



ENERGY&MOBILITY

TECHNOLOGY, SYSTEMS AND VALUE CHAIN
CONFERENCE & EXPO

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A Modular AC to DC Interface Converter to Enable Lunar Surface Power Transmission



9/14/2023

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Research Center*

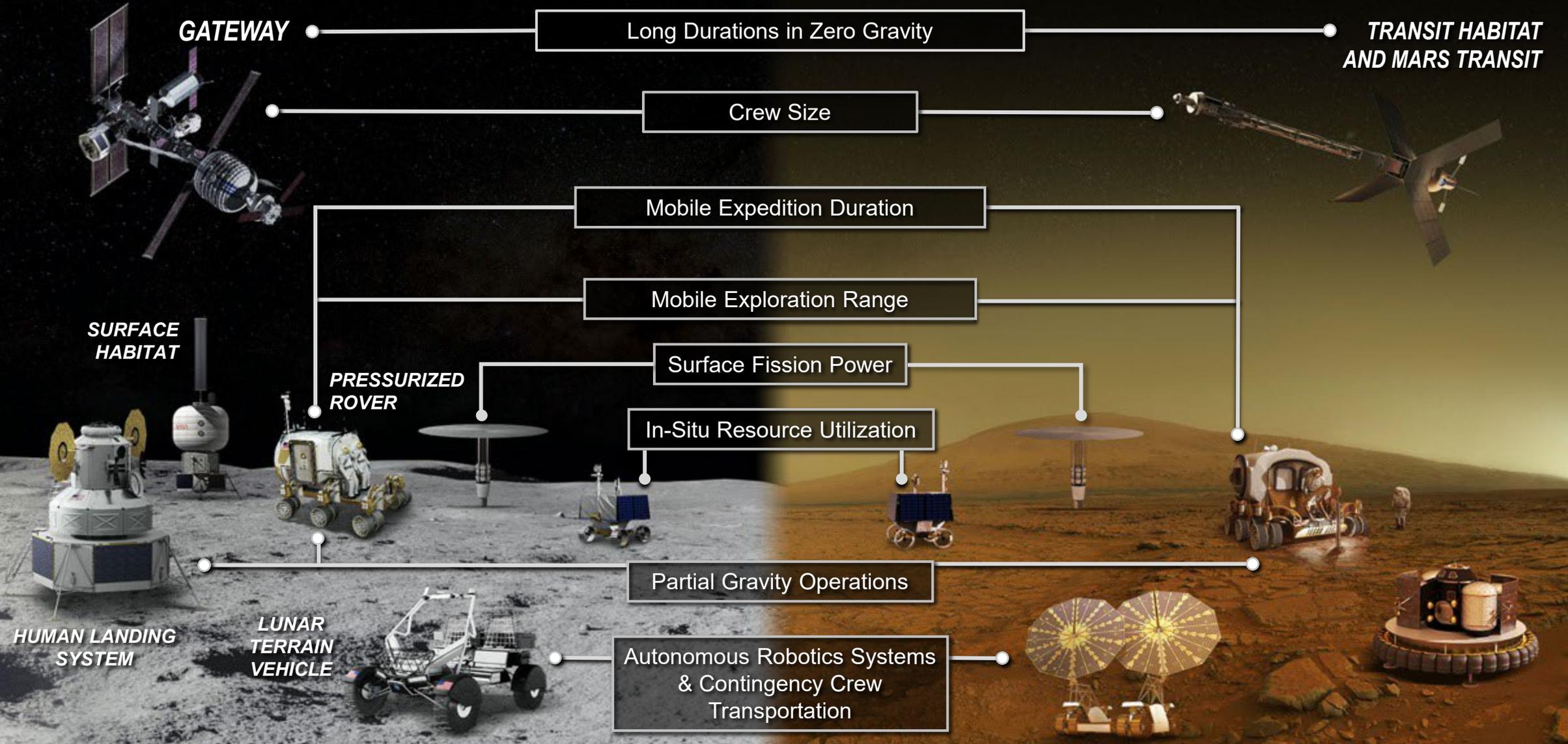


Topic

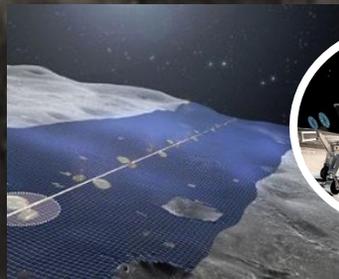
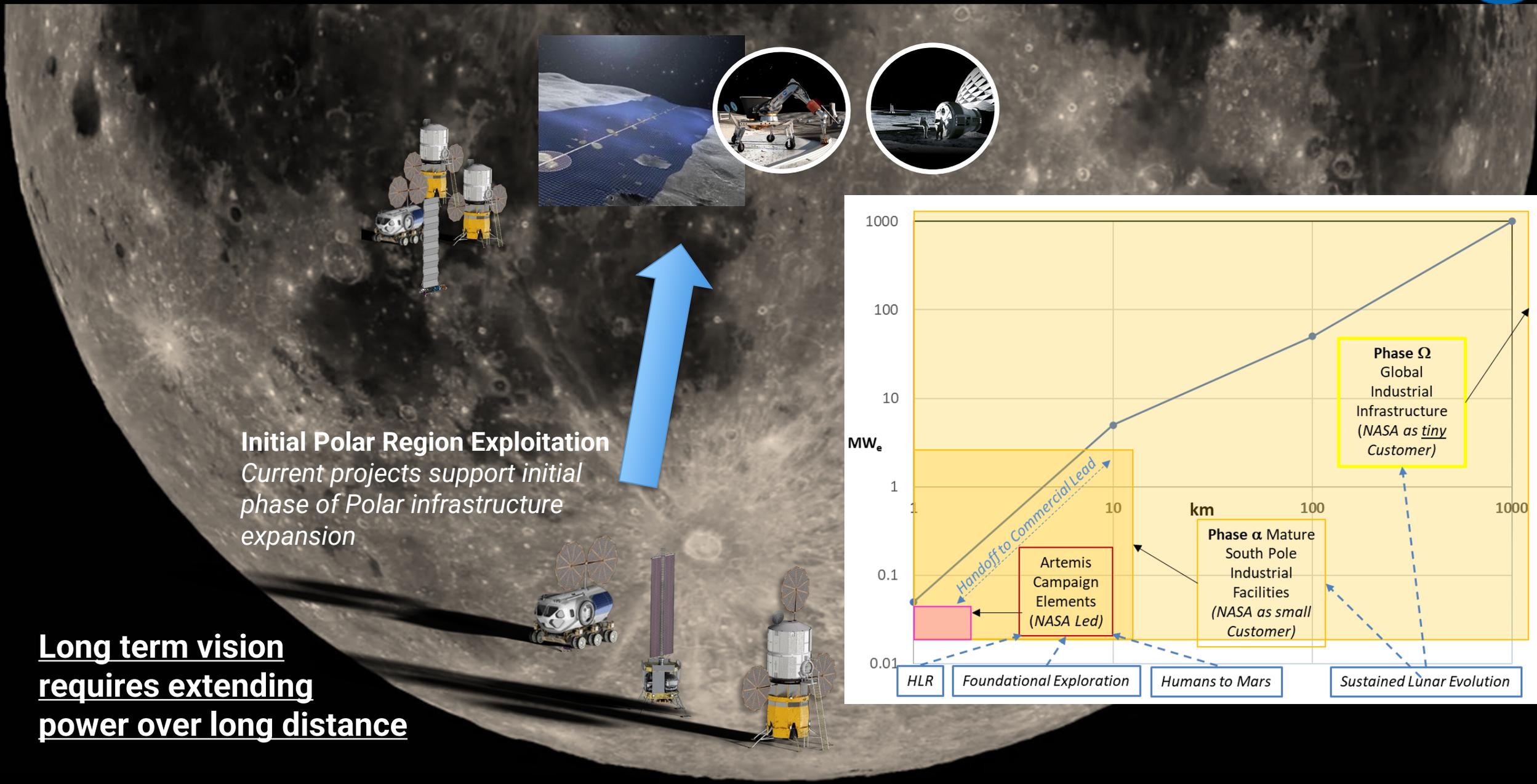
- **Introduction**
- **Lunar Grid Trade Studies**
- **Universal Modular Interface Converter (UMIC)**
 - **Conceptual Design**
 - **Breadboard Hardware Design**
- **Conclusion**
- **Future work**

