



# **Adaptable Surface Power Integration & Research (ASPIRE)**

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This presentation contains preliminary findings, subject to revision as work proceeds.

# Motivation

- **Respond to NASA Moon-to-Mars Objectives for Lunar and Mars Infrastructure and Operations<sup>1</sup>**
  - **[LI-1]** 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.
  - **[MI-1]** Develop Mars surface power sufficient for an initial human Mars exploration campaign.
  - **[OP-1]** Conduct human research and technology demonstrations on the surface of Earth,... to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.
- **Establish agency-level resource to connect and coordinate complementary surface power development efforts across NASA Mission Directorates**
  - STMD: provide test capability to characterize lunar technology options in representative mission context
  - ESDMD: demonstrate lunar power capabilities to inform requirements development
  - SMD: evaluate power approaches to extend CLPS lander operations and promote interconnectivity
  - ARMD: explore component and testing commonalities with megawatt-scale electrified aircraft
- **Fulfill GRC role as agency lead for power technology maturation and advanced development**
  - Formulate strategies for implementing an evolvable lunar surface power architecture that is extensible to Mars
  - Provide opportunities for external partners to highlight new technology approaches and advance TRL
  - Collaborate with other NASA centers, government agencies, industry and academia to establish design specifications and best practices for Artemis lunar power systems

<sup>1</sup> <https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf>

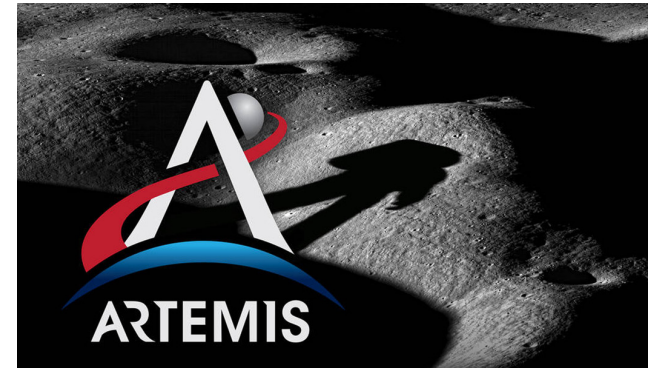
# Features and Attributes

- **Initial implementation:**

- Representative Artemis lunar base power levels (10s of kW)
- Simulated power sources and loads (solar arrays, fuel cells, FSP, habitat, ISRU)
- Long distance power transmission (kilometer scale)
- High voltage cabling with both AC and DC transmission
- Open, modular architecture for component demonstrations in system context
- Combination of Breadboard and COTS electronics hardware fidelity
- Flight-like control software, with pathway to interface standardization
- Transient day/night operations with source and load scheduling

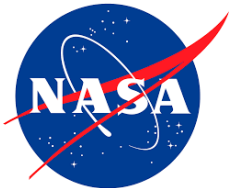
- **Future considerations:**

- Real sources and loads
- Lunar environments: temperature, dust, vacuum
- Digital Twin computer models, validated with test data
- Wireless power transmission
- Industrial-scale lunar power levels (megawatts)
- Human Mars missions

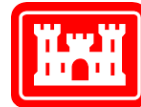


# Leveraging and Planned Partnerships

- **Key NASA Power Projects:**
  - ESDMD AMPS Project – Autonomous Power Controller (GRC)
  - STMD MIPS Project – Micro-grid Definition and Interface Converter for Planetary Surfaces (GRC)
  - LuSTR Grant: Flexible DC-Energy Router (Ohio State University)
- **NASA HQs and Other NASA Centers:** ESDMD, STMD, SMD, JSC, JPL, LaRC
- **Sandia National Lab:** Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) and Secure Scalable Microgrid Testbed
- **US Army Corps of Engineers:** Secure Tactical Advanced Mobile Power (STAMP) and Tactical Microgrid Standard
- **Johns Hopkins/Applied Physics Lab:** Lunar Surface Innovation Consortium (LSIC)
- **Ohio Aerospace Institute**



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**Leverage existing assets, advance new ideas and promote collaborative exchange**

