Lunar Surface Power Systems Architecture Vision

Presenter: Sommer Hilliard, Sr. Electronics Engineer

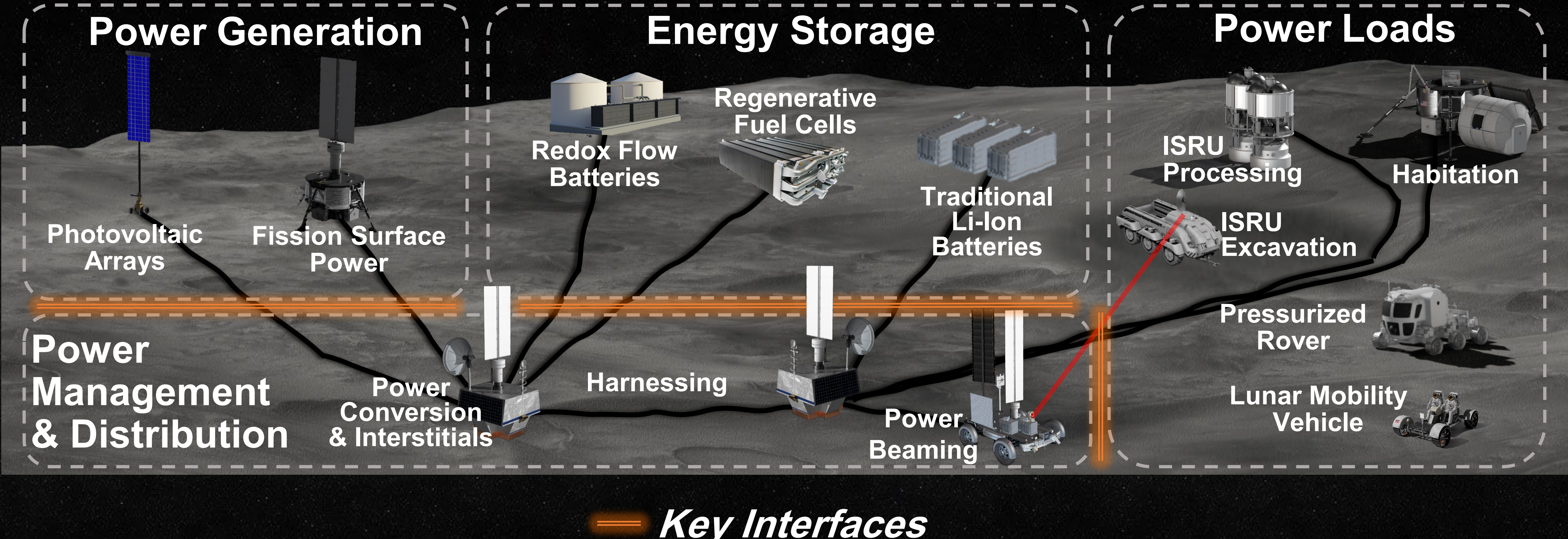
Acknowledgements: Luis Carrio, HSE Architect

Space Power Workshop
April 26th, 2023

NASA'S MOON TO MARS OBJECTIVES

- **Lunar Infrastructure Goals:**
  - ***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"***

DECOMPOSING THE LUNAR POWER GRID



Power Generation
Energy Storage
Power Loads

} *Element Endpoints*

Infrastructure { *Power Management & Distribution (PMAD)*

CORE TENETS OF LUNAR POWER ARCHITECTURE

- **Adoption of Open Systems Architecture (OSA) design principles enables sustainable architectures**
- **A sustainable Lunar surface power grid architecture should be *effective, efficient,* and *resilient***

Effective:

- **Generation & storage elements meet steady-state / dynamic load demands**
- **Power demand successfully delivered to loads**
- **Loads managed within the performance capability of the grid**

***Efficient*:**

- **System cost per kWh minimized over indefinite system life**
- **Maintenance & operational burdens minimized**

