Enabling Universal Access to Power on the Lunar Surface

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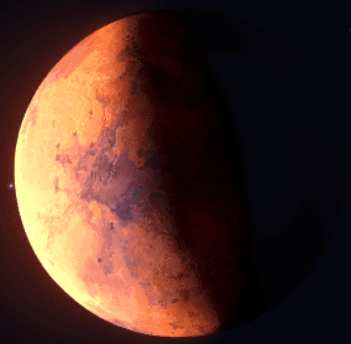
NASA Moon to Mars



- ***NASA will lead an innovative and sustainable program of exploration with commercial and international partners to send humans farther into space and bring back to Earth new knowledge and opportunities***

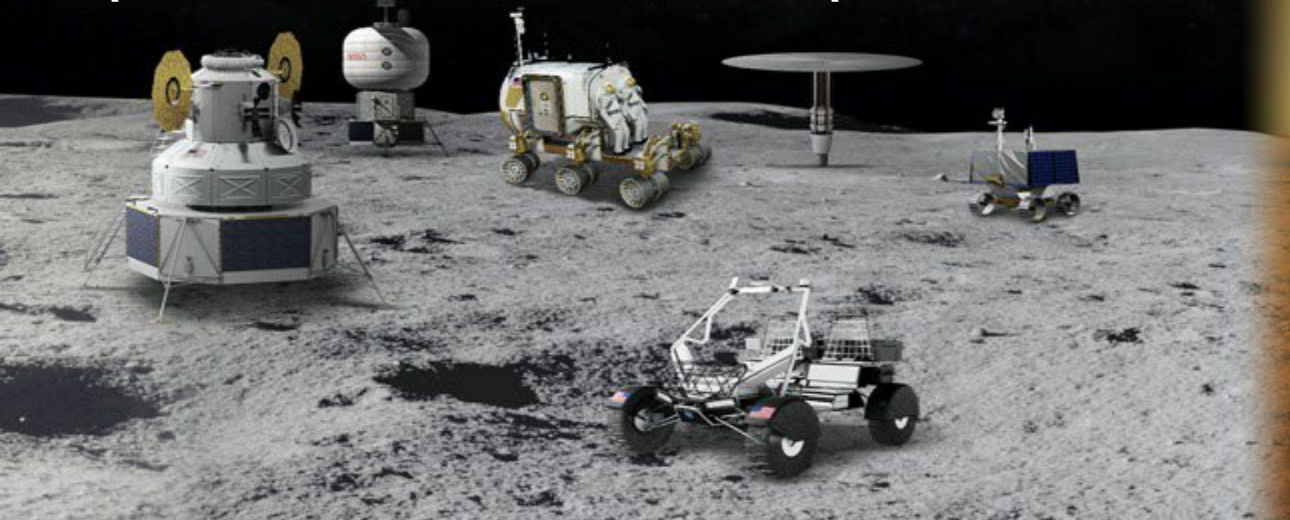
- **Moon to Mars Objectives (September 2022)**
  - Future long-term vision / Art of the possible

- **Architecture Definition Document (ADD) / Architecture Concept Reviews**
  - Distills agency-developed objectives into operational capabilities and elements that support science and exploration goals.
  - Execution