Moon to Mars Exploration

Operations on and around the Moon will help prepare for the first human mission to Mars



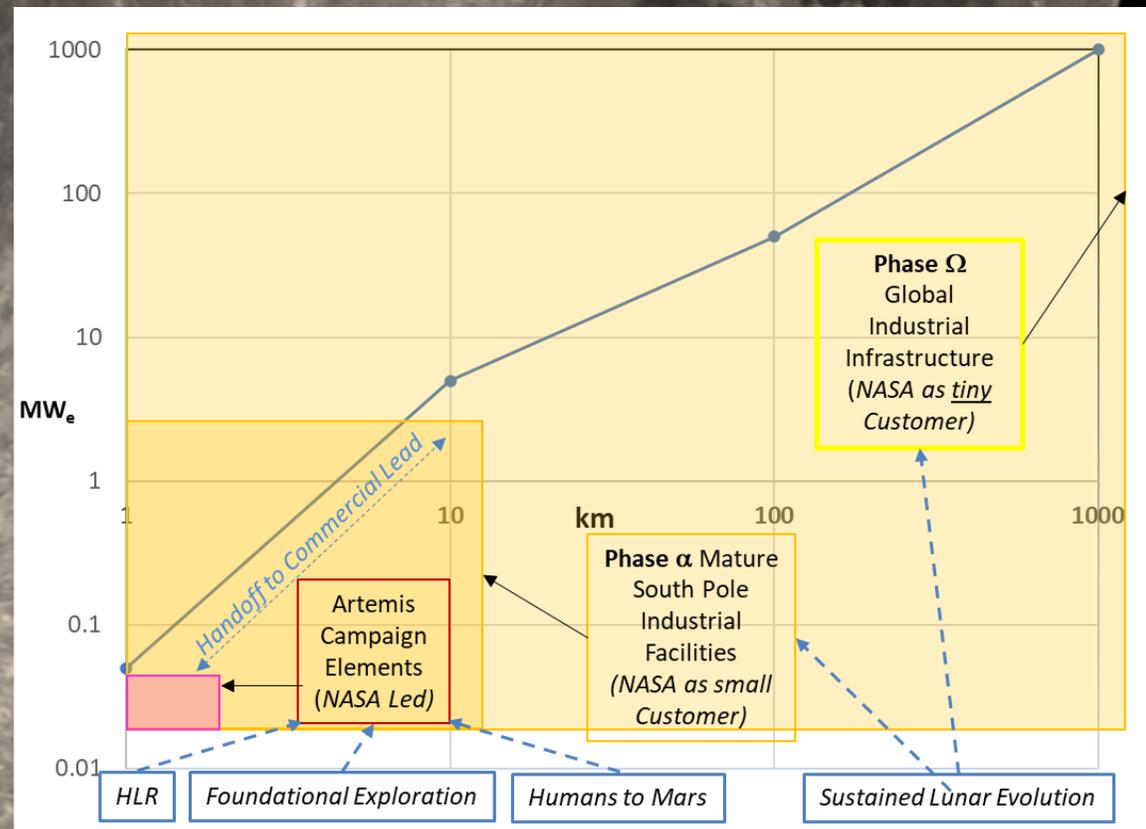
Ultimate Global Exploitation



Initial Polar Region Exploitation
Current projects support initial phase of Polar infrastructure expansion



Long term vision requires extending power over long distance



The Need for Universal Lunar Surface Power

- **Lunar surface operations will grow and expand**
 - Power demands will exceed element's capability - Self sufficient power is not feasible
 - Systems will have to be integrated together or to a power grid (shared access)
- **Power over long-distance**
 - Driven by minimum safe landing distance and radiation stand off (1km+)
 - Needed for power in permanently shadowed regions (PSR)
- **Dissimilar power sources**
 - Increase power availability – provide power during longer eclipse periods
 - Contingency scenarios - Provide needed redundancy and reliability



