

# Power Technology Development for Moon, Mars and Beyond

2025 Space Power Workshop – Torrance, California  
Jeremiah McNatt | NASA Space Technology Mission Directorate

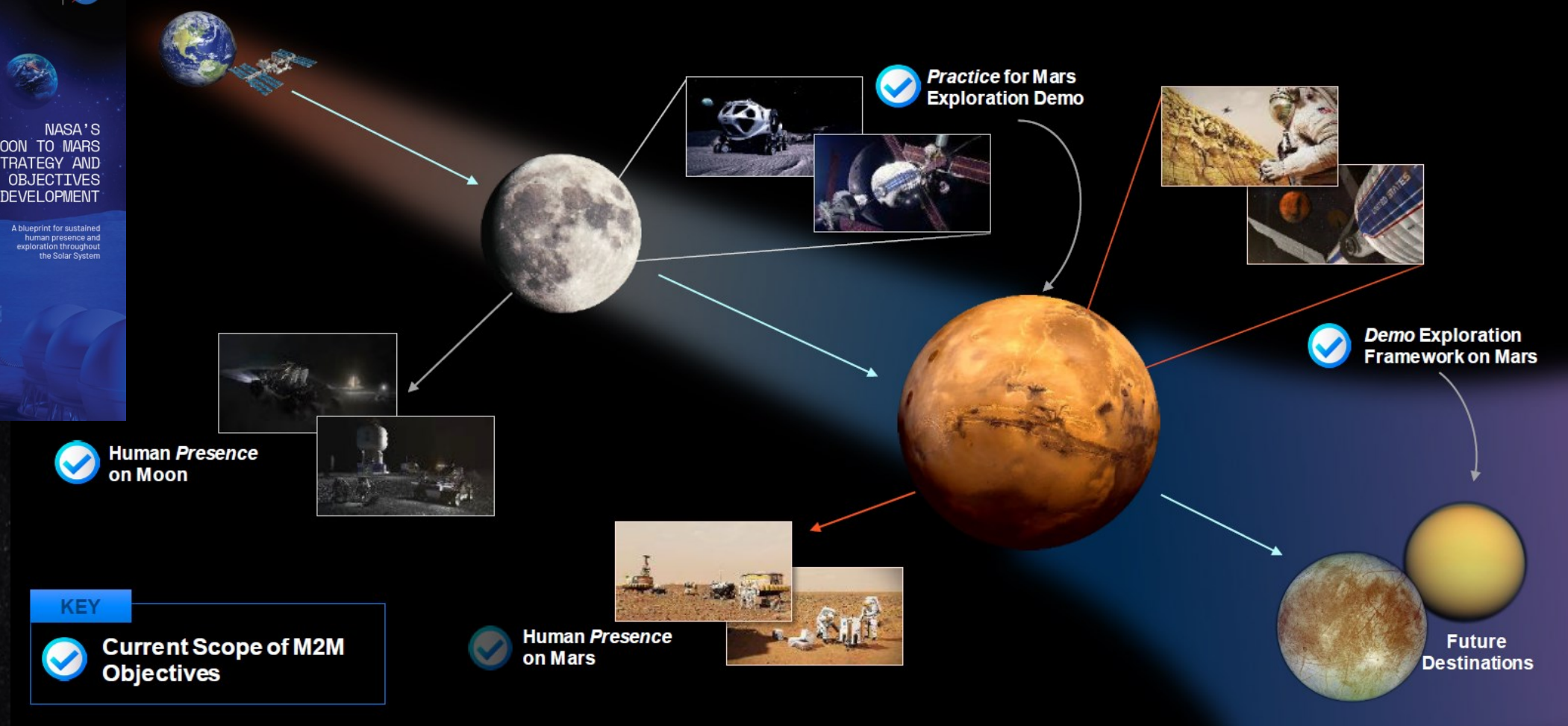
April 29, 2025

# Big Picture: Moon to Mars (and Beyond)

NASA'S  
MOON TO MARS  
STRATEGY AND  
OBJECTIVES  
DEVELOPMENT

A blueprint for sustained human presence and exploration throughout the Solar System

Released 6 April 2023



# Architecture Segments



**Human Lunar Return**

Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization on and around the Moon.



**Foundational Exploration**

Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization and Mars forward precursor missions.



**Sustained Lunar Evolution**

Enabling capabilities, systems, and operations to support regional and global utilization, economic opportunity, and a steady cadence of human presence on and around the Moon.



