On the Moon to Stay

Challenges Presented to Power Electronics Technology by Sustained Operations on the Lunar Surface

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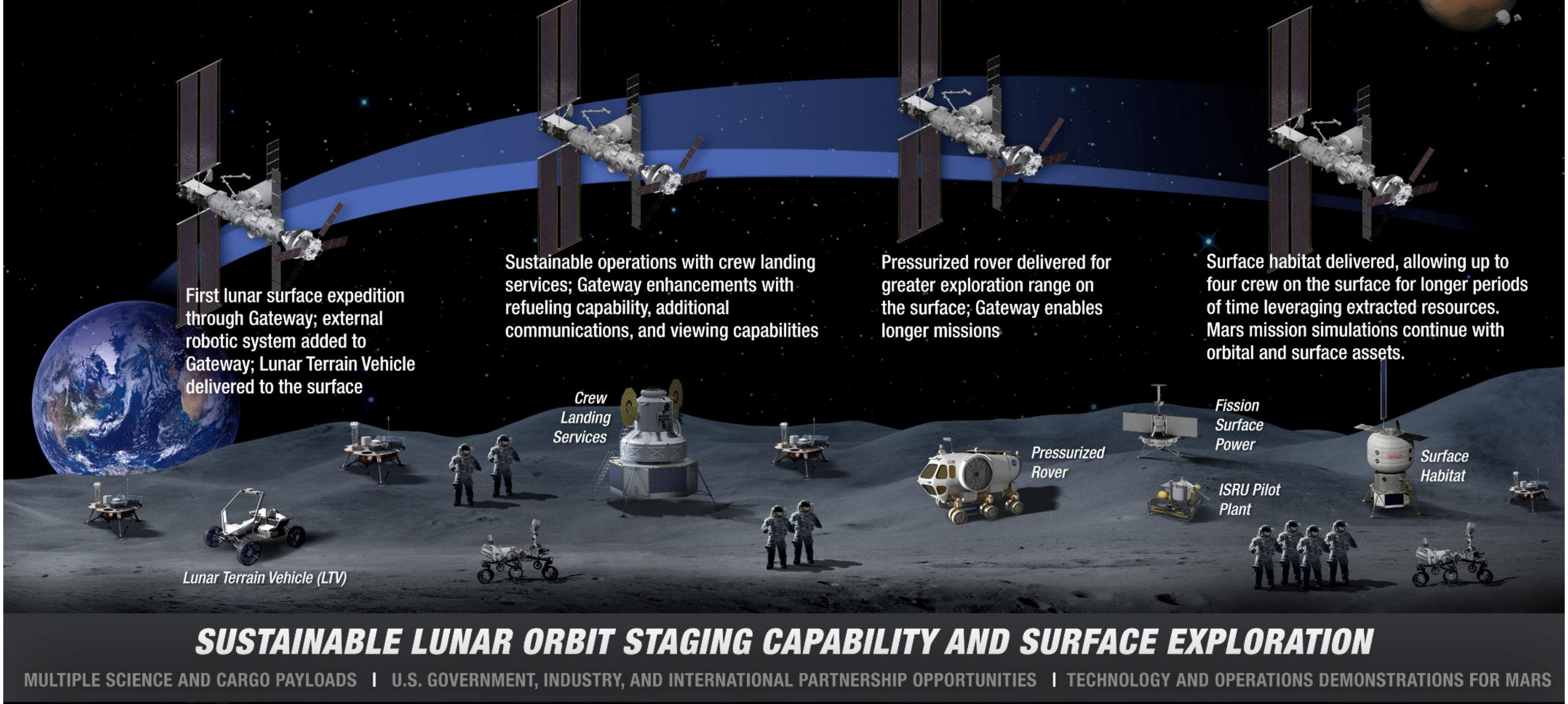
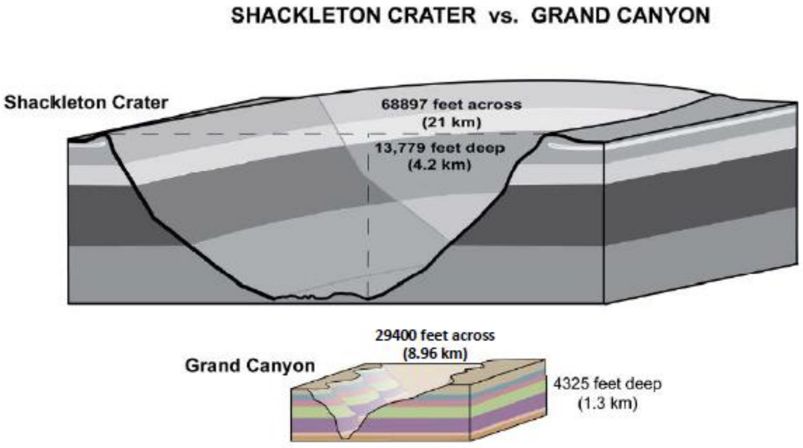
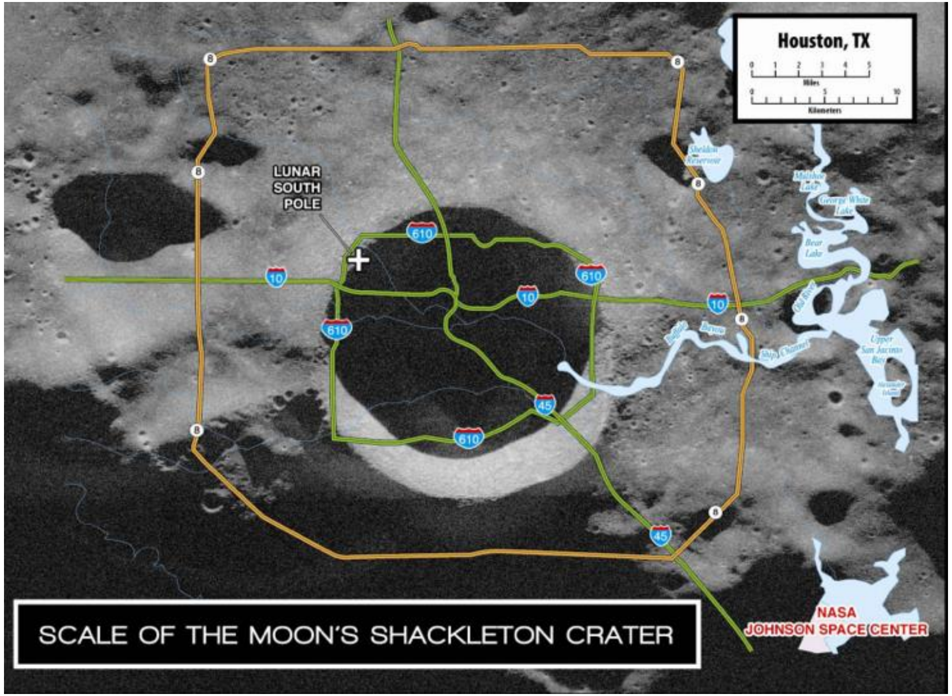
Artemis Base Camp Buildup