***Resilient*:**

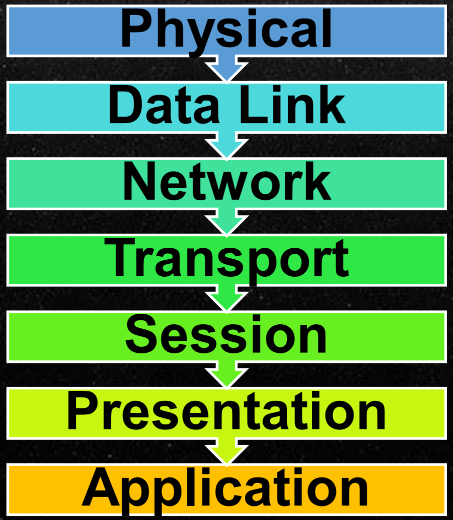
- **Grid operates through faults / functional re-configurations**
- **Reliability & fault responses consistent with power load operational tolerances**

System design focus will be on optimizing core system design tenets and enabling a sustainable architecture

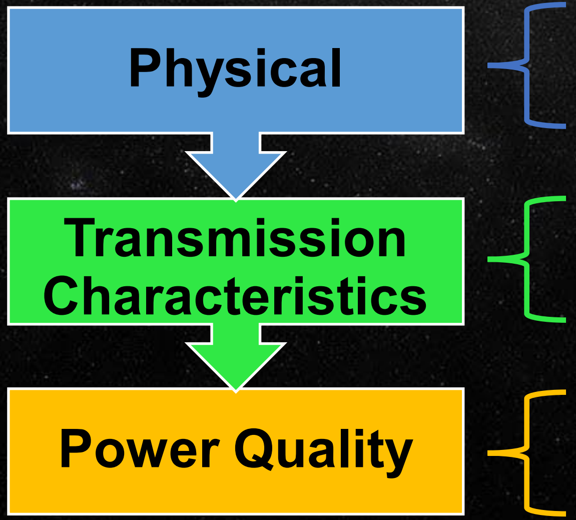
INTEROPERABILITY & MODULARITY

- **Interoperability:** Ability to successfully interact with another interface and perform required functions
- **Modularity:** Ability to be replaced by a similar module to supplant a similar function and be integrated into other systems
- Both are only relevant in the context of defined system interfaces

Open Systems Interconnection (OSI) Model for Networked Communications:



Conceptual Lunar Surface Power Systems Network Model:



- Connector & pin-out families
- Mate / de-mate frequency
- Robotic / crew handling