Lunar Power Grid

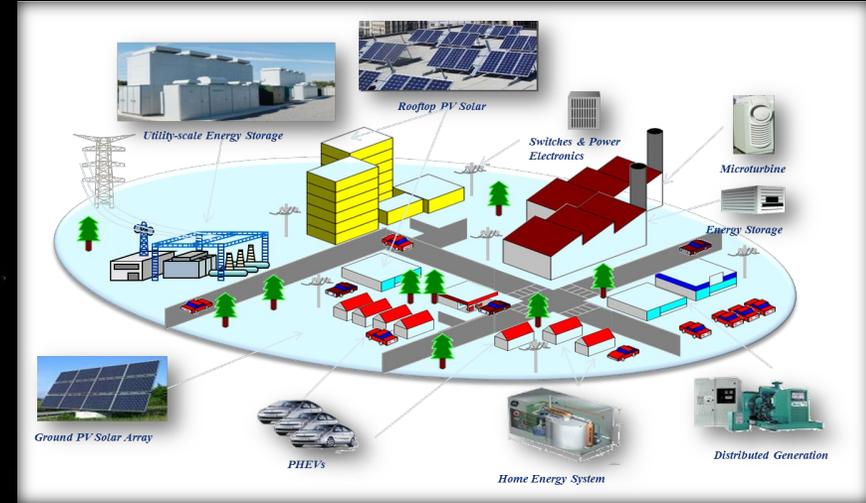


- **Benefits of a power grid**

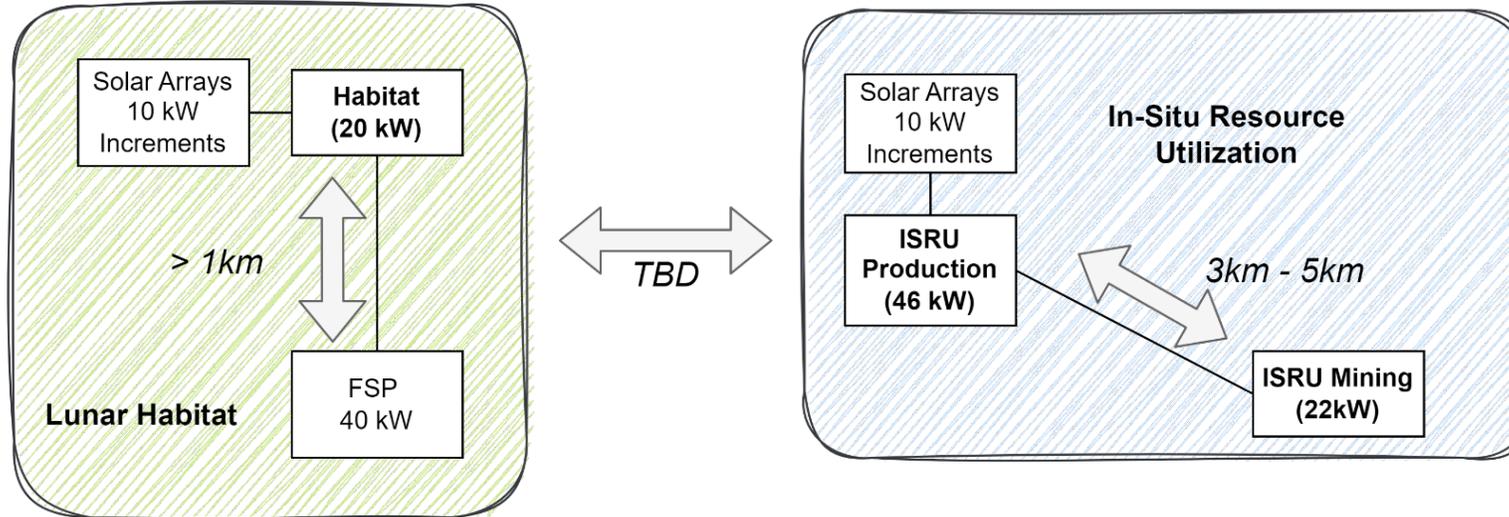
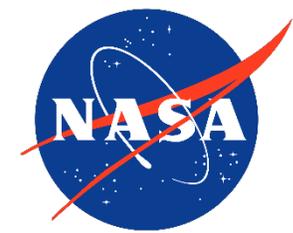
- Flexibility, evolvability, and reconfiguration
- Optimal dispatch of power sources and energy storage to service loads & enhance reliability
- Systematic integration of new sources and loads
- **Common grid interface (commonality)**
- Allows for the deployment of future loads that do not need to carry their own power generation

- **NASA STMD performing initial enabling R&D work for an Artemis grid**

- Microgrid Definition and Interface Converter for Planetary Surface (MIPS)
 - Main product: UMIC



Baseline Artemis Power System



Power Sources:

Solar Arrays

- Vertical Solar Array Technologies (VSAT)
- 10 kW increments
- 120 VDC Source

Fission Surface Power (FSP)

- 40 kW Power
- Must be located more than 1km from other lunar elements

Lunar Elements (Loads):

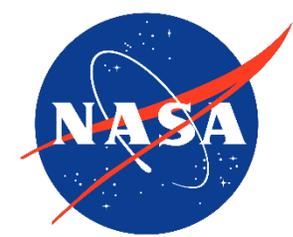
Surface Habitat

- 20 kW during habitation (must be during insolation)
- 2 kW during eclipse and non-habitation

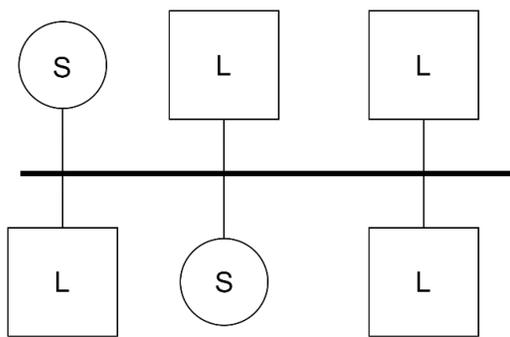
In-Situ Resource Utilization (ISRU)

- ISRU processing - 46 kW insolation / 9 kW eclipse
 - Located on crater rim (in the sun)
- Excavation - 22 kW insolation / 4 kW eclipse
 - Permanently shadowed regions (water-ice)
 - About 3km – 5km from processing facility

