Creating a Lunar Surface Power Grid

National Aeronautics and Space Administration

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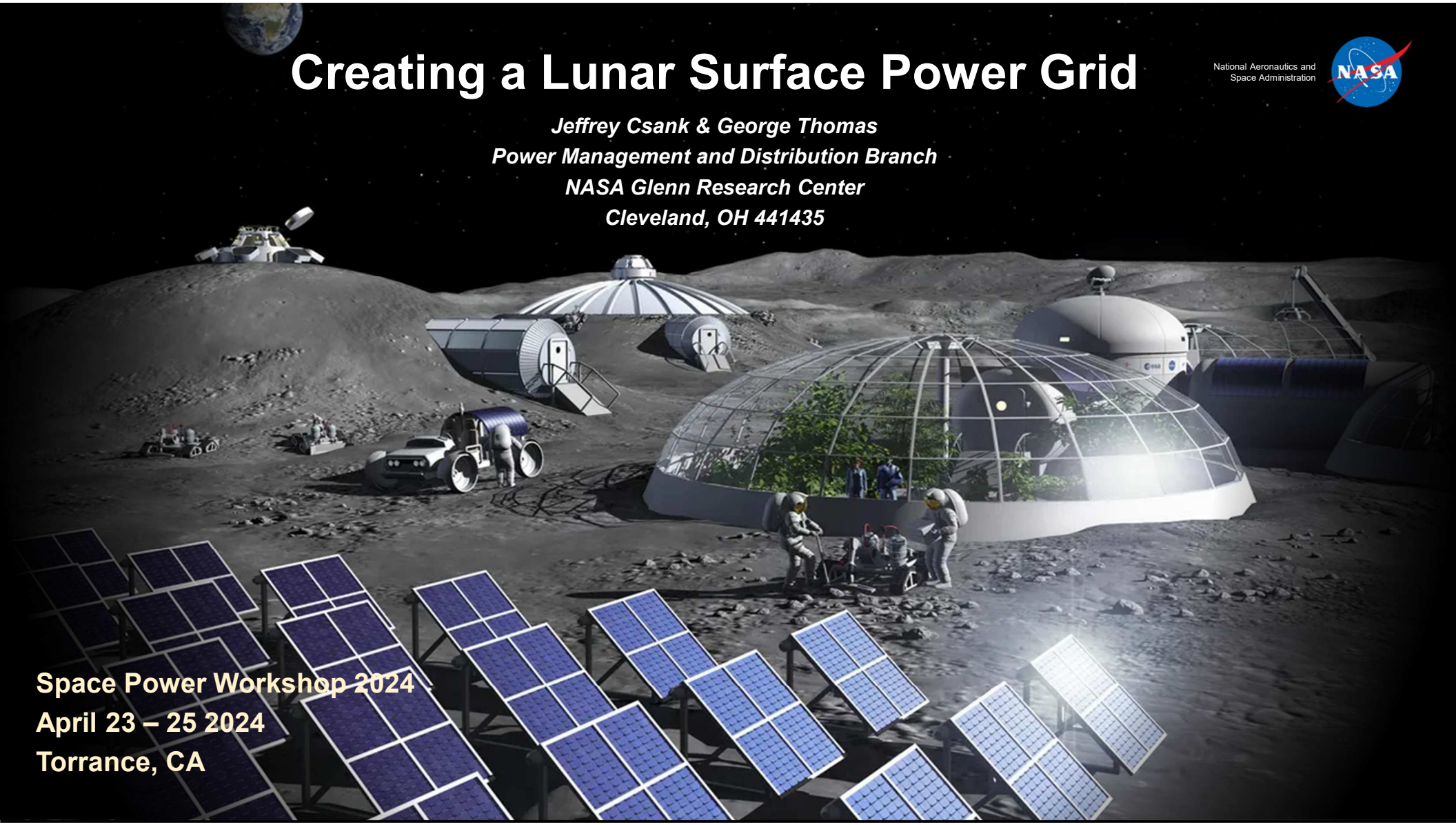


Space Power Workshop 2024
April 23 – 25 2024
Torrance, CA

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 Architecture Definition Document (ADD)

Moon to Mars Campaign Segments

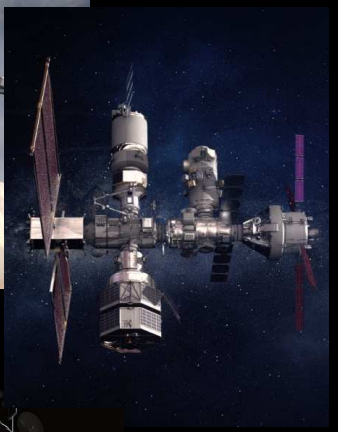
Human Lunar Return	Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (science, etc.) on and around the Moon.
Foundational Exploration	Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to 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.*