# Current Space Power Projects

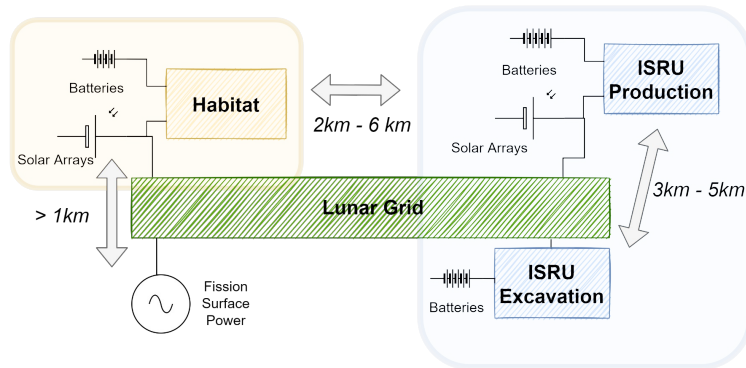
**There are many on-going projects seeking to provide lunar power solutions...**

- ESDMD Gateway Power & Propulsion Element (GRC)
- ESDMD xEVA and Surface Mobility Projects (JSC)
- ESDMD Advanced Modular Power Systems (GRC)
- STMD Technology Demonstration Missions
  - Fission Surface Power (GRC)
- STMD Game Changing Development
  - Vertical Solar Array Technology (LaRC)
  - Regenerative Fuel Cells (GRC)
  - Micro-grid Definition and Interface Converter for Planetary Surfaces (GRC)
  - Tethered Power Systems (JPL)
  - Chemical Heat Integrated Power Systems (JPL)
  - Breakthrough Distributed Power Architecture (JPL)
- STMD Tipping Points
  - Advanced Modular Power & Energy System (Infinity)
  - Rad-hard Power Controller Development (Apogee)
  - Ultra-Fast Proximity Charging (Astrobotic)
  - Bifurcated Reversible Alkaline Cell (pH Matter)
  - Propellant Fueled Solid Oxide Fuel Cell (PCI)
  - Hydrogen Electrical Power System (Teledyne)
- STMD Watts On The Moon Challenge (GRC)
- STMD ACOs
  - Lunar Lander Fuel Cell (Blue Origin)
  - Advanced Alkaline Reversible Cell (pH Matter)
  - Dust Mitigation for Flexible Solar Arrays (Maxar)
  - Flexible Solar Array Qual Protocols (Maxar)
- STMD LuSTR
  - Flexible DC-Energy Router (Ohio State)
  - Moonbeam-Beamed Lunar Power (UCSB)
  - Silicon Carbide Power Components (Vanderbilt)
- STMD Space Technology Research Grants
  - ESI 21: Advanced Materials for High-Voltage Power Transmission on the Moon
  - ESI 19: Chemical Heat Integrated Power Systems
  - ECF18: Batteries for Extreme Cold Environments
- SMD Radioisotope Power Systems (GRC)
  - Multi-Mission RTG
  - Next Gen RTG
  - Dynamic RPS
- SMD CLPS PV Investigation on Lunar Surface (GRC)
- SBIR Subtopics in Power Generation, Conversion, Storage, Management & Distribution

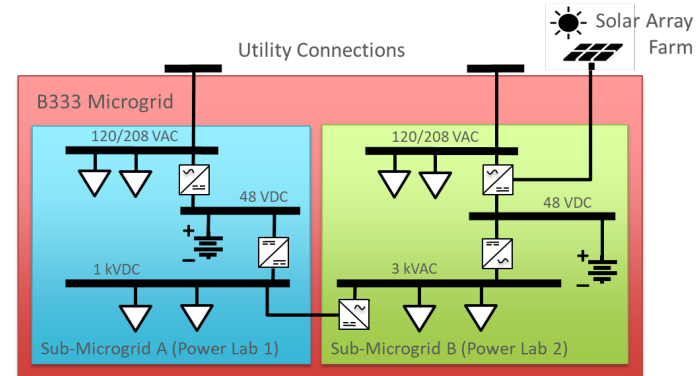
**but limited coordination among them and no common means to evaluate them.**

# GRC Lunar Micro-grid Concept

Recent **GRC Center Innovation Fund (CIF)** project provides excellent starting point to replicate lunar power architecture with testbed analog



**Lunar power architecture concept**



**Initial GRC power testbed analog**

- Lunar power architecture includes separate micro-grids at Habitat and ISRU and Bi-directional Lunar grid for efficient power sharing between micro-grids
- Architecture includes 120 VDC primary loads with interface converters that receive power via long-distance 1 kVDC or 3 kVAC transmission cables