Shackleton Crater

- ~20 km in diameter
- ~4 km deep and ~3x deeper and wider than the Grand Canyon at Enfilade Point
- Located at Lunar South Pole
- Rim and Connecting Ridge are primary targets for future lunar landings





Artemis Base Camp Zone

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POWER

The key commodity needed to exploit the Lunar Surface

Equatorial Illumination Limits

- Cyclical periods of 14 days illuminated, 14 days dark
- Consistent

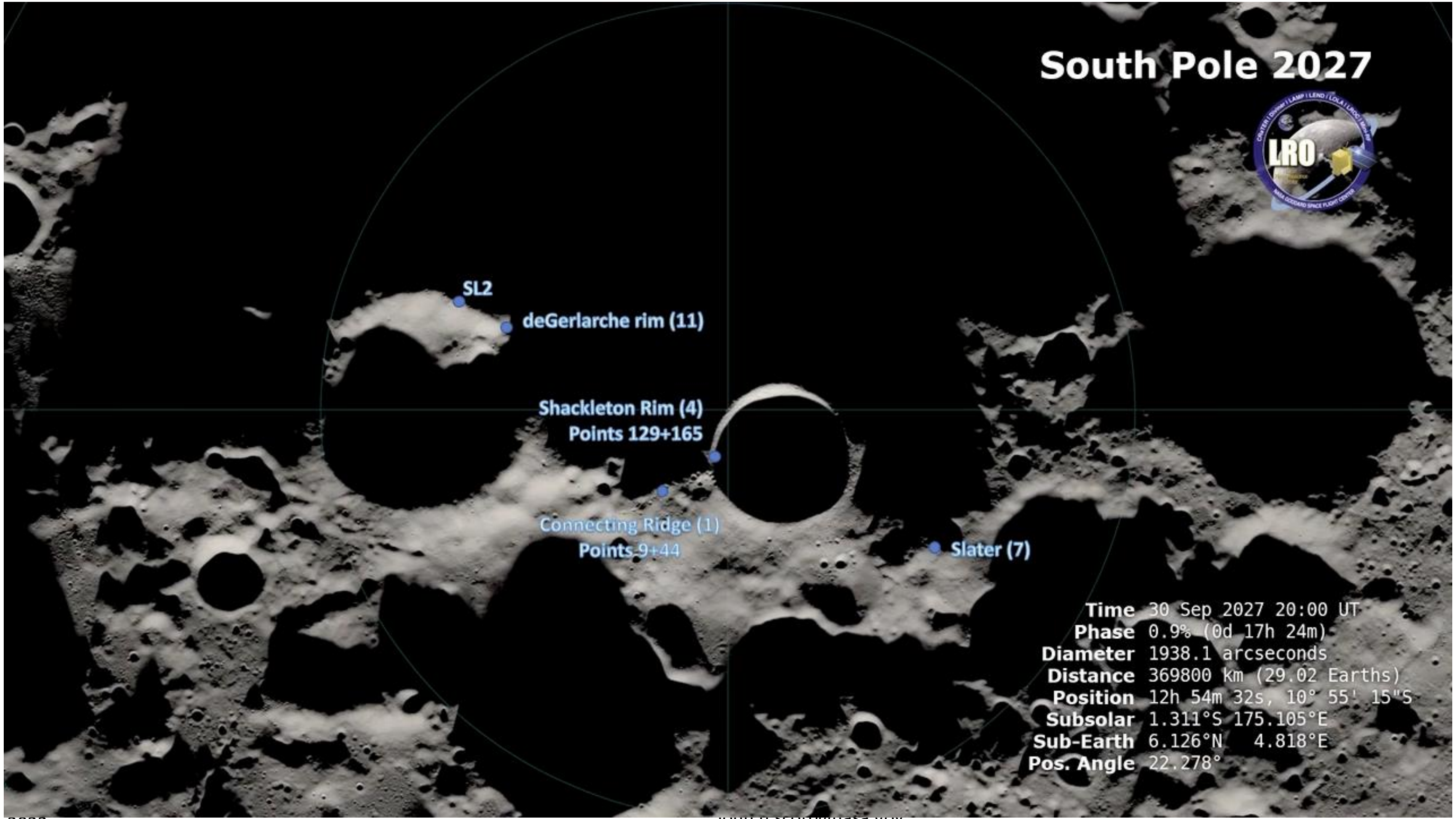
Illumination

The scarce resource needed to produce power

Polar Illumination Limits

- Intermittent with up to 100 hours darkness
- Highly dependent on location/elevation