NASA Artemis Campaign

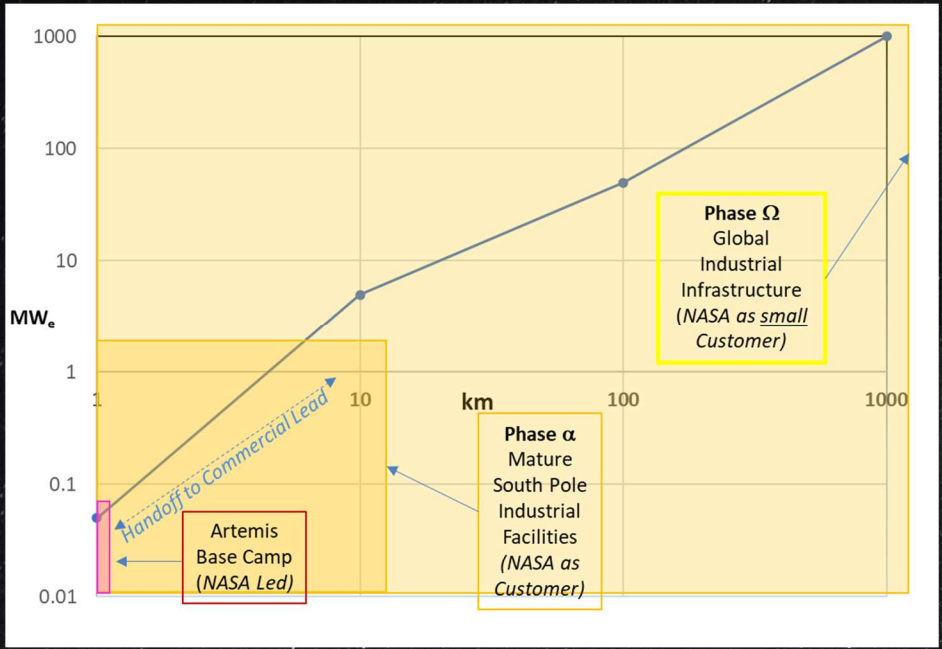
- **Artemis Campaign**
  - Reestablish a human presence on the lunar surface
    - First woman and first person of color on the Moon
    - Establish the first long-term presence on the Moon
    - Take the next giant leap – Human on Mars
  - Artemis Missions
    - ✓ Artemis 1 (2022) : uncrewed test of SLS and Orion
    - *Artemis 2: first crewed test flight of SLS and Orion*
    - *Artemis 3: first crewed lunar landing*
    - *Artemis 4: second crewed lunar landing*
    - *Artemis 5 – 8: TBD*

ARTEMIS





Envisioned Futures - Growth of a Permanent Lunar Presence



Ultimate Global Infrastructure – *Phase Ω (2040+)*

Additional technology gaps to be closed to enable building blocks for global infrastructure