Moon to Mars (M2M) Objectives

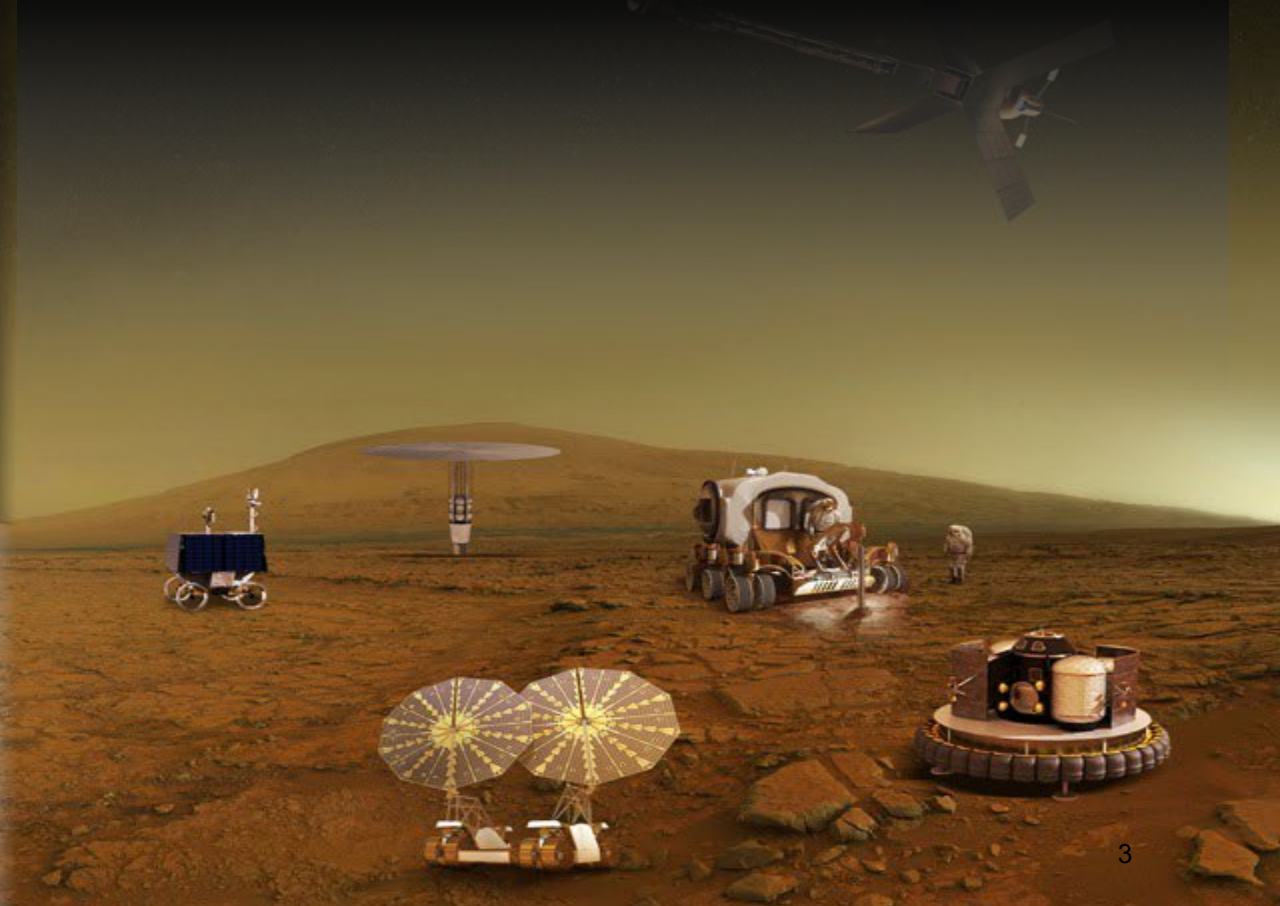
Lunar Infrastructure (LI) Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

- **LI-1L:** Develop an **incremental lunar power generation and distribution system** that is **evolvable** to support continuous robotic/human operation and is **capable of scaling to global power utilization and industrial power levels**.



Mars Infrastructure (MI) Goal: Create essential infrastructure to support initial human Mars exploration campaign.

- **MI-1M:** Develop Mars surface power sufficient for an initial human Mars exploration campaign.



Moon to Mars Architecture Definition Document (ADD)