90-Day Illumination Cycle at South Pole

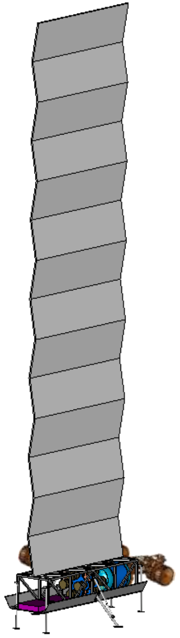


Building Blocks: Generation

Photovoltaic Arrays

50 kW_e increment, vertical deployment

~200 VDC output



Fission Power

40 kW_e increment

~240 VAC/50 Hz output

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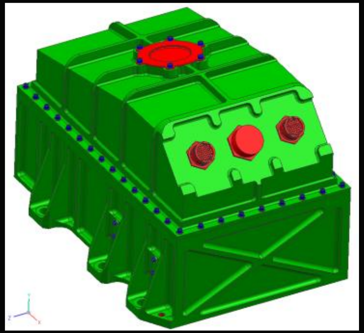
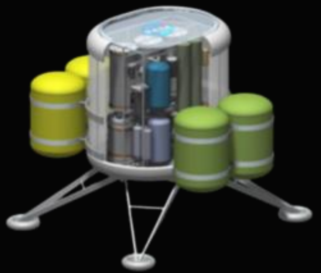
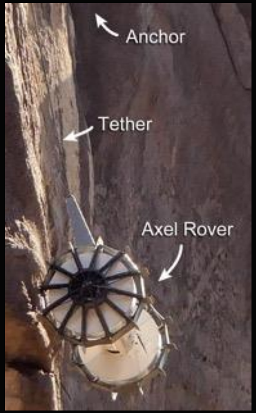
Building Blocks
Energy Storage and Power Transmission



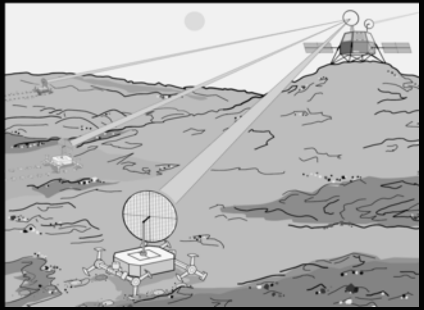
Secondary Batteries
50 $kW_e h$ increment
~30-100 VDC output