**ASPIRE can replicate the two micro-grids with link to connect high-voltage buses**

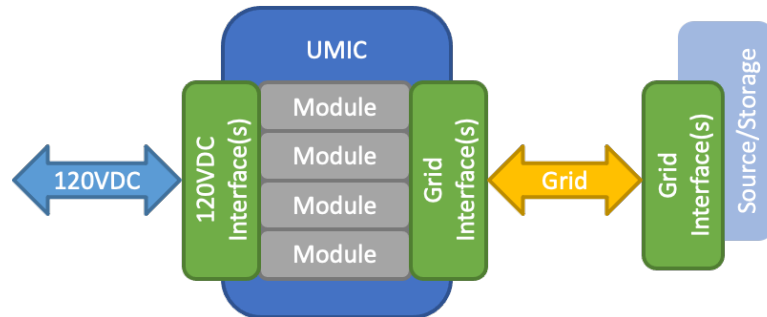
# GRC Universal Modular Interface Converter (UMIC)

Power converter that provides bidirectional power flow between high voltage power transmission and standard 120 VDC space power distribution system

UMIC is a solution to transmit 10s of KW of power over km distance, enabling power sharing, highly available/reliable power for new users

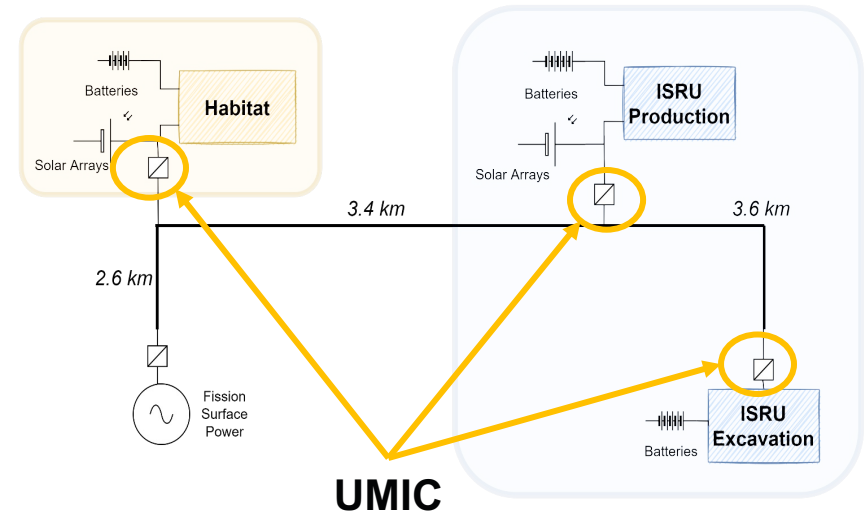
The UMIC is truly modular, as modules can be easily:

- Replaced if damaged
- Relocated to more critical areas (reusable)
- Spared (extras/backups) at low mass and volume
- Paralleled to:
  - Increase total power capability (scalable)
  - Provide inherent redundancy



Prototype development will focus on:

- Developing standard interfaces and specifications:
  - Vendor agnostic; grid-tie regulations
- Determining control strategies (local and grid)
- Characterizing performance (limits, efficiency, etc.)