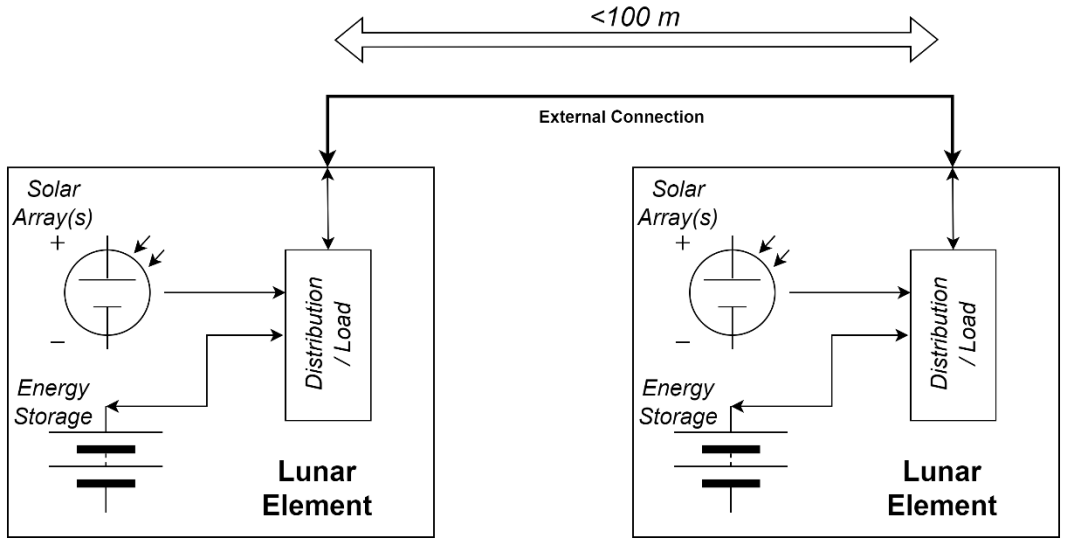
Moon to Mars Campaign Segments

Human Lunar Return	Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (science, etc.) on and around the Moon.
Foundational Exploration	Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (science, etc.) and Mars forward precursor missions.
Sustained Lunar Evolution	Enabling capabilities, systems, and operations to support regional and global utilization (science, etc.), economic opportunity, and a steady cadence of human presence on and around the Moon.
Human to Mars	Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (science, etc.) on Mars and continued exploration.
Future Segments	*Additional segment(s) will be added to enable continued exploration for the Moon, Mars, or beyond as objectives are accomplished and/or added to in the future.*

Initial Artemis Power System (No Grid)

- **Moon to Mars Segments:**
  - Human Lunar Return
  - Foundational Exploration
- **Power Strategy:**
  - Self-sufficiency
    - All power generation / energy storage is from lunar elements
  - Power exchange between lunar elements in contingency scenarios
- **Power System Size**
  - Lunar south pole
  - Power exchange must occur at a distance of less than 100 m (limitation of 120 VDC).
  - Anticipated power demands range from ~100 W to 10 kW+ per element.