Regenerative Fuel Cells
1 $MW_e h$ increment
~30-100 VDC output



Cable/Reel
10 kW_e increment
1000-1500 VDC



Power Beaming
10 kW_e increment

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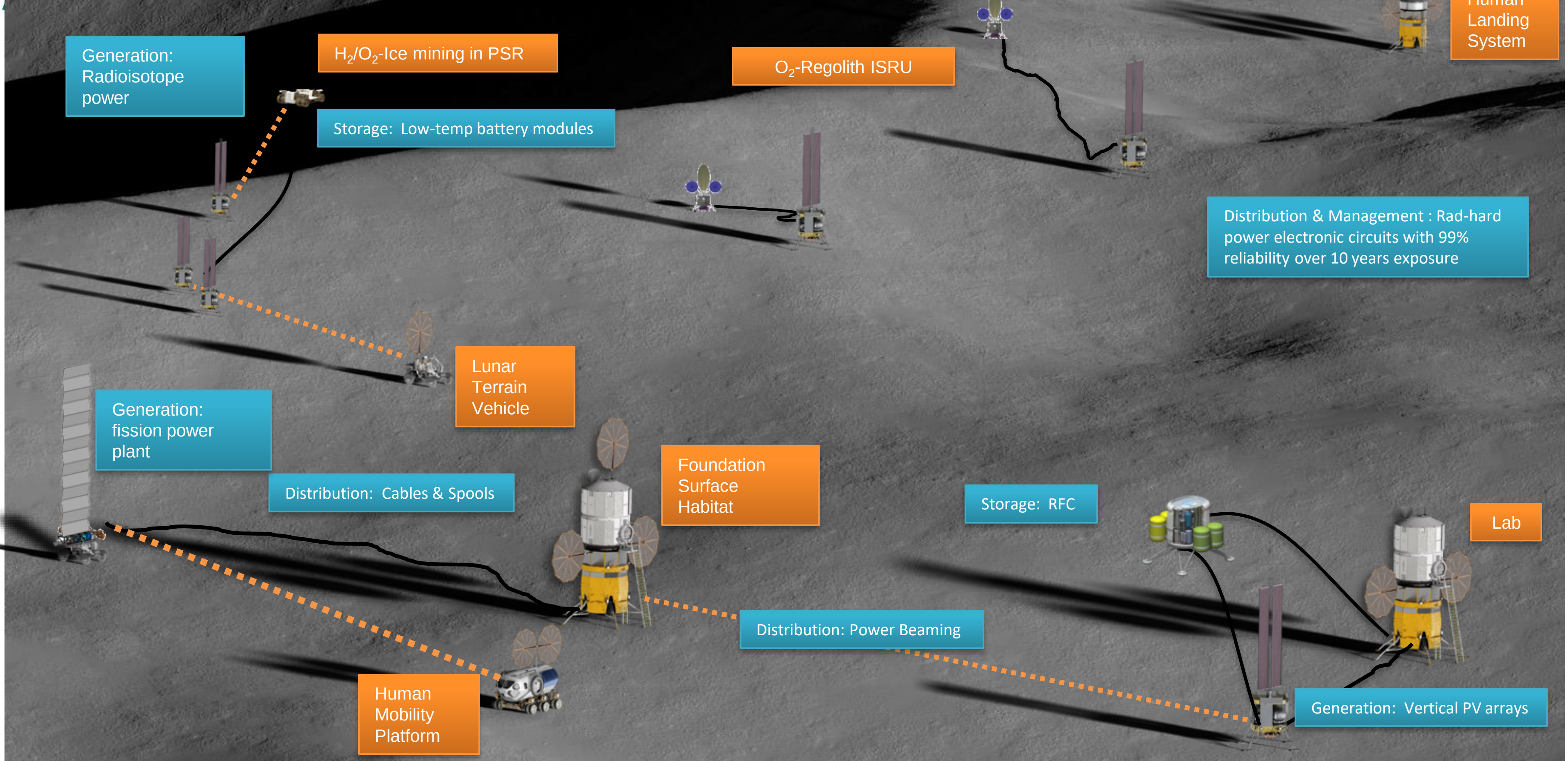
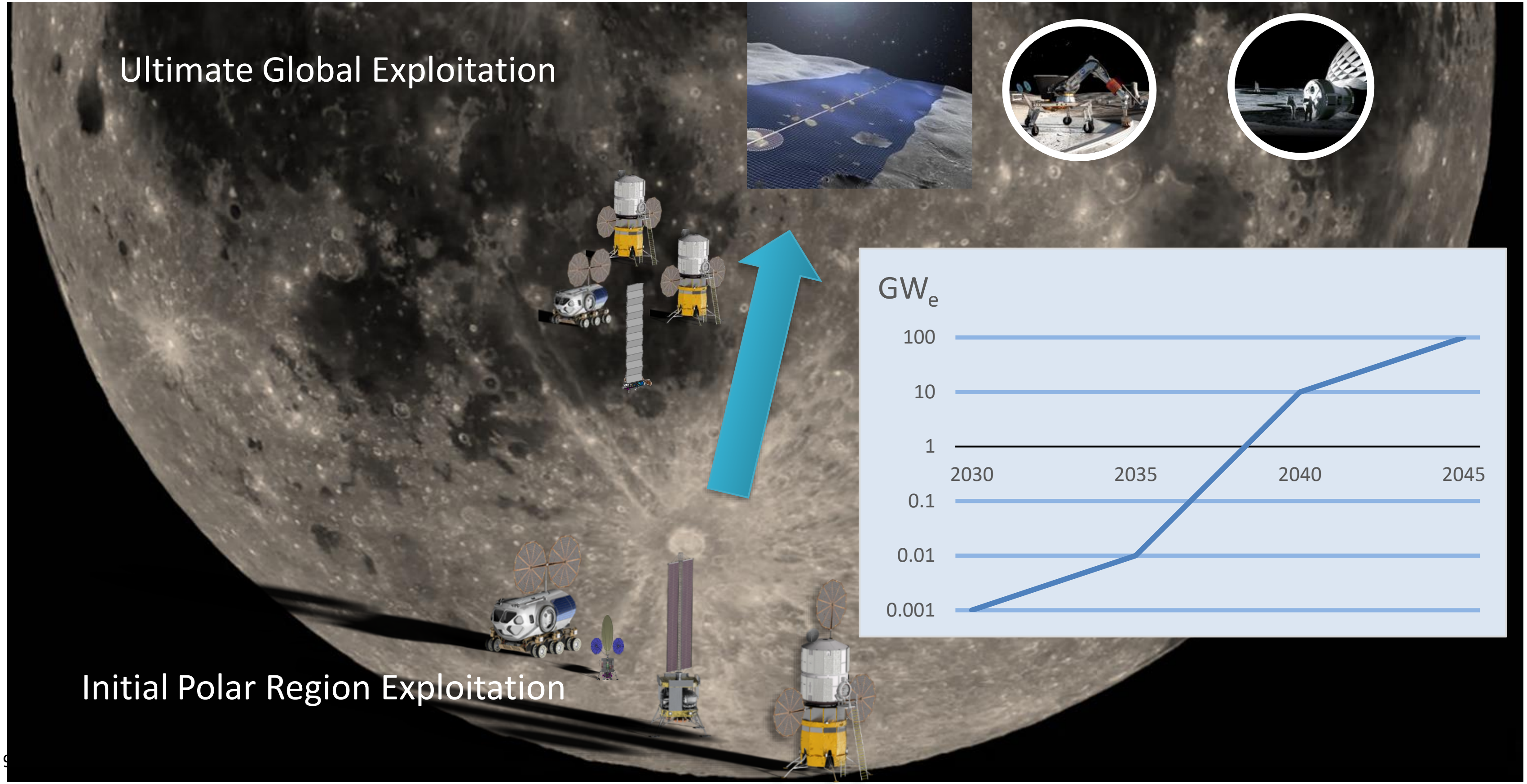
Building Block Power Technology Options for Artemis South Pole “Base Camp” (2030+)