Mature South Pole Industrial Facilities – *Phase α (2030+)*

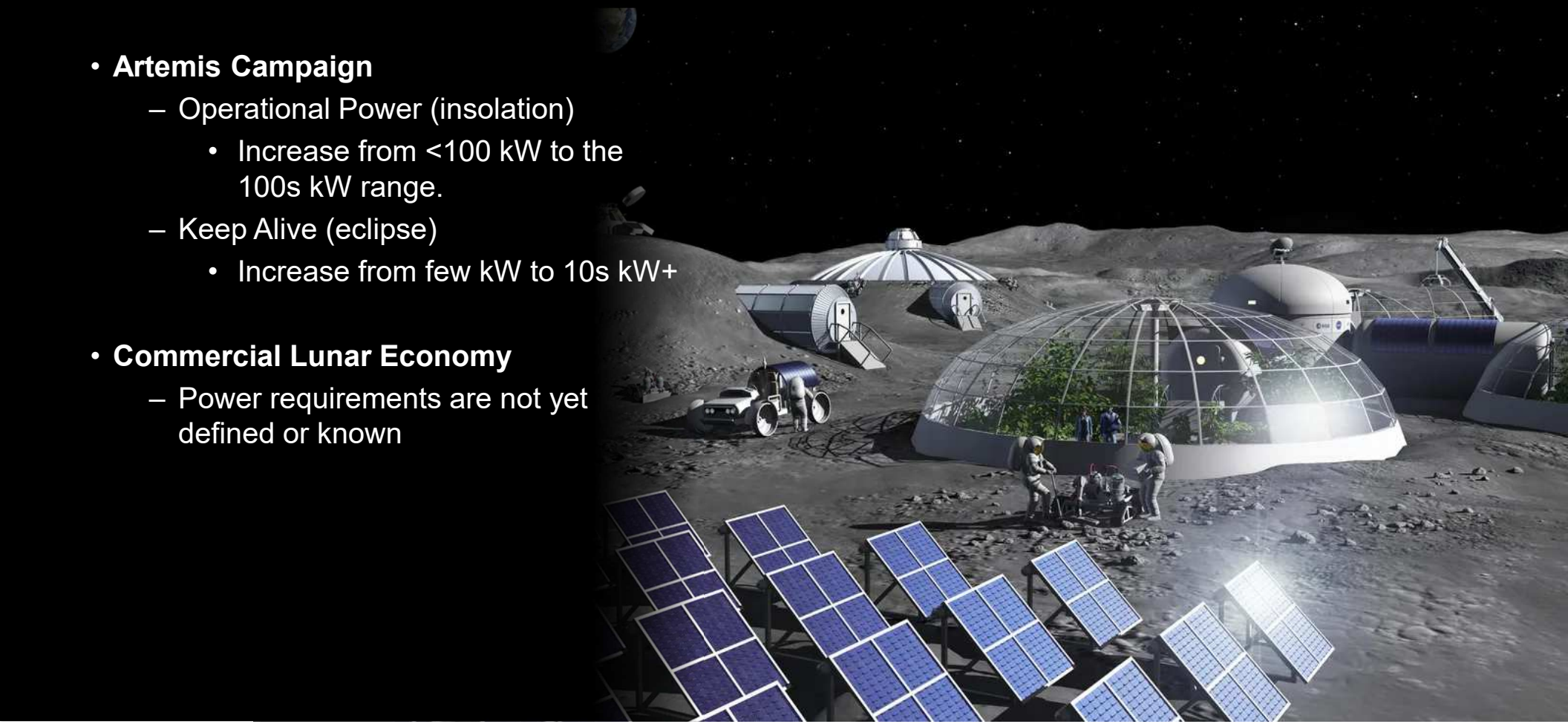
Current and high priority new technology projects support gap closure for industrial-scale Polar infrastructure building blocks beyond Artemis Base Camp

Chart provided JSC/John Scott
Former STMD Principal Technologist for Power And Energy Conversion

The Need for Universal Lunar Surface Power

Lunar surface operations will grow and expand

- **Artemis Campaign**
  - Operational Power (insolation)
    - Increase from <100 kW to the 100s kW range.
  - Keep Alive (eclipse)
    - Increase from few kW to 10s kW+
- **Commercial Lunar Economy**
  - Power requirements are not yet defined or known