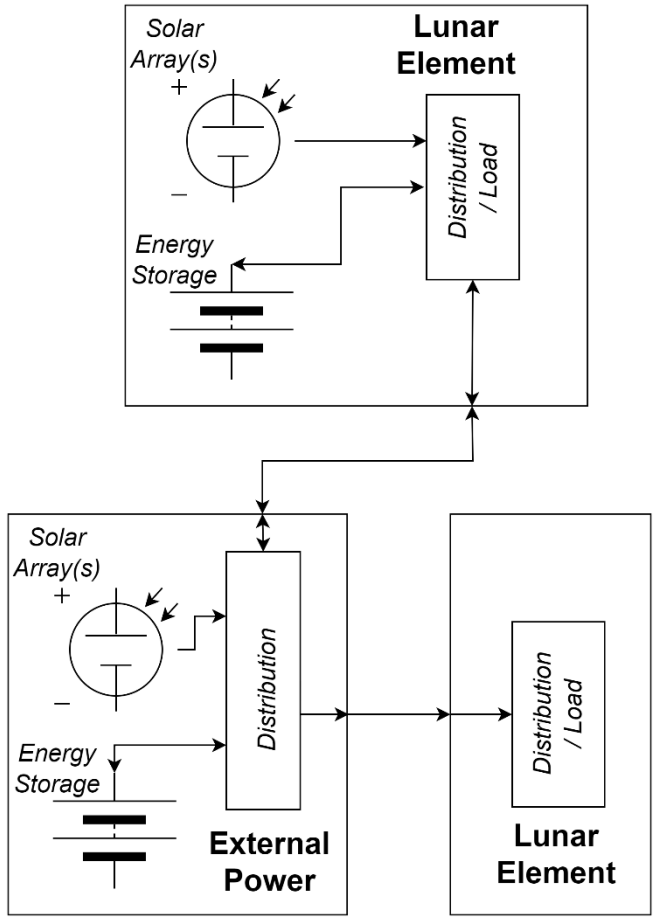
Self-Sufficient power system



Self-Sufficient power systems with the capability to exchange (share) power

Localized Power Grid

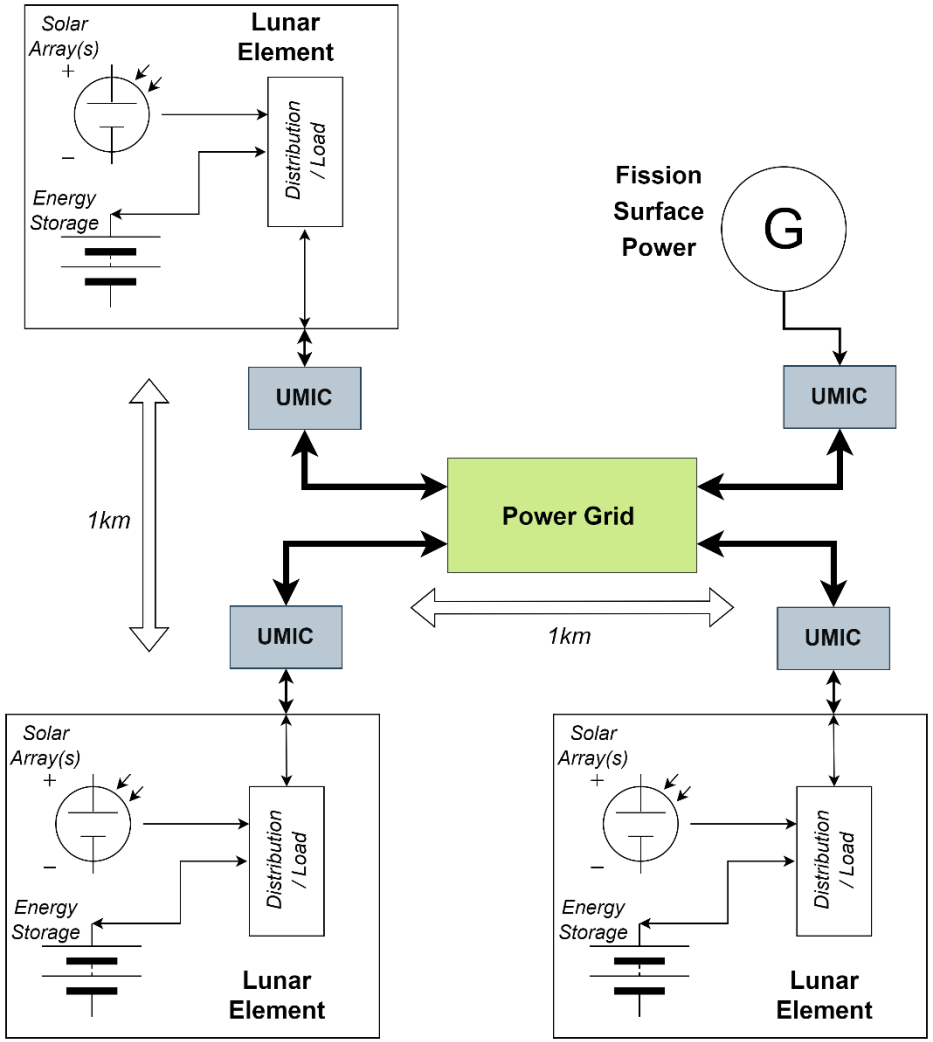
- **Moon to Mars Segments:**
  - Sustained Lunar Evolution
- **Power Strategy:**
  - External Power Augmentation
    - Dedicated elements that provide power to extend the survival period
    - Requires mobility to place power source near load(s)
    - Large energy storage and nuclear power generation (fission surface power) are options to increase eclipse power availability
- **Power System Size**
  - Lunar south pole
  - Distance between elements less than 100 m
  - Element power demands 10 kW+



Localized Power Grid where two (2) or more Lunar Elements receive power from an external power source