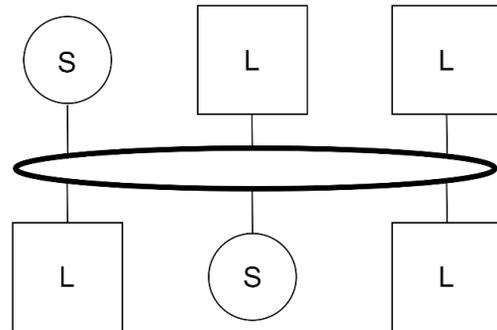
Trade Study Setup



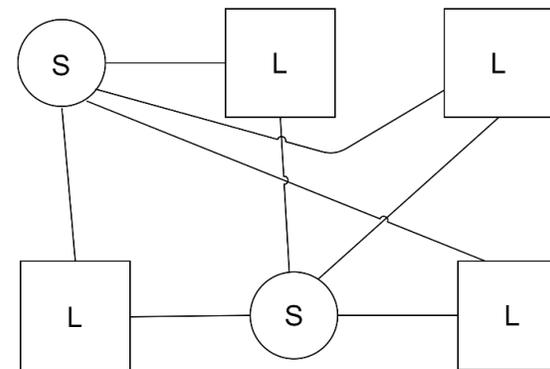
- Electrical Power System—Sizing and Analysis Tool (EPS-SAT) used for studies
 - MATLAB-based tool for power system concept analysis, available for general govt purpose use
 - <https://software.nasa.gov/software/LEW-20017-1>
 - Planetary surface cable and converter models developed and used for this work
- Transmission bus voltage, power type, and frequency allowed to vary
 - Voltage: 1.2 kV to 6 kV, DC and 3-Ph AC
 - Frequency: 60 Hz to 1 kHz
- Evaluate mass of radial, ring, and mesh architectures for overall grid design



a) Radial Network

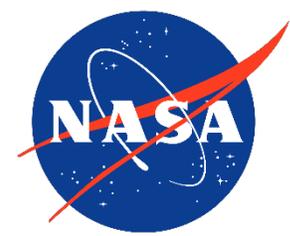


b) Ring Network



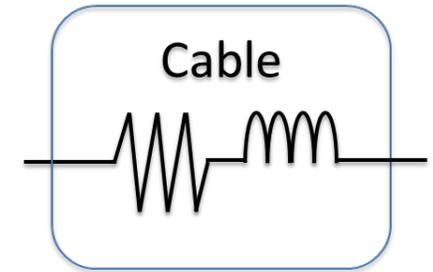
c) Mesh Network

Trade Study Modeling Assumptions



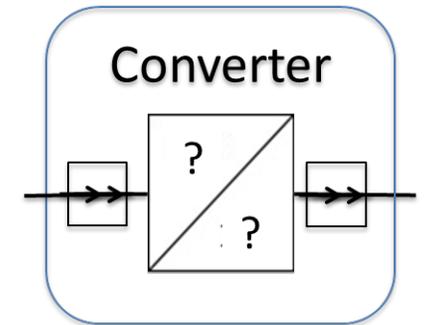
- Cables

- Single or bundle of parallel 10-14 AWG wires, ETFE insulated Cu
 - Size for >90% efficiency at 40 kW
- Skin/proximity effect, inductance, temperature modeled, others (e.g. coupling to regolith) ignored



- Converters

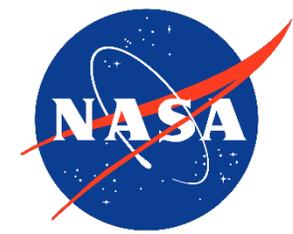
- 95% efficient if DC-DC (bidirectional DC-DC)
- 96.5% efficient if DC-AC (bidirectional inverter)
- 98% efficient if AC-AC and no AC frequency changes (a transformer)



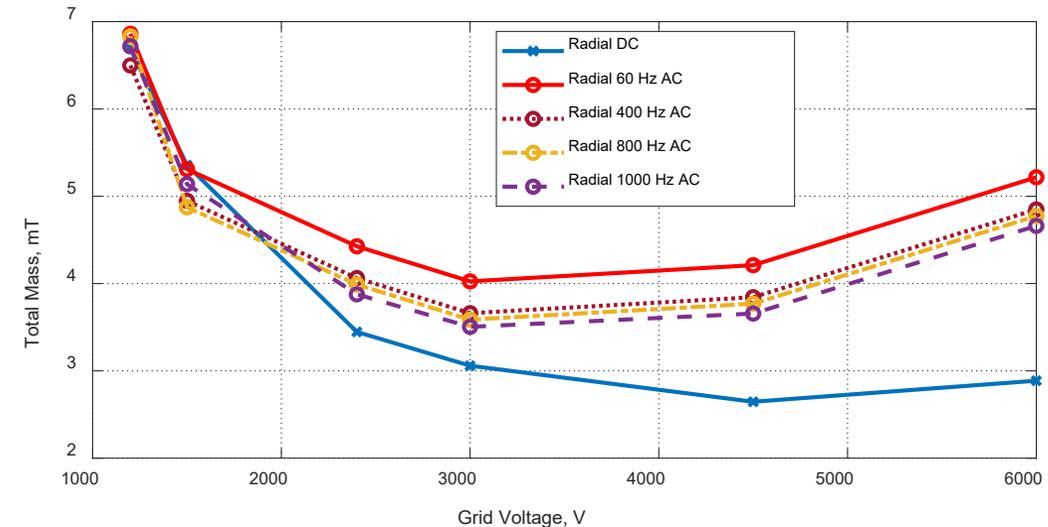
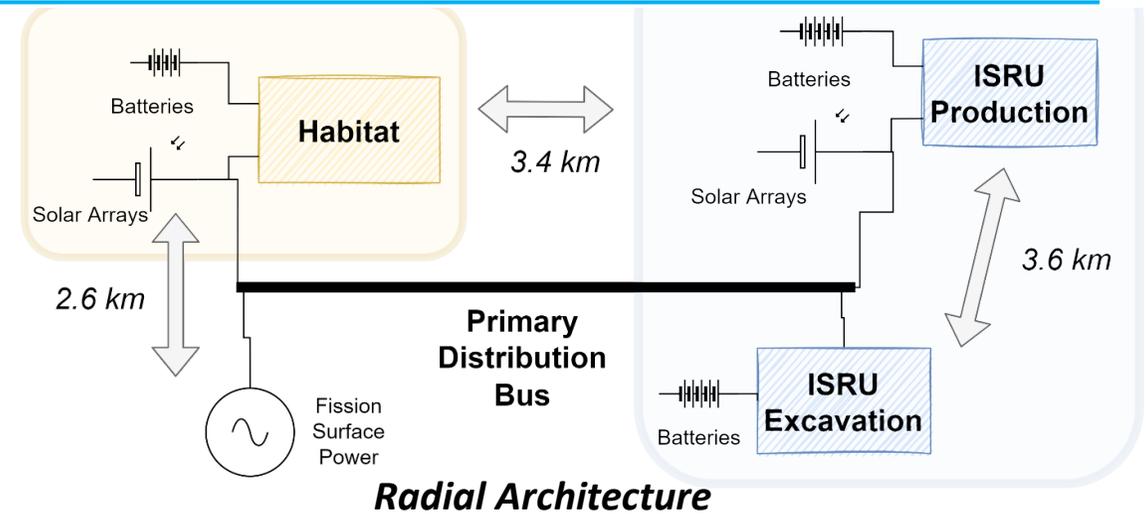
- Loads/Sources