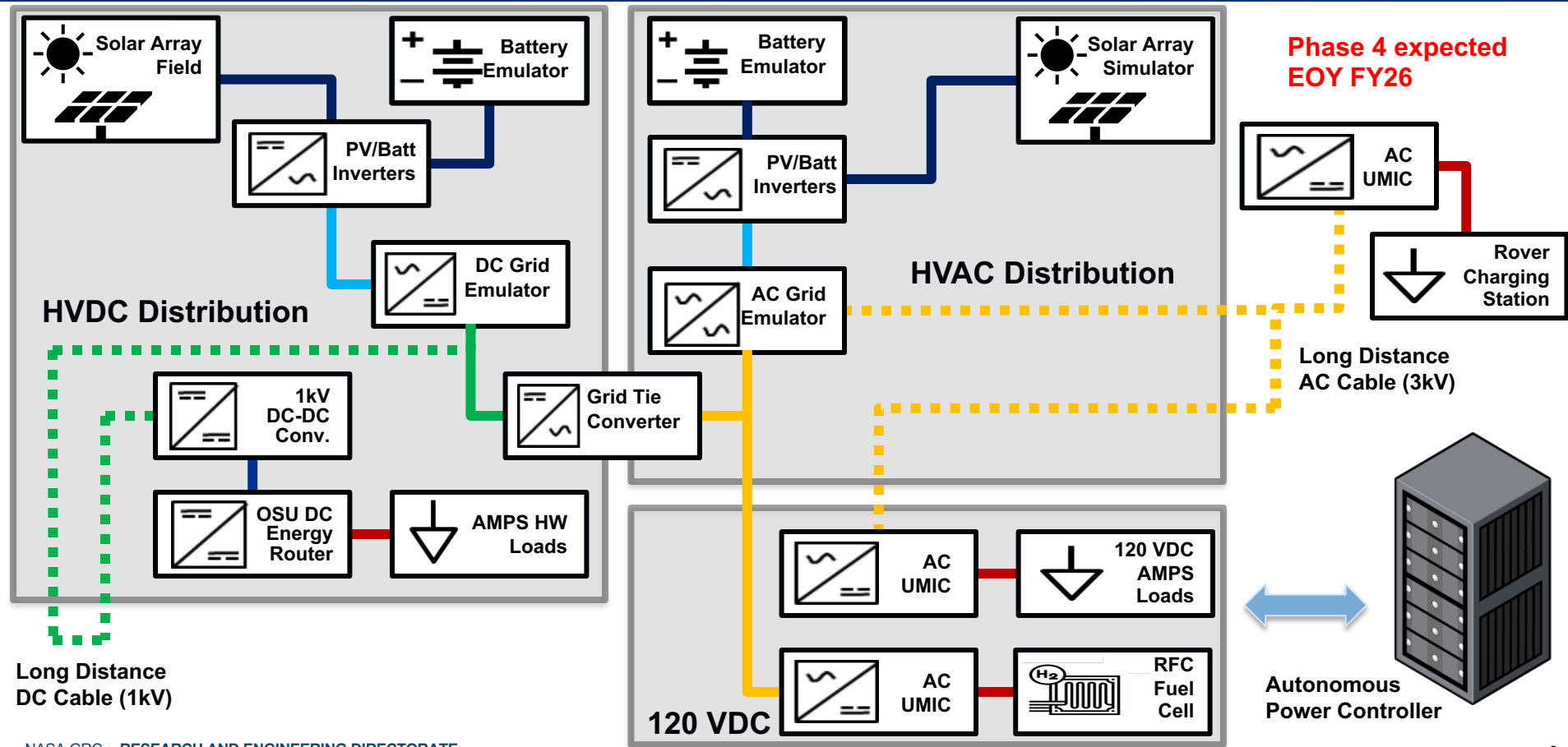


# Notional ASPIRE Buildup Approach

Phase	Objective	Deliverables	Estimated Completion
1	3 kVAC Build Up and UMIC Integration	<ul style="list-style-type: none"><li>Establish initial capability of HV AC testbed, including long distance 3-phase, 3kV 1kHz cable, UMIC, and 120VDC loads (AMPS)</li><li>Leverage existing SAES hardware and battery emulator as sources</li></ul>	Q4 FY23
2	1 kVDC Build Up and OSU Energy Router	<ul style="list-style-type: none"><li>Establish HVDC capability, including long distance 1kV DC cable, 1kV-120V converter</li><li>Add OSU DC Energy Router</li></ul>	Q4 FY24
3	Hardware Integration and AC/DC Tie	<ul style="list-style-type: none"><li>Complete lab tie between AC and DC labs</li><li>Add Rover charging station</li><li>Add RFC fuel cell capability, tie in solar array field and batteries to testbed</li></ul>	Q4 FY25
4	Autonomous Power Control	<ul style="list-style-type: none"><li>Integrate APC with testbed</li></ul>	Q4 FY26



# Notional ASPIRE Buildup Phases



# Summary & Conclusion

- **ASPIRE has potential to...**
  - Serve as agency-level lunar surface power test capability to integrate and demonstrate advanced technologies in a representative mission context
  - Investigate different lunar power architecture approaches to inform future flight system requirements and operational strategies
  - Provide a test option for external developers to evaluate new surface power technologies under consistent, realistic operating conditions
- **Technology GAPS that can be addressed with new test capability:**
  - Long distance transmission, high voltage distribution, inter-system compatibility, lunar microgrid performance and control
- **What does the LSIC power community think?**
- **What ideas do you have to enhance and expand our plans?**