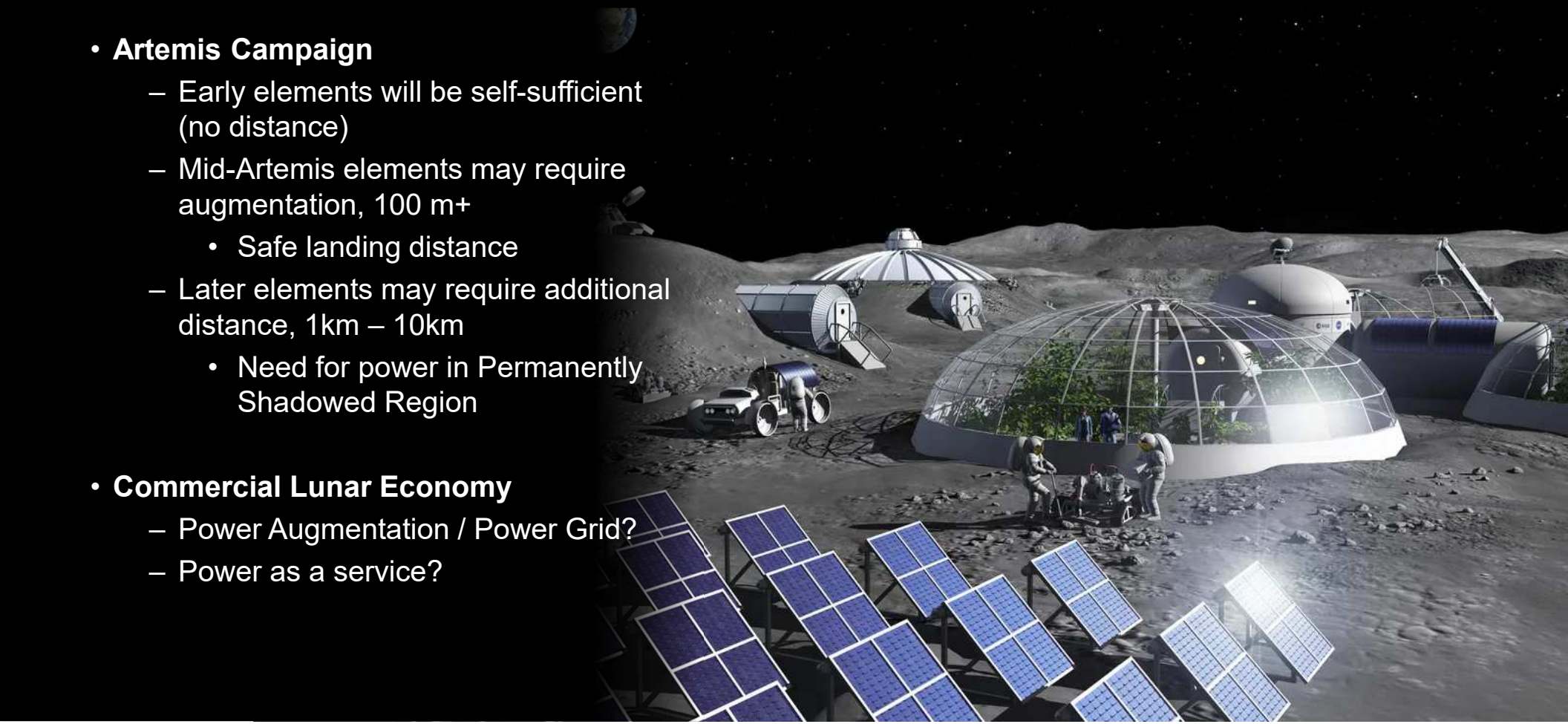


The Need for Universal Lunar Surface Power

Power over long-distance

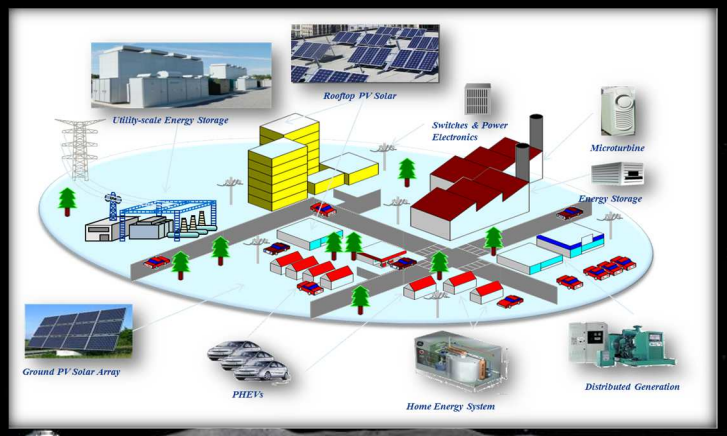
- **Artemis Campaign**
  - Early elements will be self-sufficient (no distance)
  - Mid-Artemis elements may require augmentation, 100 m+
    - Safe landing distance
  - Later elements may require additional distance, 1km – 10km
    - Need for power in Permanently Shadowed Region

- **Commercial Lunar Economy**
  - Power Augmentation / Power Grid?
  - Power as a service?