- Habitat includes 20 kW source and 20 kW load
- ISRU includes 80 kW source and 68 kW load
- FSP is a 40 kW AC source

Trade Study Results

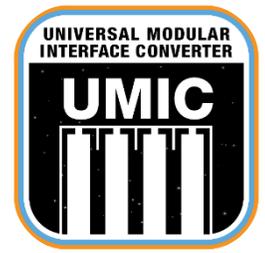
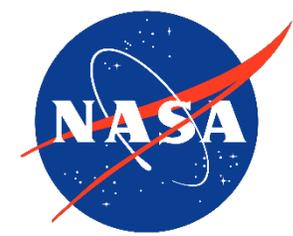


- Trade studies focused on primary power distribution system
 - Data includes mass estimates of converters and cables
- Results
 - Increasing voltage decreases mass
 - Diminishing returns above 3-4 kV
 - Increasing tie lines (radial → ring or mesh) adds mass but does not change trends
 - Easiest to start w/ radial, and add additional tie lines later (add reliability)
 - AC vs DC at a single voltage is marginal
 - Technology limitations need to be considered
 - Max DC: 1.5 kV (Rad hard limitations)
 - Max AC: none known



Recommendation: 3kVAC, 3-phase, 1000 Hz

UMIC Hardware Architecture



• Goals

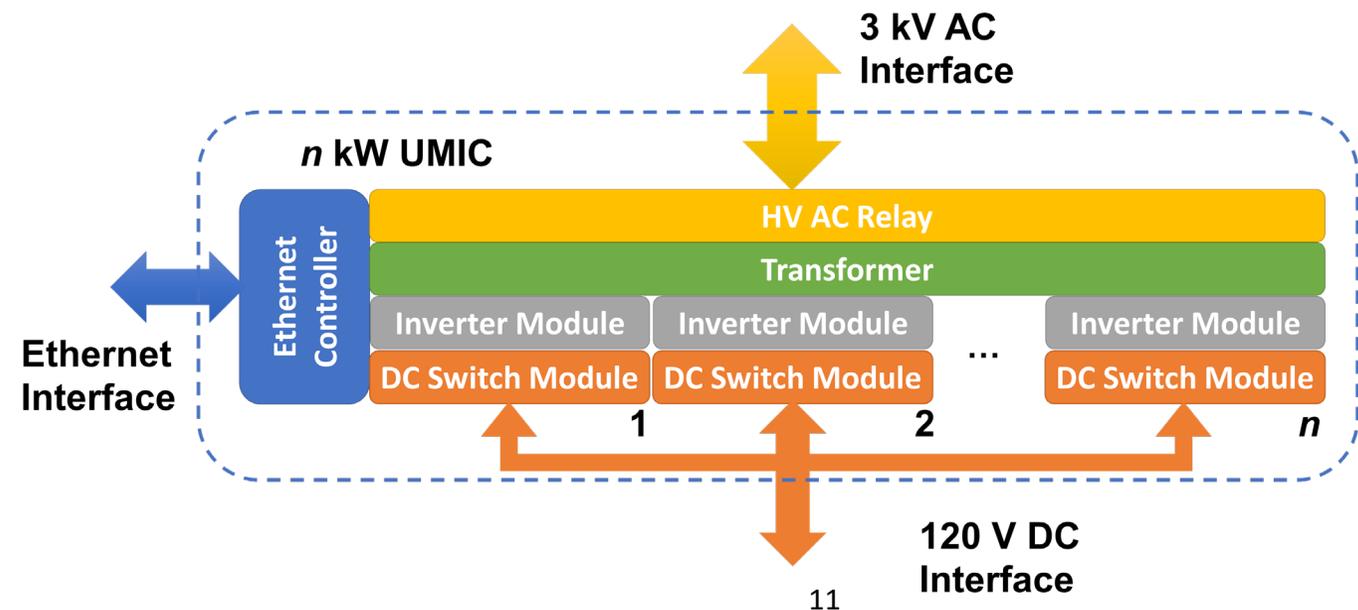
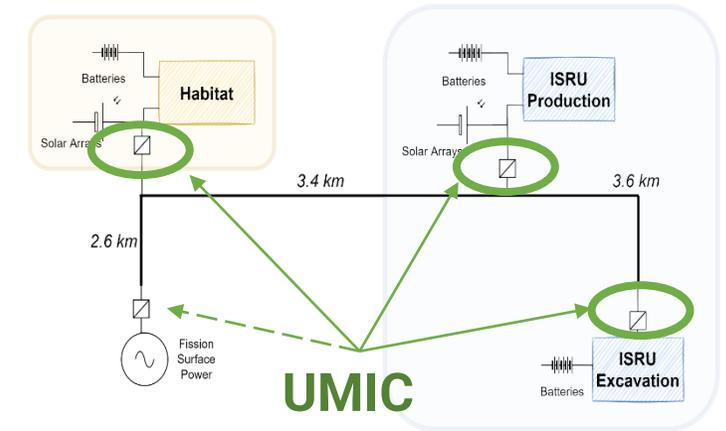
- Develop standardized interface converter between 120 VDC users and 3 kV 3-phase AC 1 kHz grid
 - A field-replaceable, bidirectional, modular, grid forming inverter
 - 1 kW per module, 10 kW total power or greater