- Interface voltages
- Waveform / frequency
- Stability & reliability

- Noise / aperiodic surges
- Emissions & susceptibility
- E3 considerations

ARCHITECTURAL FLEXIBILITY & SCALABILITY

Architectural Flexibility

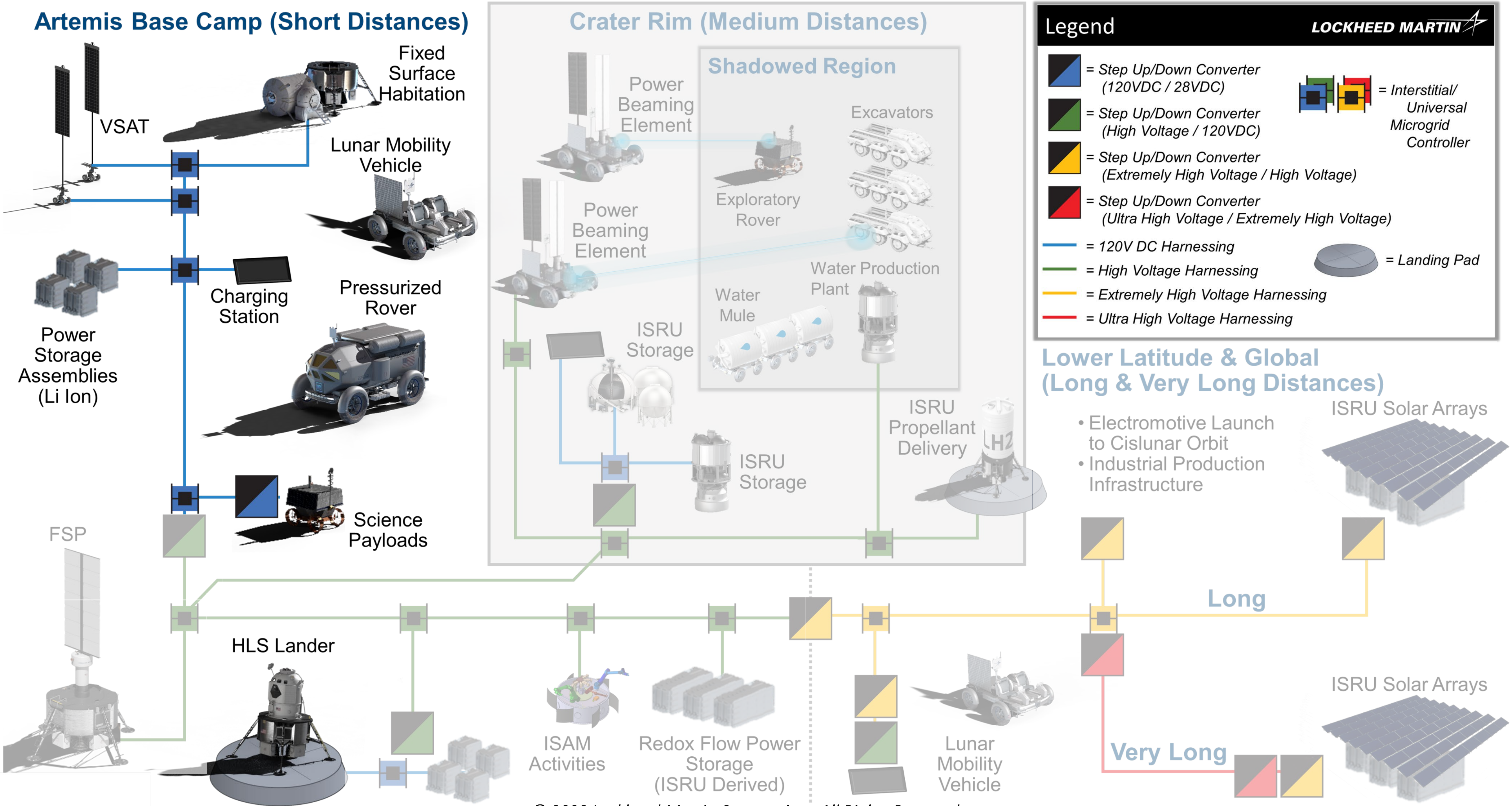
- Ability of the system to persist over time (indefinitely)
- Ability of the system to satisfy a dynamic range of both loading configurations and geographies
- Long-term resilience of the core system design

Operational Scalability

- Ability of the system to scale significantly in power generation or energy storage
- Ability of the system to scale in peak or average delivered power
- Ability of the system to grow in geographic coverage

Architecture design focus on flexible & scalable architectures enable evolution with minimal rework, redesign, and recourse