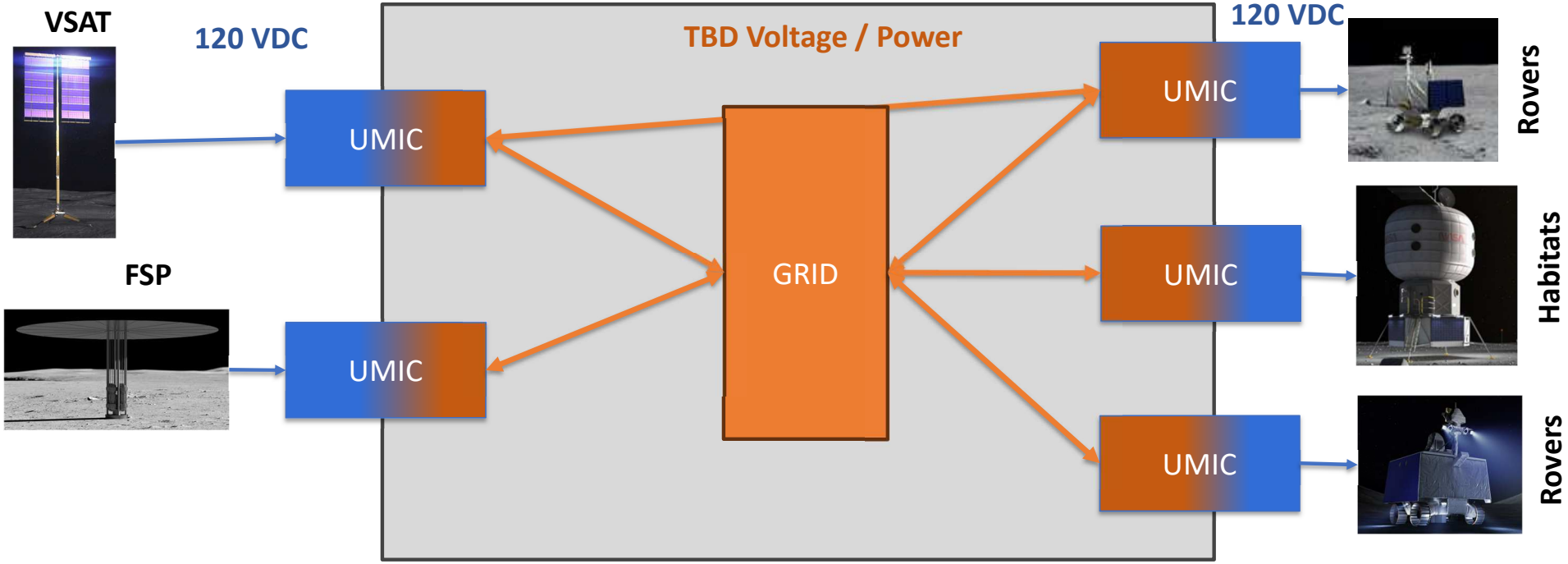


The Need for Universal Lunar Surface Power

- **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



Universal Modular Interface Converter



- Currently have standard for 120 VDC and 28 VDC (ISPSIS / HEOMD03-004)
- Power over long-distance will require increase in voltage
- Common interface can be applied to both sources and loads (bi-directional)
- Expand to include larger transmission systems

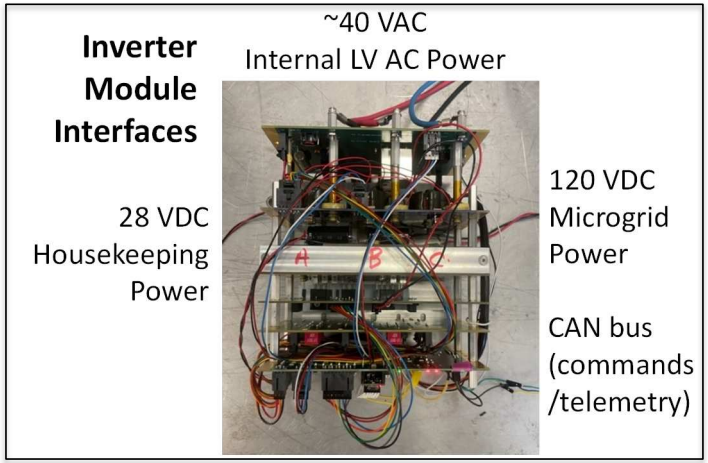
Universal Modular Interface Converter Overview

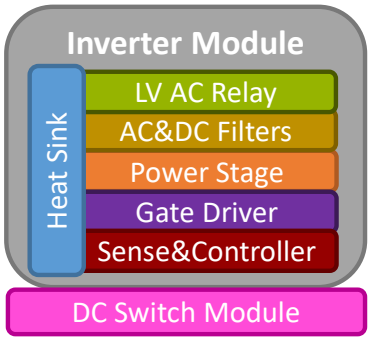
TRL 4 Breadboard Version

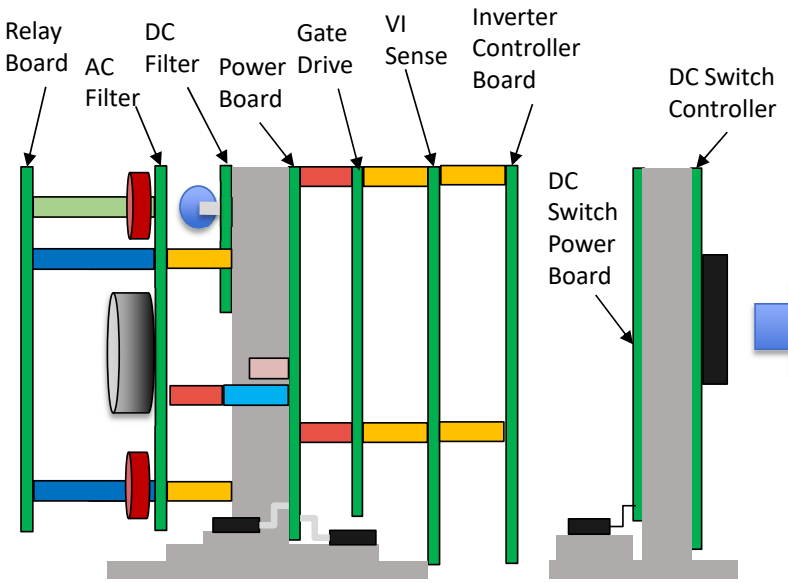
- **Universal Modular Interface Converter**
  - Modular, bi-directional converter
    - Grid side: 3-phase, 3000 VAC, 1000 Hz
    - Load/Source Side: 120 VDC
  - Full rack capable of 10 kW of power (nominal)
    - 12 kW peak
  - Parallelable - can provide more than 10 kW at single location
  - Design goals:
    - >95% efficiency
    - 350 W/kg power density (est. for flight)
  - Capability:
    - Grid forming
    - Grid syncing