• Objectives

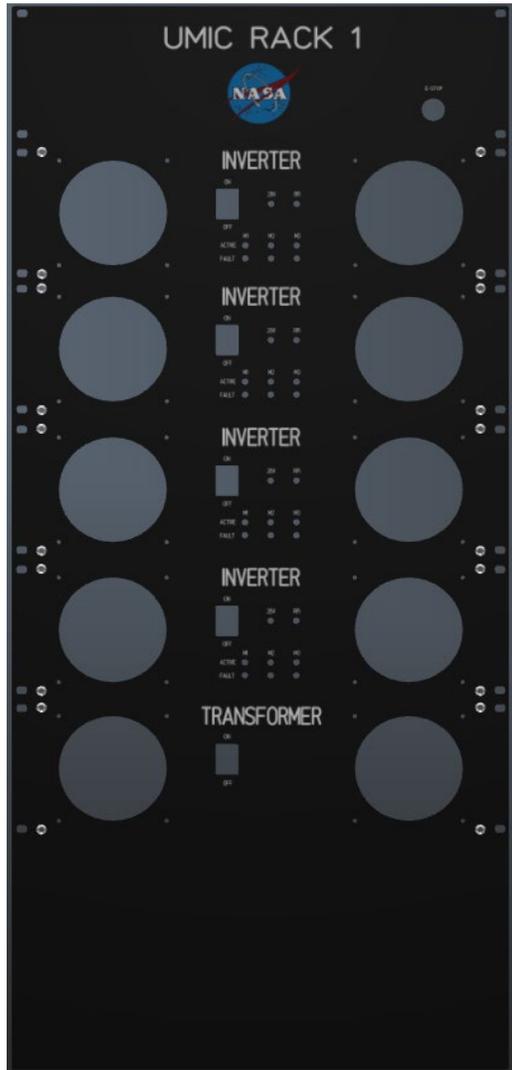
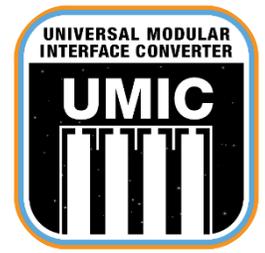
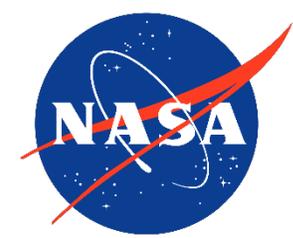
- Efficiency >95%, specific power >350 W/kg (estimated for flight)

• Implementation

- HV AC relay for isolation
- Modular/distributed transformers OR centralized transformer
- Modular, parallelizable single stage power electronics design
 - Six switch Inverter Module, produces ~40 VAC L-N (LV bus)
 - Current limiting solid-state DC Switch Module (DC switchgear)
- Ethernet Controller for external comms interface

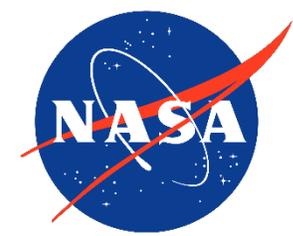


UMIC 10 kW Breadboard Rack



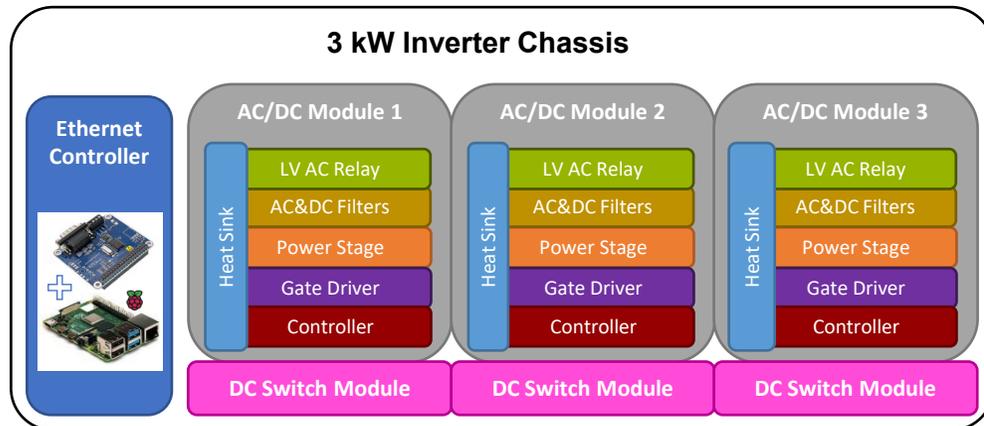
- Universal Modular Interface Converter
 - 10 kW nominal power capability (12 kW peak)
 - 19" rack based breadboard form factor
 - Composed of one transformer chassis and multiple parallel inverter chassis
 - Parallelable - can provide more than 10 kW at single location
 - Design goals:
 - >95% efficiency
 - 350 W/kg power density (est. for flight)
 - Capability:
 - Grid forming
 - Synchronization with existing grid power

UMIC 3 kW Inverter Chassis



- 3 kW inverter chassis (3U 19" rack mount form factor)
 - Each contains 3x 1 kW inverter modules

Conceptual Breadboard Inverter Chassis Design

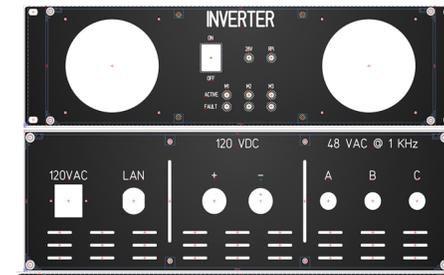


120 VDC

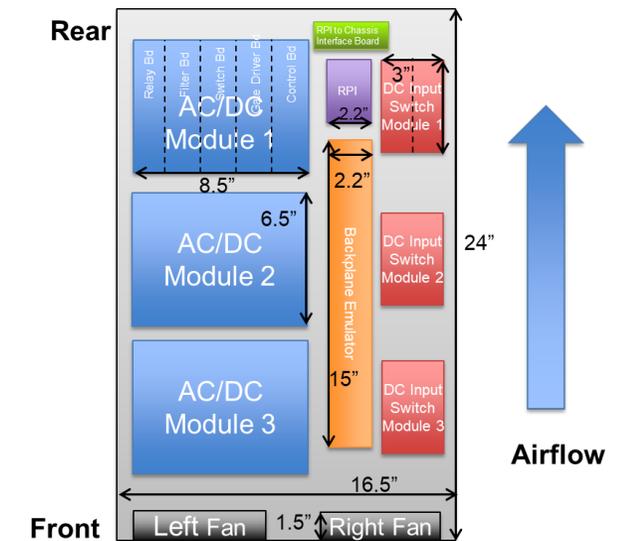


INVERTER FRONT
INVERTER REAR

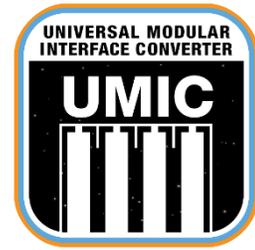
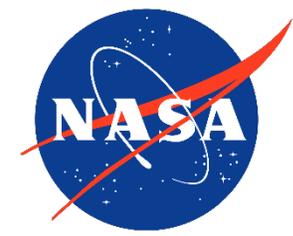
Front and Rear Panels