Power demand will incrementally increase as surface exploitation grows from initial Artemis installations at the South Pole to intensive industrial and settlement development across the Lunar surface



Polar Building Block Power Technologies Can Bootstrap Generation, Storage and Distribution at Lower Latitudes (2040+)

- Landing pads and protective structures
- 100's to 1000's metric tons of regolith-bas feedstock for construction projects
- 10's to 100's metric tons of metals, plastic and binders

Generation: Vertical PV arrays

Storage: Low temperature battery modules

Distribution: Cables & Spools

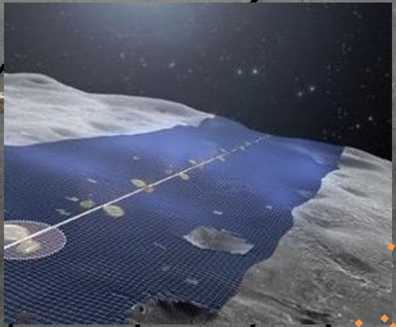
Generation: Radioisotope power

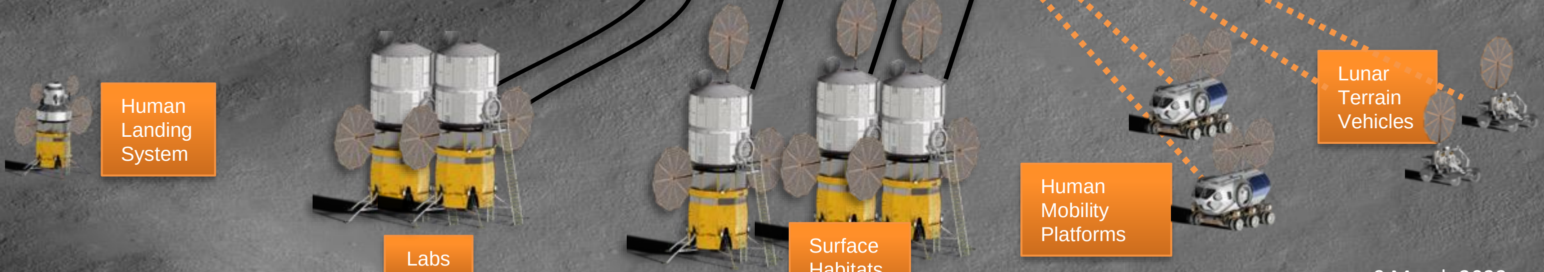
Storage: RFC

Distribution: Power Beaming

Generation: Fission power plant

Fission Power drives equipment to print photovoltaic generation, electrochemical, storage, and thermal storage from regolith