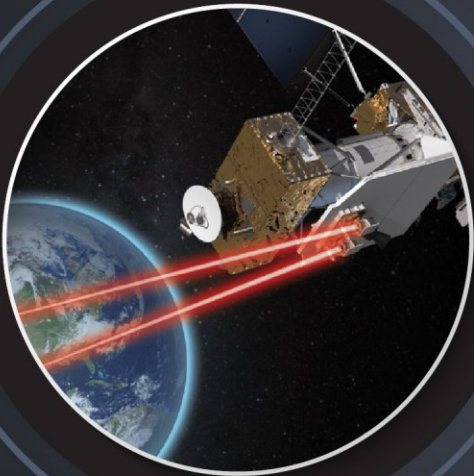
**Future Segments**

**Humans to Mars**

Initial capabilities, systems, and operations necessary to establish human presence and initial utilization on Mars and continued exploration.

# NATIONAL TECH BASE FOR CIVIL SPACE

*Space Tech leads the development, demonstration, and infusion of transformational space technologies that solve critical stakeholder needs*



**ADVANCE** US space technology innovation and competitiveness in a global context



**ENCOURAGE** technology driven economic growth with an emphasis on the expanding space economy



**INSPIRE** and develop a diverse and powerful US aerospace technology community

# NATIONAL TECH BASE FOR CIVIL SPACE

Ensuring American Global Leadership in Space Technology

## Functional Domain Areas

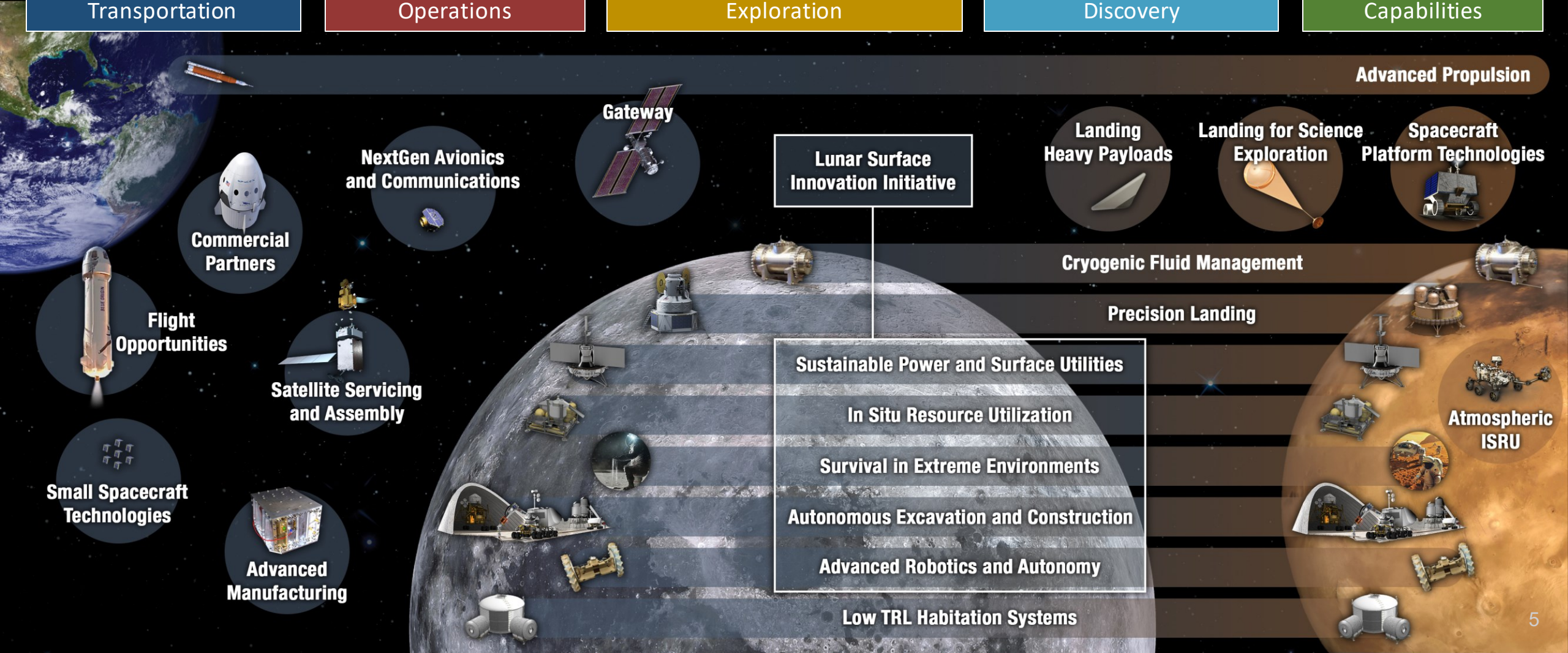
Space Transportation

Space to Surface Operations

Surface Infrastructure and Exploration

In-Space Infrastructure and Discovery

Foundational Capabilities





# Tech Base Functional Domains



**GO**  
Space Transportation

- ❖ Advanced Propulsion
- ❖ Nuclear Propulsion
- ❖ Flight Vehicle Systems (including Ascent Systems)
- ❖ Cryogenic Fluid Management



**LAND**  
Space-to-Surface Access

- ❖ Deceleration Systems
- ❖ Guidance & Navigation Systems
- ❖ Landing Systems & Environments
- ❖ Entry Modeling & Instrumentation



**LIVE**  
Surface Infrastructure and Exploration

- ❖ Surface Power
- ❖ In Situ Resource Utilization
- ❖ Surface Structures & Construction
- ❖ Environments & Dust Mitigation
- ❖ Surface Mobility & Transportation
- ❖ Surface Habitation & Logistics



**EXPAND**  
In-Space Infrastructure and Discovery

- ❖ Observation Systems
- ❖ In-Space Sustainability
- ❖ Communications, Position, Navigation & Timing
- ❖ In-Space Servicing, Assembly & Manufacturing
- ❖ Small Spacecraft & Distributed Systems



**ENABLE**  
Foundational Capabilities

- ❖ Avionics & Sensors
- ❖ Autonomous Systems & Robotics
- ❖ Advanced Materials, Structures & Manufacturing
- ❖ Advanced Power & Thermal

❖ Capability Area

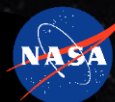
**CATALYSTS**  
Innovative Mechanisms

- NIAC/CIF/ECI
- STRG
- PCC
- Tech Transfer
- SBIR/STTR
- Flight Opportunities
- TP/ACO
- Cross-cutting Services

# Enable – Foundational Capabilities

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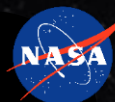
- The Foundational Capabilities Domain is responsible for leading the development of technologies that are crosscutting in nature and have applications across multiple missions use cases and environments.
