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: Electrochemical systems including fuel cells and electrolyzers; 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/component and array technology; Power conversion and management technologies including solar dynamic and high conversion efficiency thermodynamic systems; reliable, radiation tolerant devices, and wireless power transmission.

Subtopics

X8.01 Fuel Cells and Electrolyzers for Space Applications

Lead Center: GRC
Participating Center(s): JPL, JSC

Fuel Cells and Electrolyzers for Space Applications

Advanced primary fuel cell and regenerative fuel cell energy storage systems are enabling for various aspects of future Exploration missions. Proton Exchange Membrane (PEM) and Solid Oxide Based systems are of particular interest.

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 layers (GDLs) for PEM fuel cell membrane-electrode-assemblies (MEAs)
integral to PEM fuel cell 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.

**Passive liquid-feed high-pressure PEM electrolysis technology** - Water electrolysis technology is critical for water utilization and hydrogen/oxygen generation. Standard liquid-feed PEM electrolysis technology requires numerous mechanical ancillary components for reactant management functions, including pumps and two-phase water/gas separators. These components present life and reliability issues in addition to their inherent mass and volume penalties, and also require parasitic power for operation. Vapor-feed PEM electrolysis technology avoids the necessity of these ancillary components, but suffers from reduced electrochemical performance and operational constraints. Development of passive liquid-feed PEM electrolysis technology could offer the benefits of both aforementioned systems without the drawbacks. This would yield an electrolysis system with strong electrochemical performance and a minimum of ancillary components with their inherent system penalties.

**Oxidation resistant, electrically conductive, hydrophilic coatings** for internal cell components within PEM fuel cells and electrolyzers Liquid water is produced within the reactant cavities of PEM fuel cells and consumed within the reactant cavities of PEM electrolyzers. In the case of a non-flow-through PEM fuel cell, the liquid product water moves across an open but supported gas cavity and through a water/gas separation barrier into a liquid cavity. If the supporting cell components within the gas cavity are hydrophobic, the water will be transported as droplets, which could impede gas flow and subsequently reduce electrochemical performance. If these supporting components are hydrophilic, the water is more likely to be transported as a film along the support structure and not impede gas flow. In the case of a PEM electrolyzer, water is moving in the opposite direction and therefore into the reactant cavity. A hydrophilic support structure would allow a flowing film of liquid water to reach the cell MEA while still maintaining an open reactant cavity relative to gas flow. In essence, an electrolysis cell assembly designed for vapor-feed operation could operate in a liquid-feed mode. This would yield a system with strong electrochemical performance and a minimum of ancillary components with their inherent system penalties.

**Stable, highly efficient, long-life MEAs and catalysts for PEM fuel cells and electrolyzers** - PEM fuel cells and electrolyzers are key technologies for space systems utilizing hydrogen, oxygen, or water as reactants. In order to improve the life and reliability of the electrochemical stacks within these systems, as well as to reduce overall system mass/volume and cost, development of MEAs and catalysts that are stable and highly efficient is critical. Techniques to accomplish this goal include, but are not limited to, alternative noble metal and mixed oxide catalysts with increased surface areas, advanced binders and catalyst layer application techniques, alternative ionomer formulations, and high-temperature membrane compatibility.

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.

**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\textsubscript{4}/O\textsubscript{2} propulsion systems and systems for producing oxygen from planetary resources. 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\textsubscript{4}/O\textsubscript{2} 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.

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 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\textsubscript{2} 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 testing at the completion of the Phase II contract.
X8.02 Advanced Space-Rated Batteries
Lead Center: GRC
Participating Center(s): JPL, JSC

X8.03 Space Nuclear Power Systems
Lead Center: GRC
Participating Center(s): JPL, JSC, MSFC

X8.04 Advanced Photovoltaic Systems
Lead Center: GRC
Participating Center(s): JPL, JSC

- Solar cell, blanket component and advanced solar array technology with high operating efficiency (>30%), low mass (>200W/kg), and low stowed volume;
- PV technology capable of long-term, reliable of planterary surface operation under dust, temperature extreme (high and low), radiation, and other space enviromental conditions;
- Advanced concepts for array packaging, autonomous deployment, retraction and redeployment;
- Modular, high power (10s to 100s kWe) concepts with lifetimes greater than 10 years;
- High voltage (>200 Volts) array designs capable of reliable operation under space environmental conditions.

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 for clean and renewable energy for terrestrial applications.
Advanced power conversion technologies are sought for improvements in efficiency and reliability of power conversion for space exploration missions. Power levels for applications are expected to be in the range of 10s to 100s of kWe. System and component technologies are sought that can deliver efficiency and reliability improvements in this power range in the space environment.

In addition, advanced Power Management and Distribution (PMAD) technologies are required for the electrical components and systems on future high power platforms to address size, mass, efficiency, capacity, durability, and reliability improvements. Of importance are improvements in energy density, speed, efficiency, and wide temperature (-125°C to over 450°C) with a number of thermal cycles.

Power conversion and PMAD technologies must enable or enhance the ability to provide low-cost, abundant power for deep space missions, with requirements from 10s to 100s of kWe and months to years of mission duration.

Examples of Power Conversion technology areas:

- High conversion efficiency for Brayton, Stirling or Rankine power converters;
- High efficiency solar dynamic deployable solar concentrators and collectors;
- Research into advanced Power Conversion system concepts.

Examples of PMAD technology areas:

- Highly reliable devices and components;
- Radiation tolerance;
- Advanced power bus solutions;
- Technologies for high pulse power applications such as advanced energy storage devices;
- Efficient wireless power transmission.

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 for clean and renewable energy for terrestrial applications.