



## NASA SBIR 2011 Phase I Solicitation

### X8 High-Efficiency Space Power Systems

This topic solicits technology development for high-efficiency power systems to be used for the human exploration of space. Technologies applicable to both space exploration and clean and renewable energy for terrestrial applications are of particular importance. Power system needs include: electric energy generation and storage for human-rated vehicles, electrical energy generation for in-space propulsion systems, and electric energy generation, storage, and transmission for planetary and lunar surface applications. Technology development is sought in: Fuel cells and electrolyzers including both proton exchange membrane and solid oxide technologies; Battery technology including components for improved performance and safety; Nuclear power systems including fission and radioisotope power generation; Photovoltaic power generation including solar cell, blanket and array technology; reliable, radiation tolerant electronic devices; and robust high voltage electronics.

## Subtopics

### X8.01 Fuel Cells and Electrolyzers

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC

Advanced primary fuel cell and regenerative fuel cell energy storage systems are enabling for various aspects of future Exploration missions. Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and regenerative fuel cell systems are desired.

#### **Proton Exchange Membrane (PEM) Fuel Cells and Electrolyzers**

Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and regenerative fuel cell systems are desired.

#### **Oxidation Resistant Gas Diffusion Layer (GDL)**

GDLs are integral to PEM fuel cell membrane-electrode-assemblies (MEAs). Traditional carbon or graphite based GDLs are very susceptible to oxidation under certain operating conditions in the pure oxygen environment of space fuel cell systems. This results in MEA degradation and shortened life. Proposals addressing the development of oxidation resistant GDLs that remain stable to oxidation in a pure oxygen environment, and provide improved performance and longer life are desired.

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## Deionizing Water Treatment for High Pressure, High Temperature Water Electrolyzers

Ultra high purity water is needed for NASA's high pressure, high temperature water electrolyzers. Technology is needed to remove ions within the water that is circulated over the catalyzed electrodes of the electrolyzer. Ions need to be reduced below TBD ppm prior to entering the water electrolyzer. The deionizer must function in flowing water at 2000 psi and 80°C.

## High System Pressure water Pump

A water pump is needed to circulate water through a high-pressure water electrolyzer. The pump must meet the following criteria:

- Operating System pressure of >2000 psia.
- Minimum developed differential pressure of 30 psid.
- Operating temperature 20-90°C.
- Minimum liquid flow rate of 30 LPM.
- Chemically tolerant to water saturated with dissolved oxygen at 2000 psia, 90°C.
- Tolerant to two-phase mixtures of gaseous oxygen and liquid water without losing pumping effectiveness.
- Mass <math>\leq 2</math> kg.
- Volume <math>\leq 0.75</math> liters.
- Power Consumption <math>\leq 120</math> watts.

## Instrumentation, Control, Health Monitoring, and Data Handling

Highly reliable voltage monitors for batteries, fuel cells, electrolyzers, and regenerative fuel cells are needed having low mass and low parasitic power consumption. Up to 48 differential voltages (0-5 VDC) with a minimum of 120 VDC common mode rejection must be monitored for system health management over an operating temperature range of -20 to +40°C, and the system must be capable of being upgraded to meet a Grade-1 EEE reliability

## Solid Oxide Fuel Cells and Electrolyzers

Advanced primary Solid Oxide Fuel Cells (SOFC) and Electrolyzers offer notable advantages in certain space applications when integrated with, respectively, CH<sub>4</sub>/O<sub>2</sub> propulsion systems and systems for producing oxygen from planetary resources. In contrast to most terrestrial/commercial applications, solid oxide devices for spacecraft will operate on pure oxygen and clean fuel streams (e.g., pure methane.) New materials are required to enable their use in these applications. These devices typically operate at high temperatures (800-1000°C) and are expected to undergo on/off cycling in aerospace applications. Technology advances are sought that reduce the time required to get to operating temperature, enable hundreds of rapid start-up/shut-down cycles, and enable systems to

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accommodate large load swings without leakage or deposition of elemental carbon. Spacecraft solid oxide devices that operate with minimal active cooling are needed. Low recurring costs are not a priority for spacecraft fuel cell materials. Technology advances that reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of Solid Oxide Fuel Cells and Electrolyzers are desired. Proposals are sought which address the following areas:

### **Advanced Primary SOFC Systems**

Their high temperature heat rejection and high efficiency power generation from methane and oxygen make primary SOFC's attractive for application to spacecraft with CH<sub>4</sub>/O<sub>2</sub> propulsion systems. Research directed towards improving the durability, efficiency, and reliability of SOFC systems fed by propellant-grade methane and oxygen is desired. Primary SOFC components and systems of interest:

- Have power outputs in the 1 to 3 kW range.
- Offer thermodynamic efficiencies of at least 70% (fuel source-to-DC output) when operating at the current draw corresponding to optimized specific power.
- Operate as specified after at least 300 start-up cycles (from cold to operating temperature within 5 minutes) and 300 shut-down cycles (from operating temperature to cold within 5 minutes).
- Operate as specified after at least 2500 hours of steady state operation on propellant-grade methane and oxygen.
- Are cooled by way of conduction through the stack to a radiator exposed to space and/or by anode exhaust flow.

