This topic intends to develop power capabilities that are on the critical path to enabling human exploration beyond Earth orbit. Areas of primary interest are: power generation/actuation for launch vehicles utilizing non-toxic fluids; orbital and planetary surface energy storage; and non-solar power generation. The Exploration Systems Assessment Study (ESAS) architecture desires nontoxic fluids to reduce ground processing facility requirements and to increase safety for the crew. Hydrazine (toxic) is currently used to drive the Solid Rocket Booster (SRB) and Space Shuttle Main Engine (SSME) Auxiliary Power Units (APUs), which in turn provide power for actuation for engine gimbal. Development efforts using nontoxic power generation for launch vehicles is required. ESAS architecture elements, including the Crew Exploration Vehicle (CEV), Lunar Surface Access Module (LSAM), robotic missions, and surface systems, require long-life/ high-capacity/high-density energy storage on the order of up to 10 kW. Lithium ion batteries are required to be human-rated at load profiles that are currently higher than state-of-the-art, and, are required to operate over a greater range of temperatures for the lunar environment. The ESAS architecture requires advanced fuel cells to meet LSAM and surface system design margins. Fuel cell systems provide power largely independent of environment (solar incidence), which allows greater mission flexibility and will typically provide larger power levels for less total mass for short-duration missions. The exploration architecture identifies permanent human lunar habitation shortly following a set of crewed sortie missions. The permanent habitation phase requires lunar night stays, extended EVAs, expanded science and surface operations and the utilization of ISRU to demonstrate and validate capabilities needed for Mars exploration. The expected power requirements will exceed that practically furnished by conventional technologies. The ESAS study identified surface nuclear fission systems to satisfy the power requirements for lunar extended stays, particularly at non-polar regions and nuclear power extensibility to Mars exploration.

Subtopics

X8.01 Non-Toxic Launch Vehicle Power for Thrust Vector and Engine Actuation

Lead Center: GRC
Participating Center(s): MSFC

The next generation of NASA launch vehicles and spacecraft will minimize the use of hydraulic power systems due to their inherent inefficiencies. These hydraulic systems will be replaced with all electric power components. NASA is interested in optimizing these electric components to maximize system reliability and efficiency while minimizing overall size and mass. Of particular need are electric actuation systems, including electromechanical (EMA) and electrohydrostatic (EHA). These are important in order to realize the full potential of the more electric power systems. The actuator systems will consist of both the actuator and associated controls. These systems will be used for a number of applications including thrust vector control, engine actuation and vehicle surface actuation.
The technology would directly benefit programs such as Constellation which have a variety of requirements for the Crew Launch Vehicle, Cargo Launch Vehicle, Lunar Surface Access Module, and others. These systems may range from a few horsepower to greater than 50 horsepower, and the associated electronics may see temperature extremes up to 175°C. To make electric actuation a more viable option, improvements in mass, size, efficiency and power density are sought for both the actuator and associated controls. Current state-of-the-art actuators suitable for engine thrust vector control on a launch vehicle have a power density of 1kW/kg for duplex drives (two motors driving one transmission, not including inverters and controllers). Innovations are sought to increase this power density to at least twice the SOA. In addition, state-of-the-art controllers can be 20 - 50% of the actuator size and weight alone, therefore novel approaches to minimizing controller mass and volume are sought. Innovative approaches to redundant electric actuator systems and redundancy systems management will also be considered which would help reach the single fault tolerant vehicle requirements. Technologies of specific interest include:

- Lightweight, high power density electric actuators and controls in the 5 - 10 hp range for use on vehicles such as Crew Launch Vehicle and Earth Departure Stage, with an actuator density goal of 2kW/kg and controller density of at least 1.5 kW/kg;

- Lightweight, high power density electric actuators and controls suitable for 30 - 60 hp applications on vehicles such as Cargo Launch, with an actuator density goal of 2kW/kg and controller density of at least 1.5 kW/kg;

- Actuation and control technologies capable of operating over wide temperature ranges - up to a chassis temperature of 175°C;

- Novel redundant EA systems and redundancy management approaches for single fault-tolerant vehicle applications.

X8.02 Space Based Nuclear Fission Power Technologies

Lead Center: GRC

NASA is interested in the development of highly advanced systems, subsystems and components for use with fission power systems for future Lunar and Mars robotic and manned missions. Anticipated power levels range from 10's of kilowatts to 100's of kilowatts. Proposals are sought for critical technologies for fission power systems to meet the following anticipated missions and applications.