COLLABORATIVE POWER ARCHITECTURE VISION

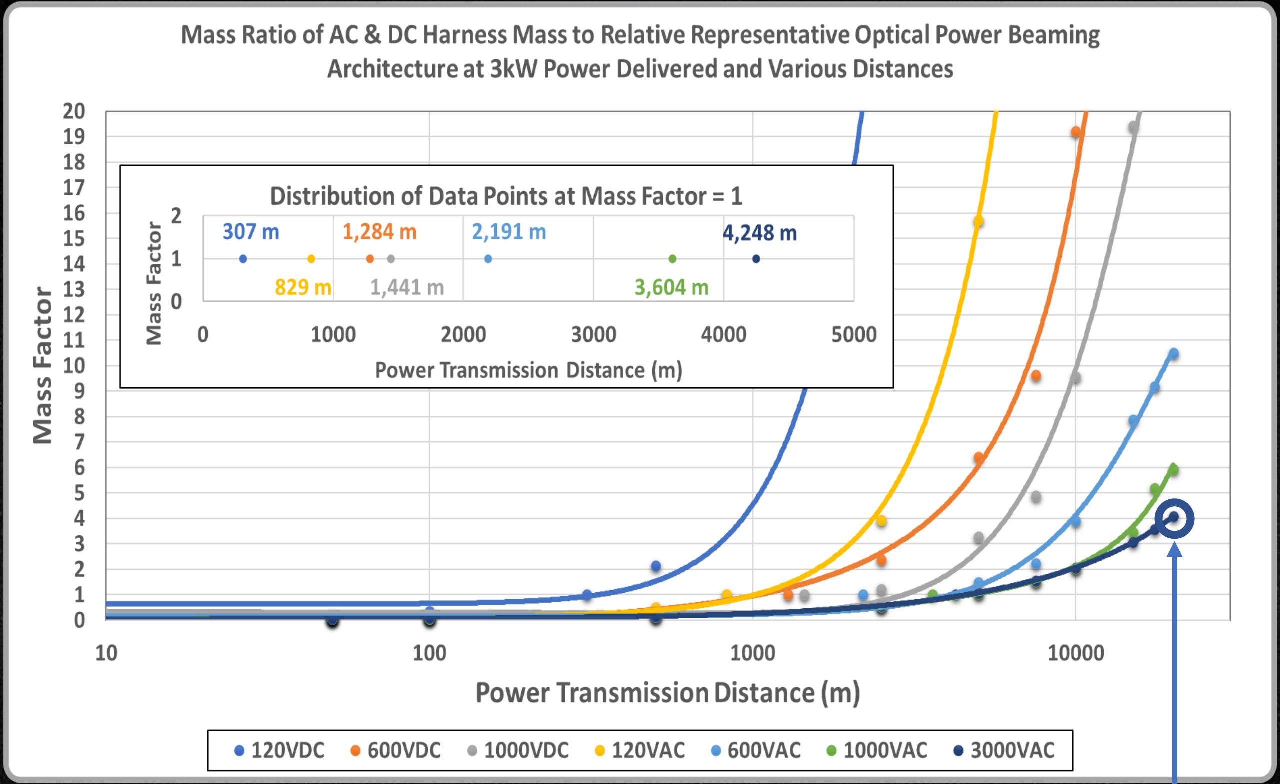


- Electromotive Launch to Cislunar Orbit
- Industrial Production Infrastructure

Legend LOCKHEED MARTIN

- 🟦 = *Step Up/Down Converter (120VDC / 28VDC)*
- 🟩 = *Step Up/Down Converter (High Voltage / 120VDC)*
- 🟨 = *Step Up/Down Converter (Extremely High Voltage / High Voltage)*
- 🟥 = *Step Up/Down Converter (Ultra High Voltage / Extremely High Voltage)*
- 🟦🟩🟨🟥 = *Interstitial/ Universal Microgrid Controller*
- — = *120V DC Harnessing*
- — = *High Voltage Harnessing*
- — = *Extremely High Voltage Harnessing*
- — = *Ultra High Voltage Harnessing*
- ● = *Landing Pad*

ONGOING LUNAR SURFACE POWER TRADES



Optical power distribution architectures mass is ~4x less than a 3kVAC system for delivery of 3kW to a distance of 20km

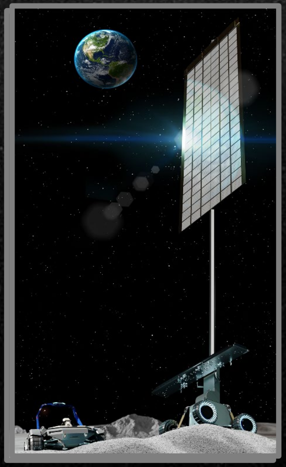
Data can be leveraged to compare costs of wired and wireless power distribution designs:

1. **Cost metrics of the relative system masses ($/kg)**
2. **Power generation costs as they scale with each distribution approach ($/kW)**
3. **Account for operational & deployment costs**

LUNAR SURFACE POWER PORTFOLIO

- >40kW$_e$ of continuous power via a direct Brayton power conversion system and a monolithic core
- Reactor design is highly scalable, capable of increasing power by orders of magnitude

Fission Surface Power (FSP)



- 10kW$_e$ of mobile power, lifetime of 10 years
- Solar array design is scalable up to 5x existing design implementation

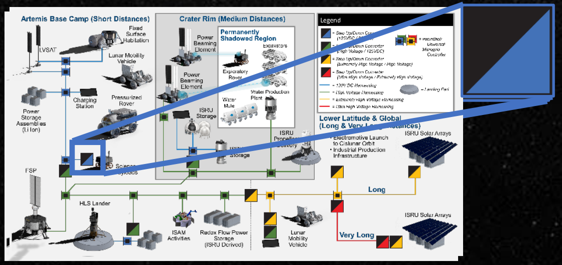
Vertical Solar Array (VSAT)

Lunar Mobility Vehicle (LMV)

- Mobility, payload capacity, and mechanisms enable power infrastructure installation and integration

GridStar® Redox Flow Batteries

- Lunar adaptation of this battery design is suited for long-duration, large-capacity storage applications