Regional Power Grid

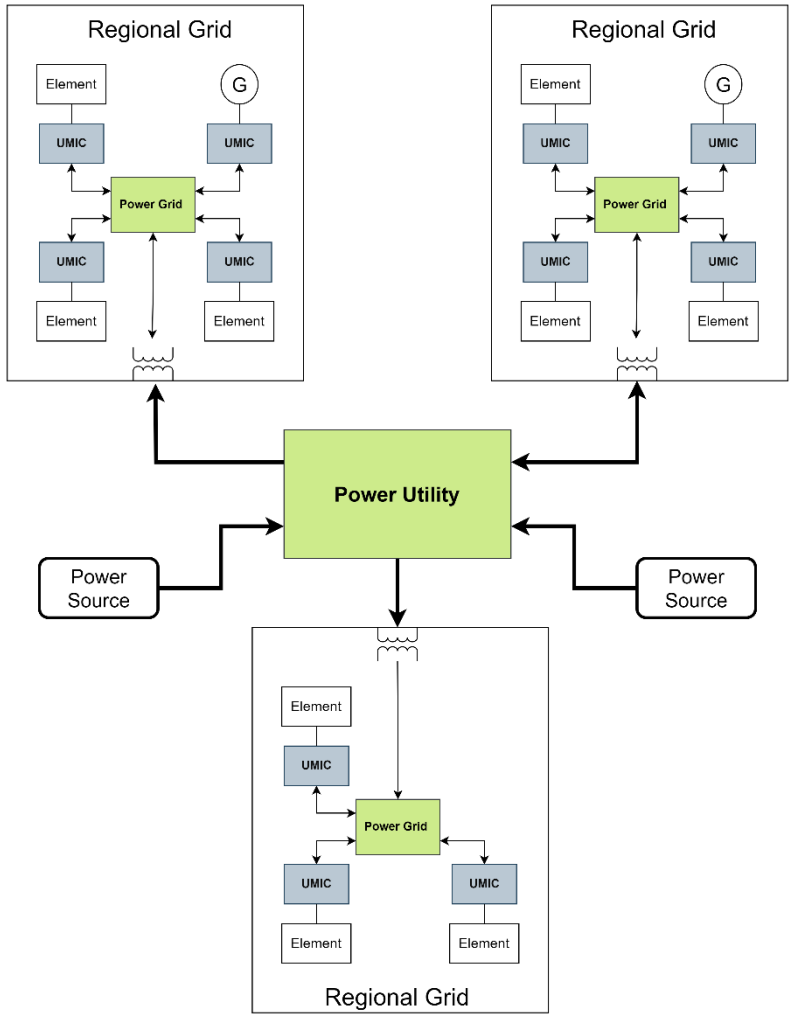
- **Moon to Mars Segments:**
  - Sustained Lunar Evolution
- **Power Strategy:**
  - Universal power
    - Power available over long-distance
    - Include power during eclipse periods
    - Large energy storage and nuclear power generation (fission surface power) are options to increase eclipse power availability
- **Power System Size**
  - Lunar south pole
  - Distances between elements can exceed 1km
  - Total line distance in the ~10 km
  - Element power demands in the 10 kW+