Chassis Top View

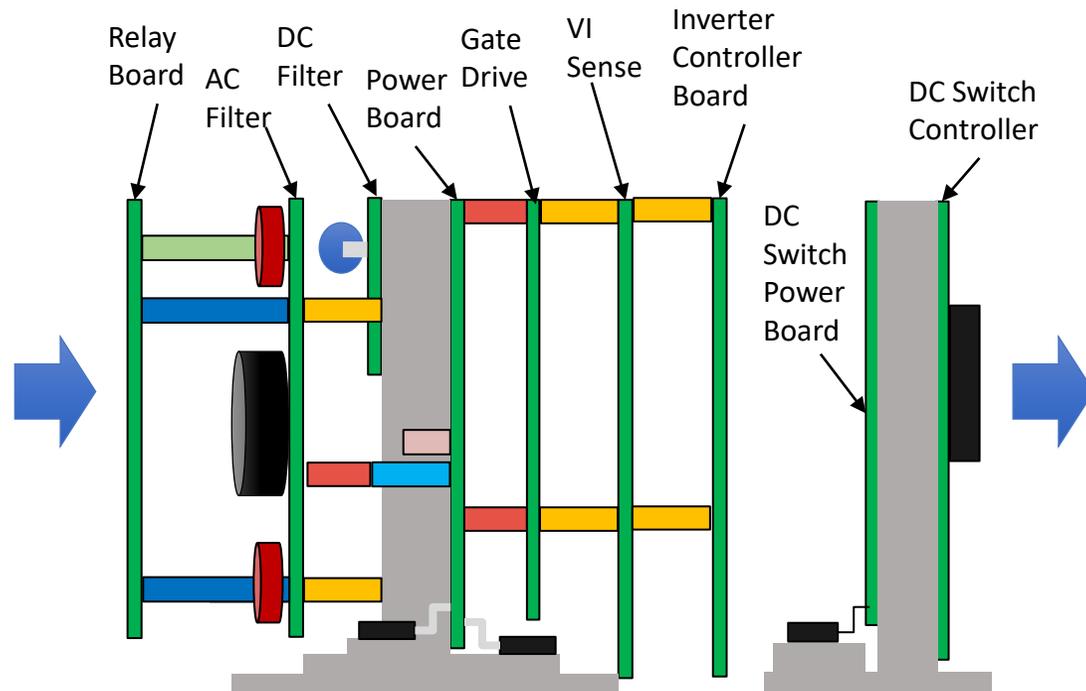
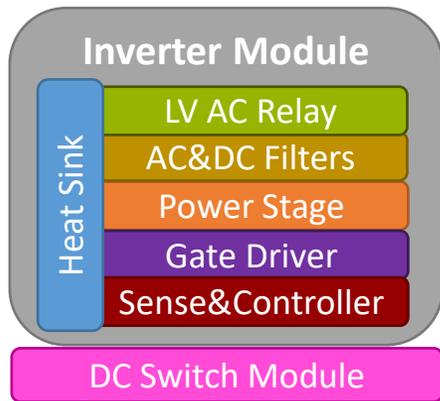


UMIC 1 kW Modular Electronics



- **1 kW Inverter Module plus 1 kW DC Switch Module**

- **Inverter:** Converts 120 VDC microgrid bus to UMIC internal low voltage 40 VAC bus
 - Includes filters, power control logic, AC isolation
 - Consists of 5 main subsystems in a stacked card form factor
- **DC Switch:** Provides DC-side current limiting & isolation capability



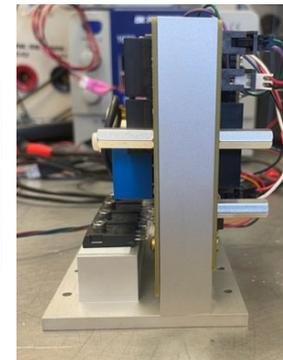
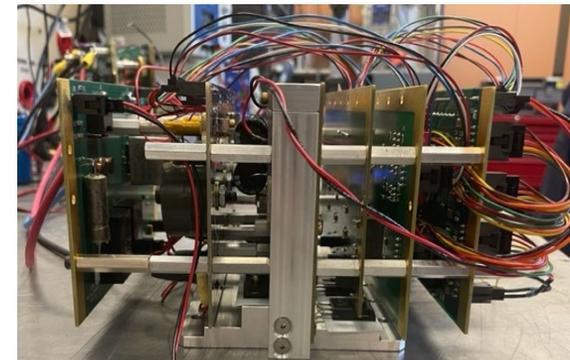
Inverter Module Interfaces

~40 VAC Internal LV AC Power

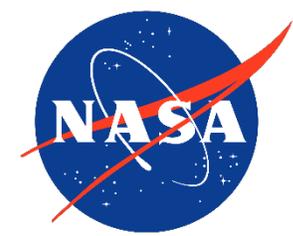
28 VDC Housekeeping Power

120 VDC Microgrid Power

CAN bus (commands /telemetry)



UMIC Transformer Designs

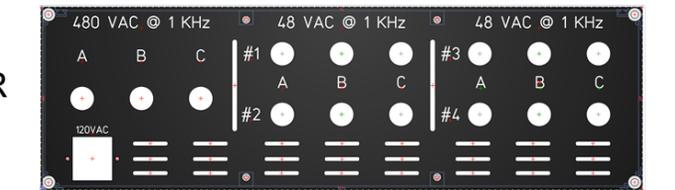


- **Transformer chassis to include all transformers needed at a given site**
 - More or less given site power needs
- **Modular (1 kVA) transformer designs (both single and 3-phase types)**
 - 10x 1 kVA three phase transformers (10 kVA total)
- **Centralized transformer design (single-phase type only)**
 - 3x 3.3 kVA single phase transformers (10 kVA total)

