced fault detection and self-diagnostics

- Advanced charge storage devices with power densities with high reliability under applied voltage and thermal stress. High energy density supporting 10ms pulse times.
  - Ultra-high reliability electrolytic capacitors
  - High speed and higher voltage ultracapacitors
  - Improved energy density thin film capacitors.

- **Areas Specifically Not of Interest:**
  - Incremental improvements to, or combinations of, existing products and technologies, wherein no significant advances in understanding or reductions in technical uncertainty are achieved; and
  - Demonstration projects that do not involve a significant degree of technical risk.

Any Concept Papers or Full Applications that focus on “Areas Specifically Not of Interest” will be rejected as nonresponsive and will not be reviewed or considered.

4. Technical Performance Targets

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 Targets” by the end of the period of performance of the proposed project in order to be considered for award.

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:

- An application seeking to develop advanced GaN/Si switch technology for module integrated inverters must clearly state the metrics (such as conduction losses, leakage currents, breakdown voltages, thermal performance, magnetics loss, reliability etc) achievable at the start of the program and the end of the program. A research plan in terms of materials growth, device processing, device design, circuit design, and package development to achieve the necessary performance should be presented. Furthermore, the proposed effort should discuss the impact of the technology on the full cost of photovoltaics: the effect of module weight on balance of system cost, the effect of sub-module power point tracking on module reliability, aging, and cost, and the estimated cost of the power converter.

- Similarly, an application seeking to advance the state-of-the-art for SiC bipolar switches for utility-scale inverters 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 design, circuit design, and package development to achieve the necessary performance should be presented.
- An application 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 Applications should include preliminary data to support claims of material characteristics, component performance, converter design and reliability.

a. Primary Technical Targets

ID Number	System Categories	Cost	Voltage and Power	CEC Efficiency	Size
1.1	CATEGORY 1 **SUB-MODULE CONVERTER**	$0.05/W	>3 CONVERTERS PER MODULE	>98% cell-to-AC MPPT	SINGLE-CHIP DC/DC INSIDE MODULE FRAME
1.2	CATEGORY 2 **MICROINVERTER**	$0.2/W	>600 V >250 W	>98% cell-to-AC MPPT	< 2 LBS PART COUNT < 10
1.3	CATEGORY 3 **BUILDING**	<$0.10/W	100KW	>98% cell-to-AC MPPT	< 50 LBS
1.4	CATEGORY 4 **UTILITY-SCALE**	$0.10/W	> 2 MW SCALABLE	>98% module-to-grid MPPT	< 1000 LBS

In addition to the Primary Technical Targets detailed above, applicants must address the following key technical requirements:

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.

1) Reliability of Proposed Technology at Scale

The applicant must describe the design and assembly approach(es) that will ensure 30+ year reliability for the proposed converter. These should include best practices such as selection of components (where possible) with proven reliability. The applicant should consider robust converter architectures with N-1 reliability for unproven components and graceful shutdown under fault conditions. All converters must be passively cooled. Depending on application, converters should be designed for ease-of-maintenance (e.g. hot-pluggable replacement).

3) Technical Strength of the Project 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 for Category 1 & 2 should be able to demonstrate specific expertise on advanced switch and passive component technologies, MPPT and fault algorithm development, thermal management, high-reliability packaging, and PV module manufacturing.

The teams for Category 3 should be able to demonstrate specific expertise on advanced switch and passive component technologies, MPPT and fault algorithm development, thermal management, high-reliability packaging, and commercial PV installation and siting.

The teams for Category 4 should be able to demonstrate specific expertise on magnetic materials, advanced switch technologies, thermal management, high-reliability packaging, and utility-grade power quality management (e.g. design and implementation of VAR and harmonic support