  - From LEO, to the Moon, to Mars, and Beyond
- The Advanced Power Capability Area enhances and enables the performance of technologies ranging from basic R&D to mid-TRL development
- Current areas of interest include:
  - Radioisotope Power Systems Utilizing Non-Plutonium Sources
  - Battery Modularity and Performance Improvement
  - Solar Cell and Array Performance Improvement
  - Long Duration Primary Fuel Cells
  - Improved Radiation Hard Power Electronics
  - Wireless Power Transfer



# Live – Surface Infrastructure and Exploration

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- The Live Domain is responsible for developing technologies that enable humans to live and work sustainably in the extreme lunar and Mars environments.
- Surface Power: Providing power to elements on and near the surface of the Moon, Mars and other bodies.
- Technology development is driven to meet mission needs (environment, power level, duration)
- Technology needs span the full range of power systems:
  - Power Generation
  - Energy Storage
  - Power Management
  - Power Transfer



# Catalysts – Mechanisms for Engagement

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- Catalyst Programs span Domains and enable engagement between STMD and the Space Technology Community
- Support full range of TRL from early stage to flight projects
- Examples of interest to Space Power Community
  - ACO – Announcement of Collaborative Opportunity
  - ECF – Early Career Faculty
  - NIAC – NASA Innovative Advanced Concepts
  - NSTGRO – NASA Space Technology Graduate Research Opportunities
  - SBIR – Small Business Innovation Research

# Prioritizing Technology Investments

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- NASA's Space Technology Mission Directorate (STMD) is refining its strategy for prioritizing technology investments
- A set of 187 shortfalls (identified technology areas that require further development) were established that encompass and expand the needs of each major technical area.
- NASA asked for feedback on these shortfalls at <https://spacetechpriorities.org/>
- The shortfall rankings were released in July 2024
- These shortfalls will be revised/updated based on ranking and feedback, expected on an annual basis
- 8 shortfalls were established for Power



# Power Shortfalls

## Generate

- High Power Energy Generation on Moon and Mars Surfaces
- Power for Non-Solar-Illuminated Small Systems
- Lunar Surface Power Generation from ISRU Derived Resources
- Martian Surface Power Generation from ISRU Derived Resources