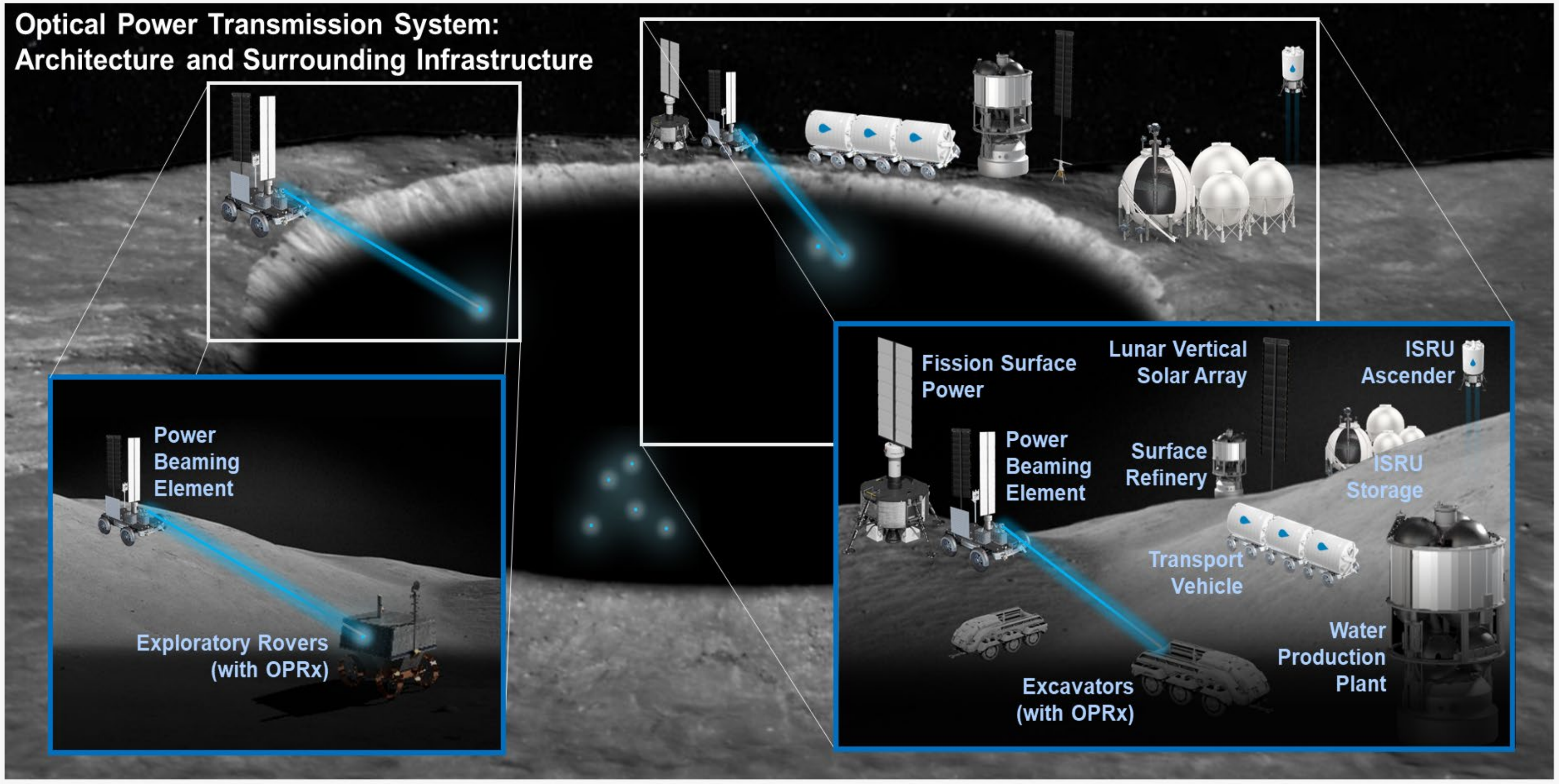


PMAD Development

- Bidirectional, GaN based 120V/28V DC-DC converter, in addition to other PMAD technologies

SUMMARY

- **The lunar surface power architecture will serve as the fundamental backbone of future lunar infrastructure development**



- **Optimize the architecture for effectivity, efficiency, and resilience**
- **OSA design principles can be leveraged to implement a sustainable architecture that persists indefinitely**

LOCKHEED MARTIN