Regional Power Grid where power is transmitted at longer distances

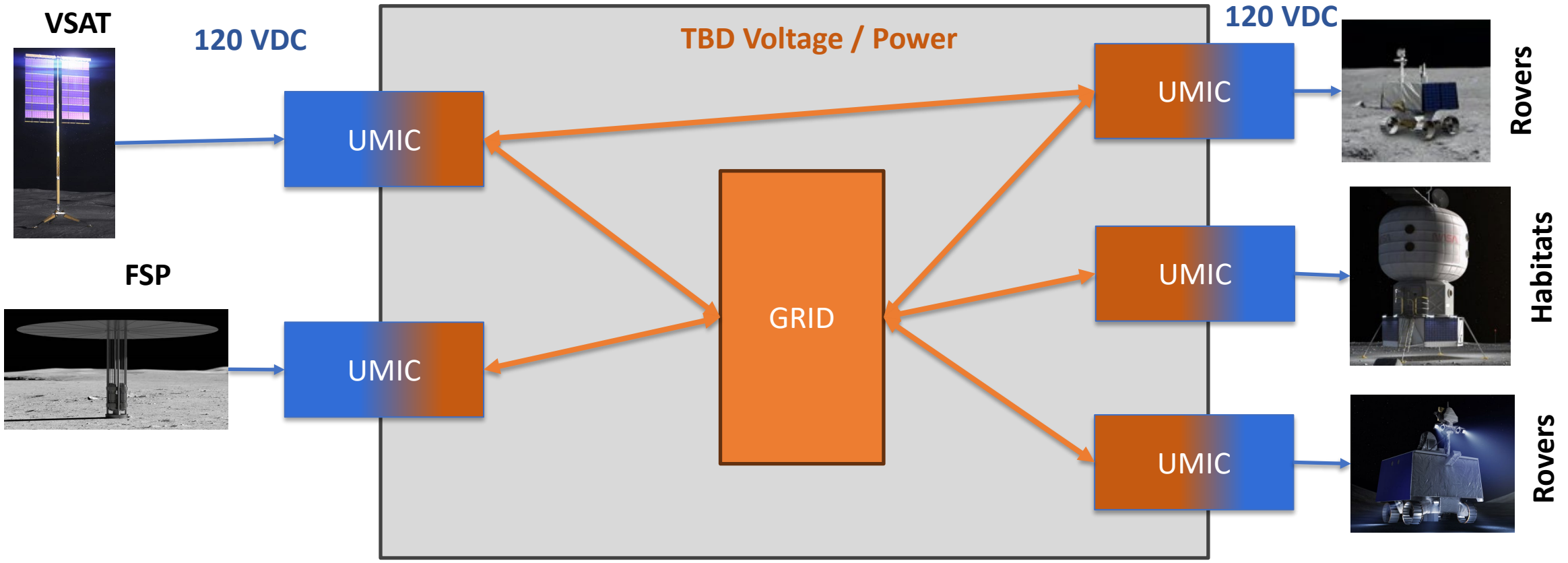
Full Lunar Power Grid / Lunar Power Utility

- **Moon to Mars Segments:**
  - Beyond M2M/Artemis
- **Power Strategy:**
  - Universal power / Lunar Utility
    - Power availability beyond the lunar south pole (towards equatorial region)
    - CONOPS to be developed – may include company managing the power grid like the terrestrial power system
- **Power System Size**
  - Beyond the lunar south pole
  - TBD Distances (100km+)
  - TBD Total power (1 MW+)



Lunar Power Grid (utility) where power can be generated/delivered/used at different locations that extend the lunar south pole

Universal Modular Interface Converter



- **The UMIC enables long-distance power transmission and a power grid**
  - Connects power sources and loads together over-long distance and allows for a power grid as the system evolves.
  - Source and loads design to current 120 VDC and 28 VDC power standards
    - ISPSIS / HEOMD03-004

Power Standards

- **Secondary / Distribution Power Standards**
  - International Space Power System Interoperability Standard (ISPSIS)
    - 120 VDC and 28 VDC
    - D.J. Sadey and N.A. Carbone, “International Space power System Interoperability Standards,” 20220009953, NASA, July 26, 2022.
- **Grid Related Power Standard**
  - Lunar power grid will require additional standards/documents
  - Transmission Power Quality Standard
    - Power quality at the grid voltage – can be written once grid voltage is confirmed
  - Grid Architecture Document
    - Describes the various architectures
  - Grid Operation Standard/CONOPS
    - Describes how the system will operate, shed loads, etc.
    - Compliments power quality standard

Conclusion

- **The need for power on the lunar surface will grow through the Artemis Campaign and beyond**
  - Technologies developed under the Artemis Campaign can influence a commercial lunar economy

- **Commercial lunar economy will require:**
  - Additional power standards and concept of operations
    - Requires a better understanding of the lunar environment before fully developing
    - Take advantage of current Artemis Campaign to learn about the environment
  - Opportunity for government and industry to collaborate and define the future lunar power grid

Thank you