## Store

- Energy Storage to Enable Robust and Long Duration Operations on Moon and Mars

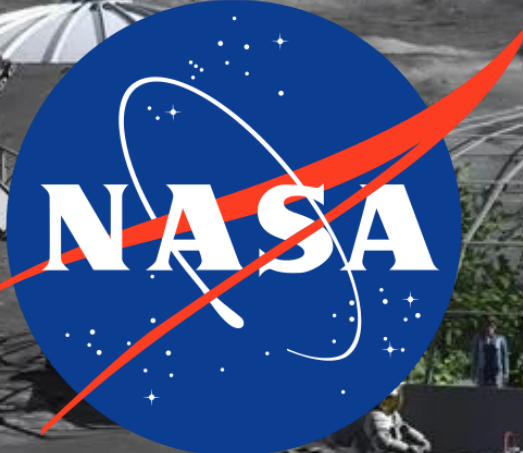
## Manage

- Power Management Systems for Long Duration Lunar and Martian Missions

## Distribute

- High-Power, Long-Distance Energy Transmission Across Distributed Surface Assets
- Power and Data Transfer in Dusty Environments

Thank You



# Energy Generation

## High Power Energy Generation on Moon and Mars Surfaces

Meeting the need for a lunar surface power generation capability that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels. This shortfall includes solar and nuclear power generation capabilities. The primary function of these systems is the production of power, where the system is likely standalone, and may be deployed from or consist of a whole landed unit. These systems are envisioned to be able to be connected to local users and to a node within a power grid (interfaces, PMAD, and energy storage are captured in other capability goals).

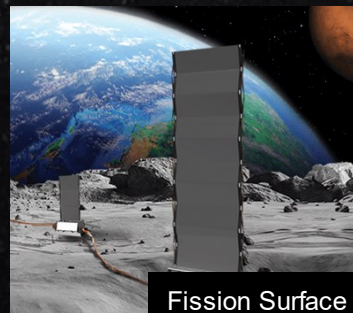
## Power for Non-Solar-Illuminated Small Systems

Small rovers, science landers, and resource prospecting systems would benefit from 50-100 We up to multi-100 We, sun-independent power sources. These missions may span from short duration to multiyear timelines. Longer term needs are to provide power to distributed sensor payloads for long duration science investigations. Static and dynamic radioisotope systems (DRPS) include an interest in development and testing of power conversion technologies that utilize alternative isotopes to plutonium.

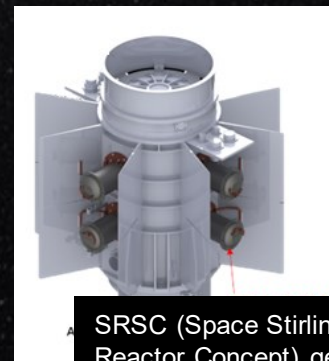


Vertical Solar Array Technology (VSAT) NASA Government Design

Ranked #2 of 187

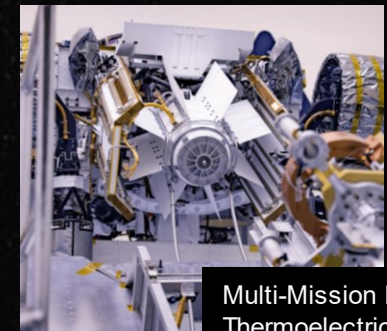


Fission Surface Power (FSP) System Concept



SRSC (Space Stirling Reactor Concept) generator

Ranked #27 of 187

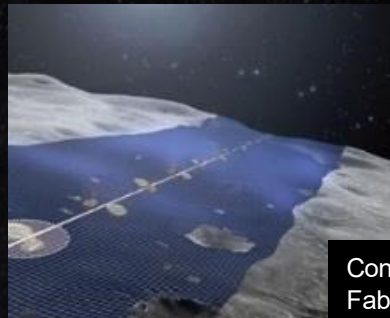


Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) for NASA'S Mars 2020 Perseverance rover

# Energy Generation

## Lunar Surface Power Generation from ISRU Derived Resources

ISRU based production of energy generation feedstocks and components will be necessary to grow a lunar economy and global industrial power grid. This shortfall addresses the need to develop technologies that use ISRU derived elements to create power components such as photovoltaics, cable, and battery anodes/cathodes).