The current Vision for Exploration identifies the first human lunar landing in 2018 with subsequent long duration lunar stays of approximately 6 months in 2022. Fission-based systems are anticipated to enable the long duration stay over the lunar night. Initial planetary base power levels are anticipated to be between 30 - 50 kWe.

Planetary surface human base applications may include: habitats, resource processing and propellant production/liquefaction/maintenance, surface mobility for both robotic and piloted rovers, excavating and mining equipment and science stations. Human Mars mission activities could require power in the 100 kWe range.
Potentially, robotic outpost as a precursor to human Mars exploration with 50 - 500 day stays could be the proving ground for smaller fission systems. A 20 - 30 kWe system could support science applications such as: deep drilling, resource production demos, rovers, weather stations, etc.

Specific technology topics of interest are:

- Advanced, high efficiency, high temperature power conversion > 20%, 25 kWe to 100 kWe unit size;
- Electrical power management, control and distribution. 1000 - 5000 V;
- High temperature, low mass thermal management/heat rejection 2;
- Deployment systems/mechanisms for large radiators, surface mobility systems for remote emplacement of power systems, innovative methodology for use of indigenous shielding materials;
- High temperature materials or coatings compatibility with local soil and atmospheric environments;
- Systems/technologies to mitigate planetary surface environments. Dust accumulation, wind, planetary atmospheres (CO₂, corrosive soils, etc.);
- Power system design considerations for long life (> 5 years), autonomous control and operation, including sensor technologies;
- Radiation tolerant systems and materials (including lunar, Mars and in-space environments) for robust, long life operation;
- Innovative methodologies and approaches to accelerated life testing.

In addition to reducing overall system mass, volume and cost, increased safety and reliability are of extreme importance. It is envisioned that these technologies would be used on robotic and human missions and it is to NASA’s advantage to develop those technologies that transcend robotic to human mission requirements with a minimum of redesign. Technologies that easily and efficiently scale in power output and can be used in a host of applications (high commonality) are desired.

X8.03 Space Rated Batteries and Fuel Cells for Surface Systems

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

Human-rated energy storage devices are required to enable future robotic and human exploration missions. Advanced battery, fuel cell and regenerative fuel cell systems are sought for use in a wide range of Exploration mission applications including portable power for landers, rovers, and astronaut equipment, and stationary energy storage applications such as base power, and storage systems for crew exploration vehicles and spacecraft. Technology advances that will reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of electrochemical systems, specifically rechargeable batteries and fuel cell systems are desired. The
specific advancements of interest are outlined below.

**Advanced Secondary Battery Systems**

Areas of emphasis for advanced battery systems include technology advancements that contribute to the following cell-level performance goals: specific energy > 180 Wh/kg, calendar life > 15 years, and operating temperature range -60°C to 60°C and cycle life at 100% DOD > 2000 cycles. Systems that combine all of the above characteristics and demonstrate a high degree of safety are desired.

Specific technology areas sought are improved component materials that include non-toxic cathodes with specific capacities in excess of 250 mAh/g at the C rate and 25°C, and electrolytes that provide safe, non-flammable, non-hazardous operation. Cells that exhibit tolerance to mild abuse such as overcharge and over temperature are desirable. Chemistries and/or cell design capable of rapid recharge.

Innovative concepts for the design and management of packaged battery modules with specific energy >140 Wh/kg and energy density > 300 Wh/l are of keen interest.

Proposals addressing micro-batteries, structural batteries, and/or integrated power generation and are sought.

**Fuel Cell Systems**

Fuel cell (FC) systems with power capabilities in the range of 100-1000 watts and 1-10 kW are of interest, as are regenerative fuel cell (RFC) energy storage systems in the 10 - 25 kW power range.

Specifically, technological advances are sought for FC/RFC based systems that contribute to system simplicity and improved reliability through (1) innovative, integrated system-level design concepts, and (2) passive ancillary components. An example of these advances at the system level is primary and/or regenerative fuel cell systems that minimize or eliminate reactant re-circulation external to the stacks themselves. Examples at the component level include replacement of pumps and other active, motorized mechanical ancillary components with passive devices that perform the functions of both reactant management and thermal control.

Advanced FC/RFC development at both the system and component levels should focus exclusively on proton-exchange-membrane PEM technology utilizing pure hydrogen, oxygen, and water as reactants.