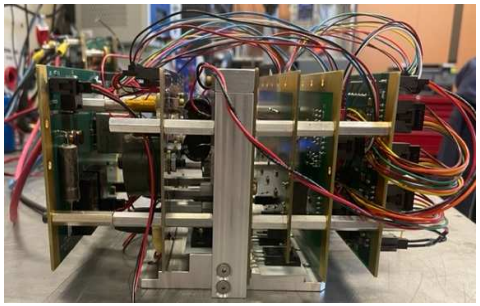
1kW Inverter / Rectifier Modules

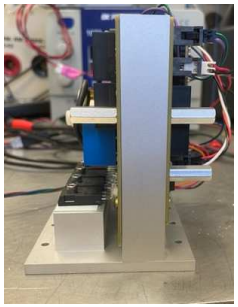
- **1 kW Inverter Module plus 1 kW DC Switch Module**
  - **Inverter**: Converts 120 VDC microgrid bus to UMIC internal low voltage 40 VAC bus
    - Includes filters, power control logic, AC isolation
    - Consists of 5 main subsystems in a stacked card form factor
  - **DC Switch**: Provides DC-side current limiting & isolation capability







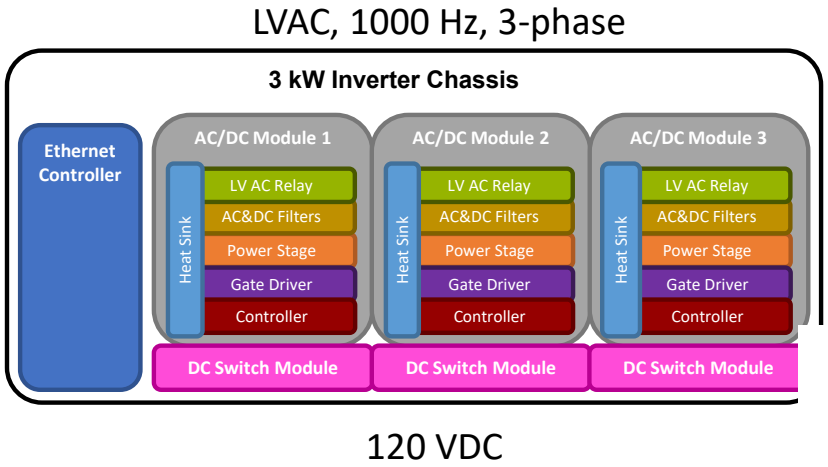




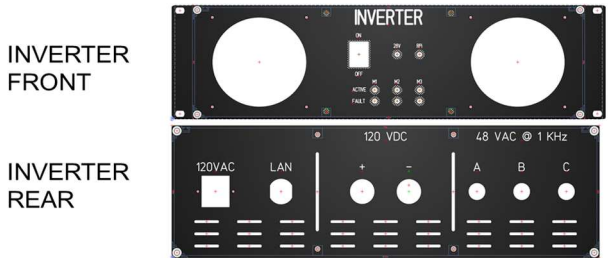
3 kW Chassis Implementation

- **Common 19” rack form factor selected for packaging**
  - Volume enough for 3 kW of inverter modules