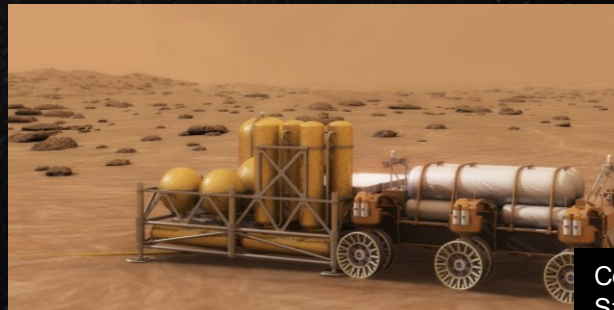


Concept of Silicon Solar Cells Fabricated with Materials Extracted from Lunar Regolith by ISRU Processes

Ranked #178 of 187

## Martian Surface Power Generation from ISRU Derived Resources

Mars ISRU are expected produce methane and oxygen among others. These resources can be utilized to produce power through fuel cell systems. This shortfall addresses the need for the ability to efficiency convert liquid oxygen and liquid methane to power in a mass optimal solution for rovers and landers as a high reliable, scalable system.



Concept of a Mars ISRU Production and Storage Facility

Ranked #183 of 187

# Energy Storage

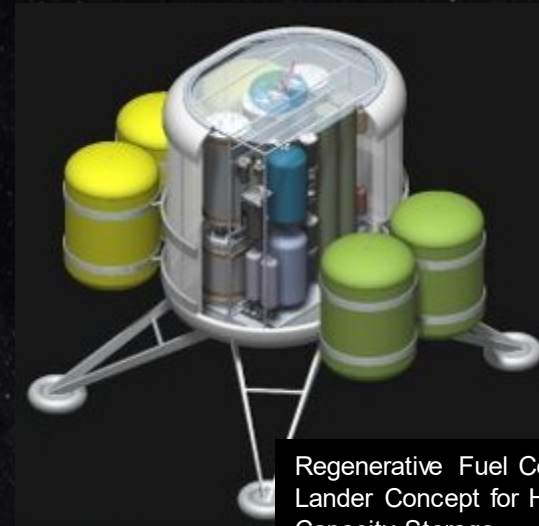
## Energy Storage to Enable Robust and Long Duration Operations on Moon and Mars

Energy storage technologies will be needed, and these systems will require high specific energy to reduce overall mass. Advanced chemistries and/or novel thermal materials/controls will be needed to allow for survival and operation during the lunar night.

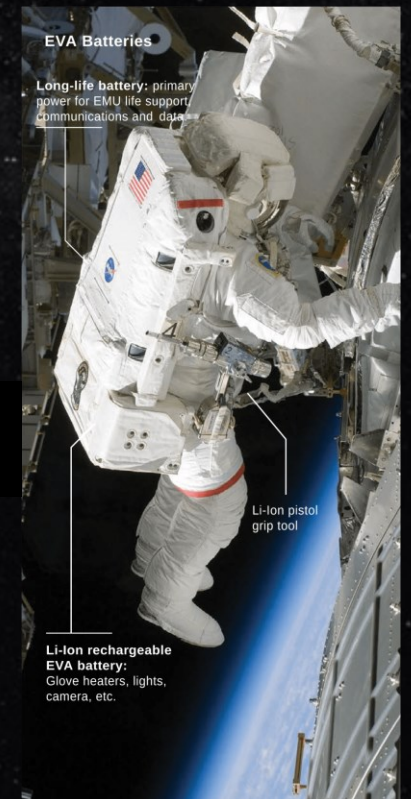
These systems are envisioned to range from large energy storage systems to support extended eclipse/night survival/operations to mobile energy storage for human and robotic exploration of the lunar surface (small platforms, multi-purpose vehicles, EVA suits, tools and potentially operations in PSRs).

Understanding and monitoring the internal conditions these energy storage systems will help to ensure safety and reliability. This shortfall includes technologies that help to monitor the internal environment of energy storage systems.

Ultra low temperature batteries can provide power for exploration into PSRs and other cold environments. Additionally, such technology could allow for hibernation for lunar night survival.



Regenerative Fuel Cell Lander Concept for High Capacity Storage



EVA Batteries  
Long-life battery: primary power for EMU life support, communications and data

Li-Ion pistol grip tool

Li-Ion rechargeable EVA battery: Glove heaters, lights, camera, etc.