TRANSFORMER FRONT



TRANSFORMER REAR



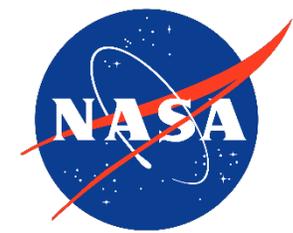
NASA 1 kVA 3-phase design



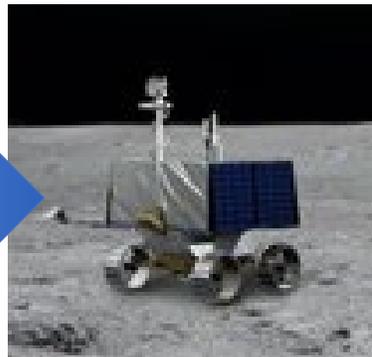
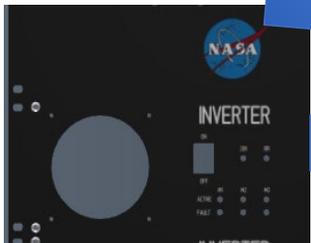
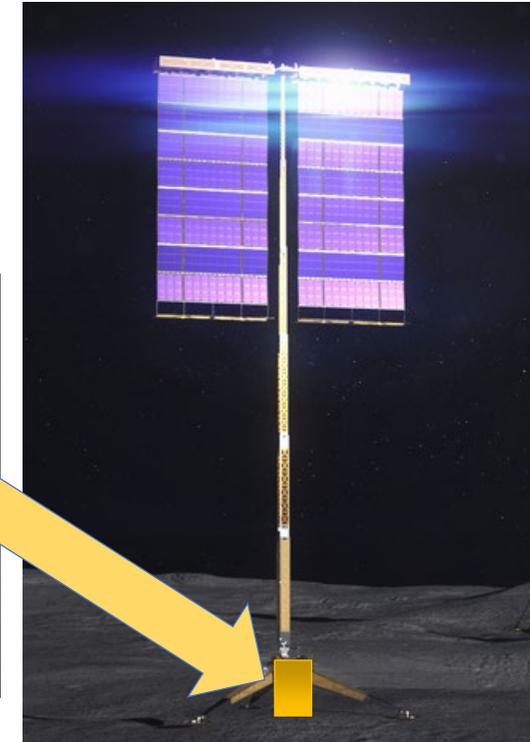
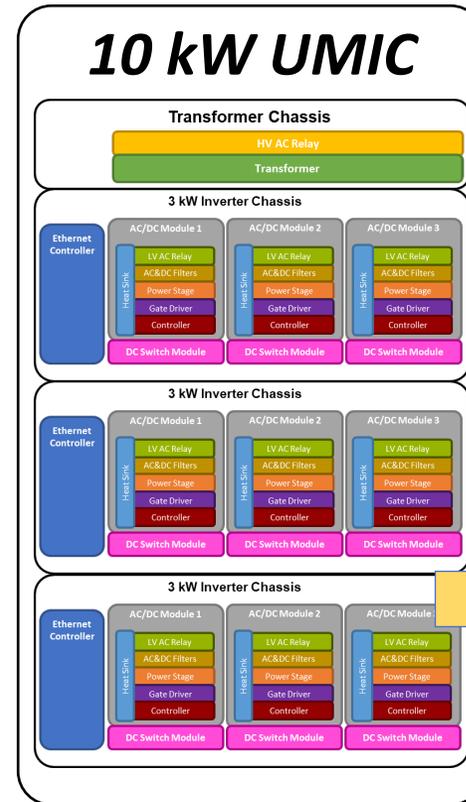
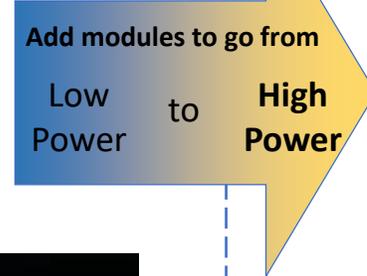
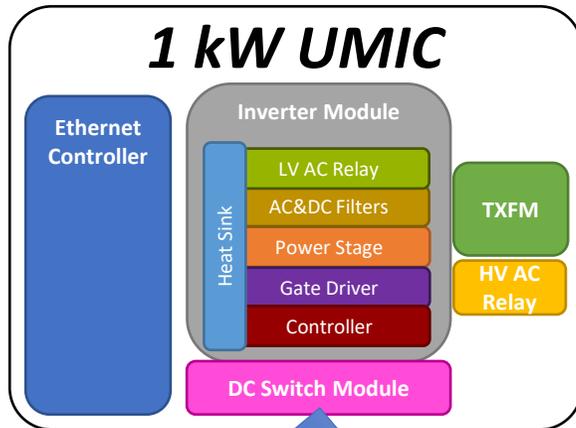
3.3 kVA single-phase design (3x for 10 kW)



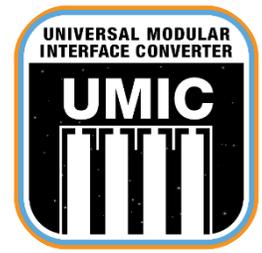
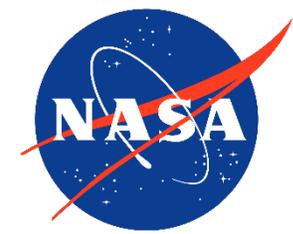
Scalability and Applicability



1. Modularity allows UMIC to scale based on site needs
2. UMIC designed for compatibility with different DC loads/sources
 - e.g., 1 kW rover vs 10 kW VSAT

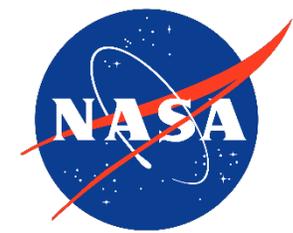


Breadboard Expected Outcomes



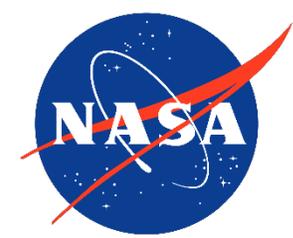
- Validate concept with the following demos
 - Bidirectional AC power transfer between two 10 kW UMICs via 1 km cable
- Characterize UMIC to inform future development
 - Identify challenges, find areas for improvement in HW design
 - Determine suitability of UMIC interface definition

Conclusions



- Future planetary surface missions will need universal access to reliable power
 - Artemis
 - Commercial Lunar Development
 - Mars
- The UMIC enables high voltage, bidirectional power transmission
 - Necessary for universal, reliable planetary surface power over km distance
- NASA is making investments to advance the UMIC technology and make it available for future government and industrial use

Future Work



- Seek opportunities to advance UMIC technology
 - Increase TRL
 - Build for and demonstrate in environments beyond lab
 - Provide a solution for tech demos requiring power transmission
 - Push beyond breadboard
 - Design for form and fit in addition to function
 - Demonstrate wide applicability, a truly universal solution
 - Grid-to-120 VDC load or grid-to-120 VDC source interface converter
 - Solar and/or energy storage interface converter
 - Capable of different AC grid voltages or frequencies with different transformer

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