### **Advanced Solid Oxide Electrolyzers**

Their high temperature heat rejection and operation, along with high efficiency, make solid oxide electrolyzers attractive as the final step of producing oxygen from Lunar or Martian regolith by way of hydrogen or carbothermal reduction. They are also attractive components for Sabatier reactors producing methane from the Martian atmosphere. Research directed towards improving the durability, efficiency, and reliability of solid oxide electrolyzers is desired. Solid oxide electrolysis systems of interest:

- Require power inputs in the 1 to 3 kW range.
- Operate as specified after 10,000 hours of operation fed by water with mild contamination.
- Operate as specified after 100 start-up cycles (from cold to operating temperature within 5 minutes) and 100 shut-down cycles (from operating temperature to cold within 5 minutes).
- Offer thermodynamic efficiencies of at least 70% (DC-input to Lower Heating Value H<sub>2</sub> output) when operating at the current feed corresponding to rated power.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental

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testing at the completion of the Phase II contract.

## **X8.02 Space-Rated Batteries**

**Lead Center: GRC**

**Participating Center(s): JPL, JSC**

Advanced battery systems are sought for future NASA Exploration missions to address requirements for safe, human-rated, high specific energy, high energy density, and high efficiency power systems. Possible applications include extravehicular activities, landers, and rovers. Areas of emphasis include advanced cell chemistries with aggressive weight and volume performance improvements and safety advancements over state-of-the-art lithium-based systems. Novel rechargeable battery chemistries with advanced non-toxic anode and cathode materials and nonflammable electrolytes are of particular interest. Priority will be given to efforts addressing novel cathode materials that can be paired with advanced silicon anodes.

The focus of this solicitation is on advanced concepts and cell components that provide weight and volume improvements and safety advancements that contribute to the following cell level metric goals:

- Specific energy >350 Wh/kg at C/2 (Fully charged or discharged in 2 hours).
- Energy density > 650 Wh/l at C/2.
- Tolerance to abuse such as overcharge, external short-circuit, and over temperature.
- Calendar life >10 years.
- Cycle life >250 cycles at 100% depth of discharge.

Systems that combine all of the above characteristics and demonstrate a high degree of safety and radiation tolerance are desired. Cell safety devices such as shutdown separators, current limiting devices that inhibit thermal runaway, venting, and eliminate flame or fire; autonomous safety features that include safe, non-flammable, non-hazardous operation especially for human-rated applications are of particular interest.

Proposals should include analysis that demonstrates the potential of the proposed technology to meet the projected performance parameters. Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II breadboard demonstration, and when possible, deliver a prototype/ demonstration unit for functional and environmental testing at the completion of the Phase II contract.

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## X8.03 Space Nuclear Power Systems

Lead Center: GRC

Participating Center(s): JPL, JSC, MSFC

NASA is developing fission power system technology for future space transportation and surface power applications using a stepwise approach. Early systems are envisioned in the 10 to 100 kWe range that utilize a 900 K liquid metal cooled reactor, dynamic power conversion, and water-based heat rejection. The anticipated design life is 8 to 15 years with no maintenance. Candidate mission applications include initial power sources for human outposts on the moon or Mars, and nuclear electric propulsion systems (NEP) for Mars cargo transport. A non-nuclear system ground test in thermal-vacuum is planned by NASA to validate technologies required to transfer reactor heat, convert the heat into electricity, reject waste heat, process the electrical output, and demonstrate overall system performance.

The primary goals for the early systems are low cost, high reliability, and long life. Proposals are solicited that could help supplement or augment the planned NASA system test. Specific areas for development include:

- 900 K NaK heat transport loops, including pumps and accumulators.
- 10 kWe-class Stirling and Brayton power conversion devices.
- 450 K water heat rejection loops, including pumps and accumulators.
- Composite radiator panels with embedded water heat pipes.
- Radiator deployment mechanisms and structures.
- Radiation tolerant materials and components.
- 120 V - 1k V power management and distribution (PMAD) for high power DC and AC systems, 1 kW to 100 kW respectively.

The NASA system test is expected to provide the foundation for later systems in the multi-hundred kilowatt or megawatt range that utilize higher operating temperatures, alternative materials, and advanced components to improve system performance. For the later systems, specific power will be a key performance metric with goals of 30 kg/kWe at 100 kWe and 10 kg/kWe at 1 MWe. Possible mission applications include large NEP cargo vehicles, NEP piloted vehicles, and surface-based resource production plants. In addition to low cost, high reliability, and long life, the later systems should address the low system specific mass goal. Proposals are solicited that identify novel system concepts and methods to reduce mass and increase power output. Specific areas for development include:

- High temperature reactor fuels and structural materials.
- Reactor heat transport technologies for 1100 K and above.
- 100 kWe-class Brayton and Rankine power conversion devices.

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- Waste heat rejection technologies for 500 K and above.

#### **X8.04 Advanced Photovoltaic Systems**

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC

Advanced photovoltaic (PV) power generation and enabling power system technologies are sought for improvements in capability and reliability of PV power generation for space exploration missions. Power levels for PV applications may reach 100s of kWe. System and component technologies are sought that can deliver efficiency, cost, reliability, mass and volume improvements under various operating conditions.

PV technologies must enable or enhance the ability to provide low-cost, low mass and higher efficiency for power systems with particular emphasis on high power arrays to support solar electric propulsion missions. Examples of PV technology areas:

- Very large solar array concepts (>300kW) operating at high voltage (>200V).
- High voltage electronics for use in solar electric propulsion vehicles operating at bus voltages >200 VDC.
- Advanced concepts for array packaging, deployment and retraction.
- Advanced PV blanket and component technology/designs.
- Array concepts and module/component technologies that emphasize cost reduction (in materials, fabrication and testing).
- Automated/modular fabrication methods.
- Component and material availability/ high volume production capability.
- Ground testability/ space qualification for large array structures.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. A major focus will be on the demonstration of dual-use technologies that address exploration mission needs but also benefit clean/ renewable energy for terrestrial applications.