Small Scale Battery Technologies will Support Spacesuits and a Variety of Other Systems



Battery Packs Used to Upgrade Hubble

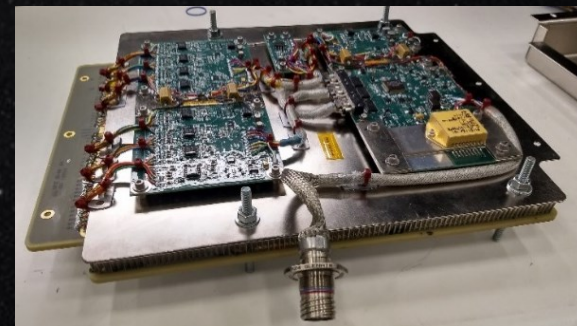
Ranked #57 of 187

# Power Management

## Power Management Systems for Long Duration Lunar and Martian Missions

Power management systems provide monitoring, control, and regulation to ensure sufficient power is available at all stages reliably throughout a mission. State of the art electronics do not provide sufficient durability to support long duration operations in the Lunar and Martian thermal, dust, and radiation environments and are not maintainable in those environment.

This shortfall addresses the need for power management subsystems built from common, interchangeable building blocks that can be used across multiple vehicles and surface elements would optimize spares and reduce maintenance impacts for long duration in-space operations.

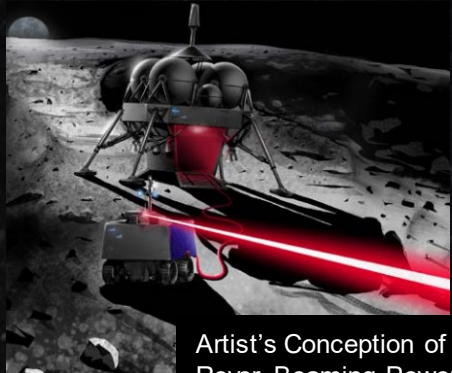


Power Management Electronics for a Lunar Surface Testbed

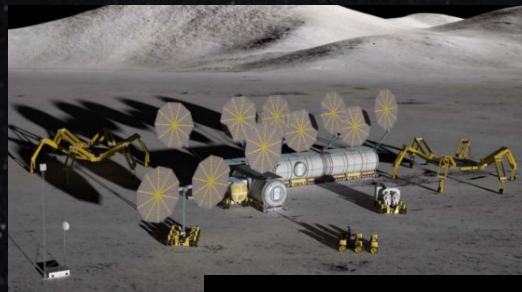
# Power Distribution

## High Power, Long Distance Energy Transmission Across Distributed Surface Assets

Common interfaces will allow for the distribution of power from generation source to user and bi-directional distribution among elements on the lunar surface. Both wired (cables, connectors) and wireless (power beaming) technologies may be suitable solutions to achieve this goal dependent on power level, distance, and environmental factors.. Radiation hardened power electronics and advanced power management and distribution systems will be necessary. All of these technologies will help lead to the development of a lunar power grid.



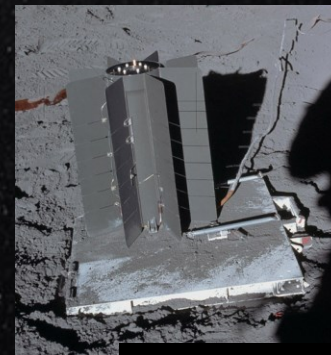
Artist's Conception of a Rover Beaming Power



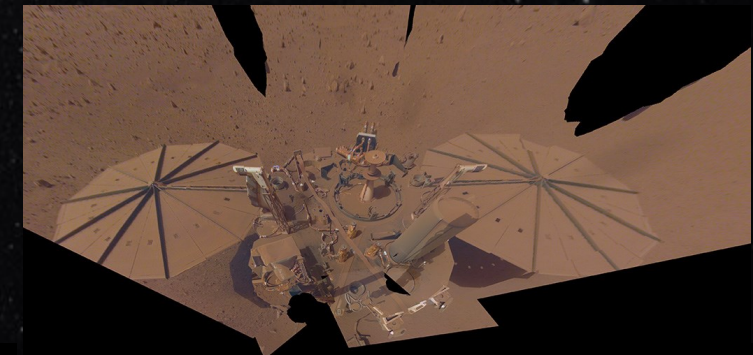
Small Lunar Research Site with a Local Power Grid

## Power and Data Transfer in Dusty Environments

Lunar and Mars surfaces present challenges of dust migrating into and interacting with electrical connections. These connectors range in size and voltage and may include additional data transfer systems such as fiber optics. Connections may be made robotically or through crew assisted means.



Apollo 14 RTG Covered in Dust



Mars InSight Lander Covered in Dust

Ranked #32 of 187

Ranked #34 of 187