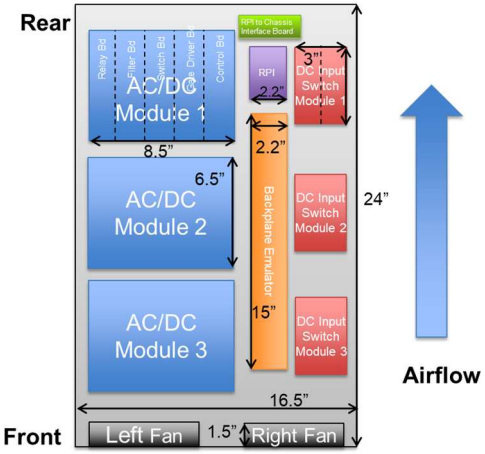
Conceptual Breadboard Chassis Design



Front and Rear Panels



Chassis Top View

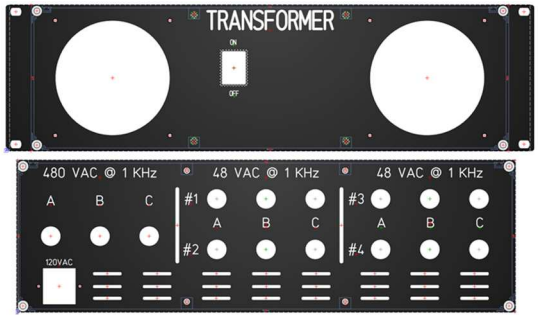


UMIC Transformer Chassis

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

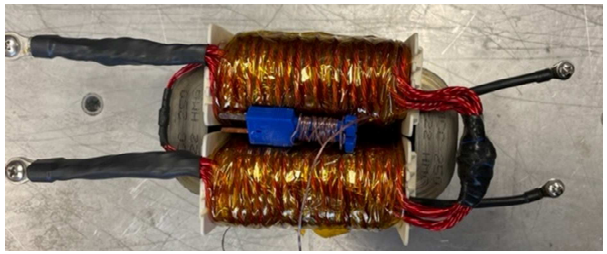
TRANSFORMER FRONT

TRANSFORMER REAR



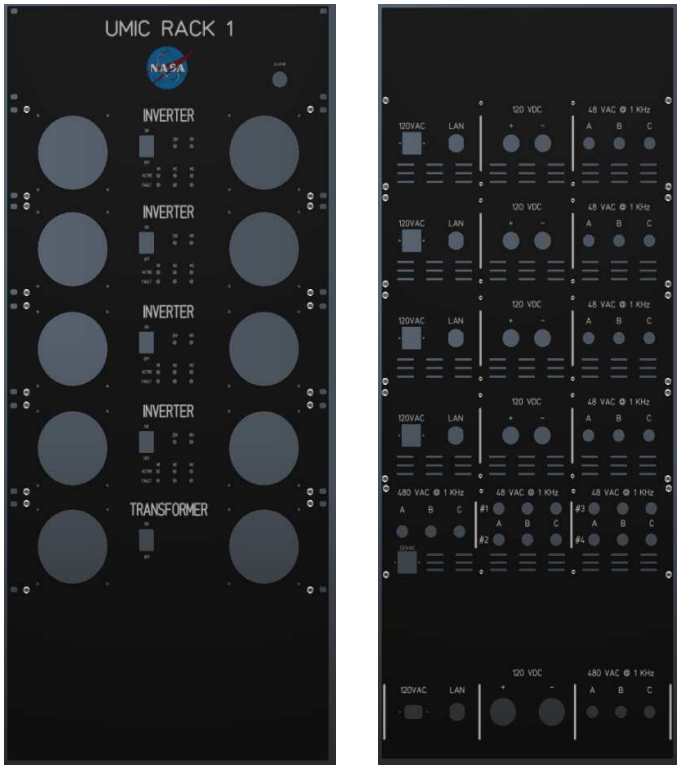
NASA 1 kVA 3-phase design

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



10 kW UMIC Rack

10 kW UMIC Rack

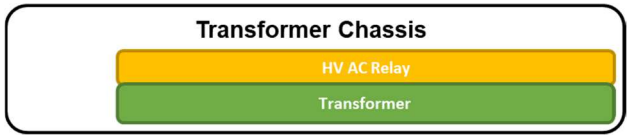


10 kVA continuous with margin, 12 kVA peak

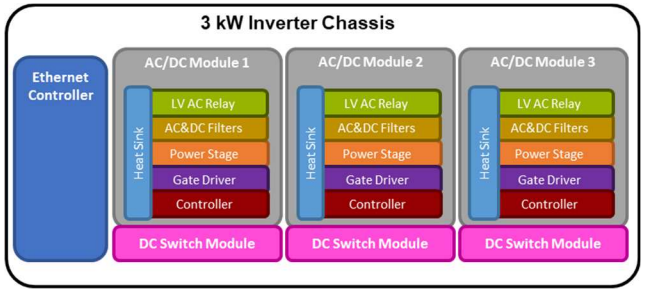
TRL 4 Breadboard Version

10 kW UMIC Rack

- 1x Transformer Chassis (10 kVA)



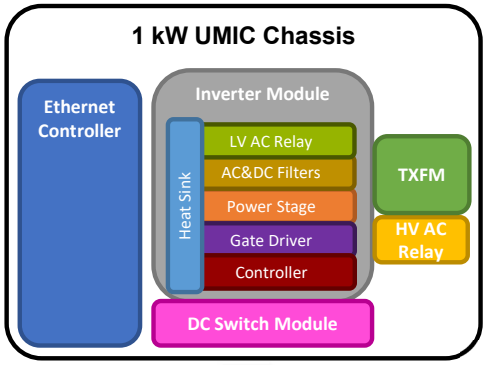
- 4x Inverter Chassis (3 kW each)

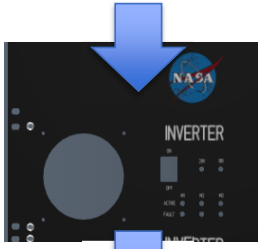


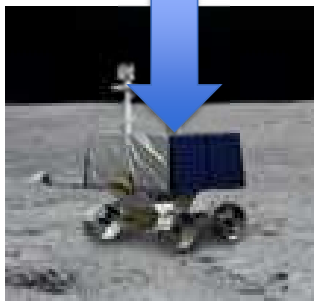
- Interface Rear Panel
  - 120 VDC
  - 3 kV AC
  - Ethernet/LAN
  - 120 VAC mains power (housekeeping/fans)

UMIC Scales to Application

1 kW UMIC

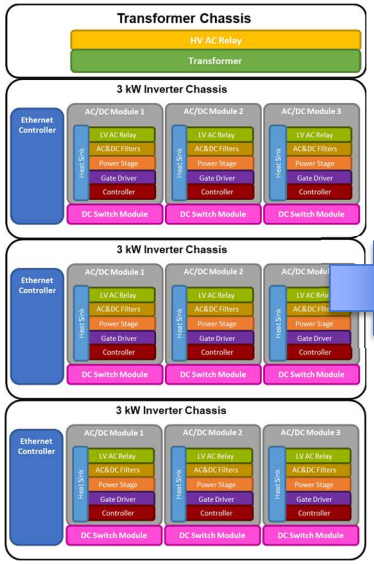


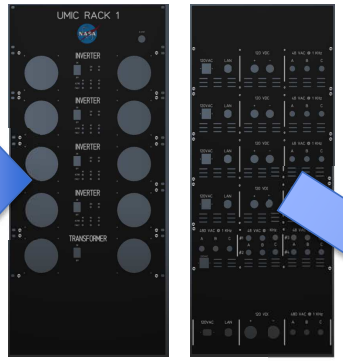


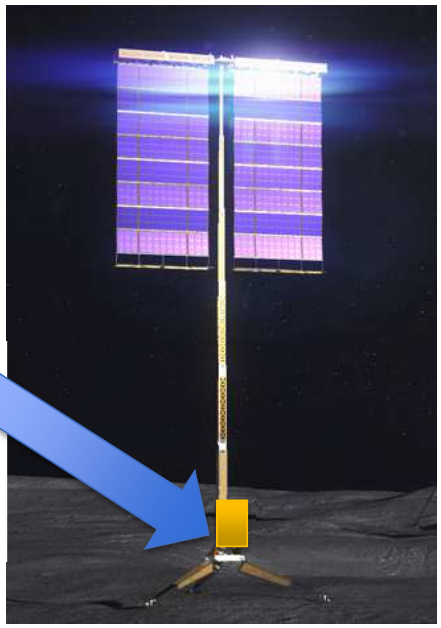


Add modules to go from Low Power to **High Power**

10 kW UMIC







UMIC Technology Development

- **TRL 4 – Breadboard Version**
  - UMIC 001 Demonstration with low voltage AC, Jan 2024.
  - UMIC 001 Demonstration with high voltage AC, April 2024
  - UMIC 002 Demonstration, planned for June 2024
  - UMIC 001 and UMIC 002 Full System Demonstration, September 2024
    - 120 VDC -> High Voltage AC -> 120 VDC

- **Ongoing and Future Work**
  - Internal technology advancement opportunities
    - Increase power density (decrease mass)
    - Improve overall design and advance towards flight
  - External collaborations
    - Lunar technology demonstration
    - Technology advancement and demonstration

Conclusion

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

- **The Space Technology Mission Directorate (STMD) Game Changing Development (GCD) Program is investing in the Universal Modular Interface Converter (UMIC)**
  - Bi-directional converter that enables long-distance power transmission
  - Standardized interface allow for loads/sources to continue to design for the current 120 VDC Space Power Standard
    - Does not require standards to be developed prior to successful demonstration

- **NASA GRC is open to external collaborations / tech transfer of the UMIC**

Links:

Moon to Mars Objectives: https://www.nasa.gov/wp-content/uploads/2022/09/m2m-objectives-exec-summary.pdf
Artemis Definition Documents: https://www.nasa.gov/moontomarsarchitecture-architecturedefinitiondocuments/
STMD Solicitations and Opportunities: https://www.nasa.gov/directorates/spacetech/soliciations
NASA Research Opportunities: https://nspires.nasaprs.com/external/

Thank you