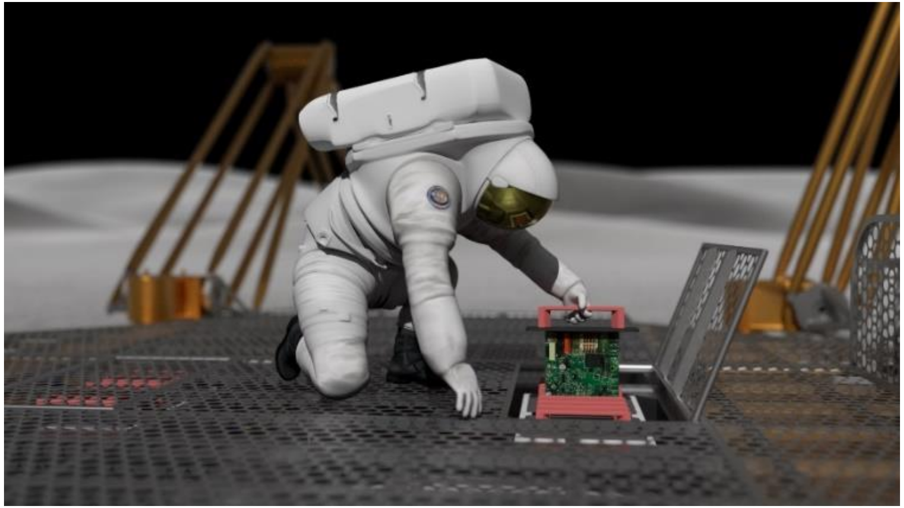




Envisioned Future Capabilities

Power Electronics:

Bring to TRL 6 by 2030 a suite of power management, control, and regulation circuits & software operating at up to 1000 V and at maximum specific power and which are maintainable in the Lunar dust environment and 0.99 reliable for 10 years in the relevant Lunar radiation and thermal environments and in the Lunar hard vacuum and Mars atmosphere environments.



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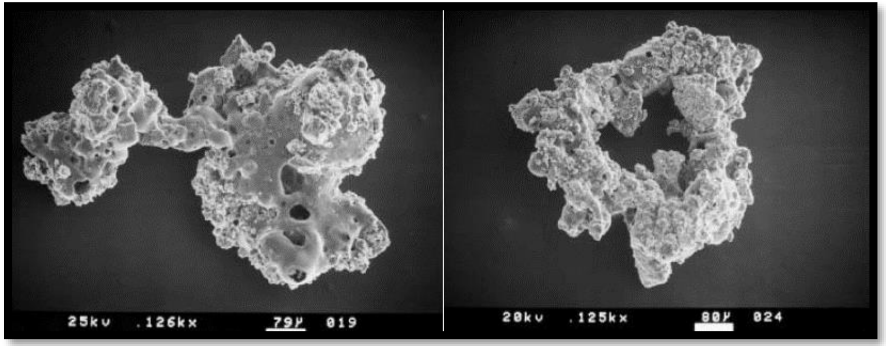
Lunar Environments

Lunar Surface Temperatures

-173 C to 130 C

(-250 C in Permanently Shadowed Regions)



Lunar regolith (i.e. lunar dust) is angular, abrasive, irregular in shape, small in size, and adheres to surfaces

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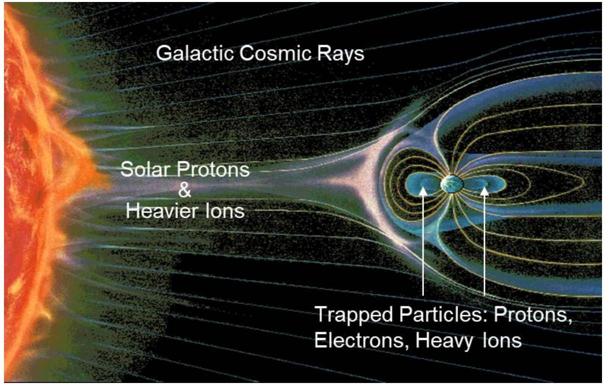
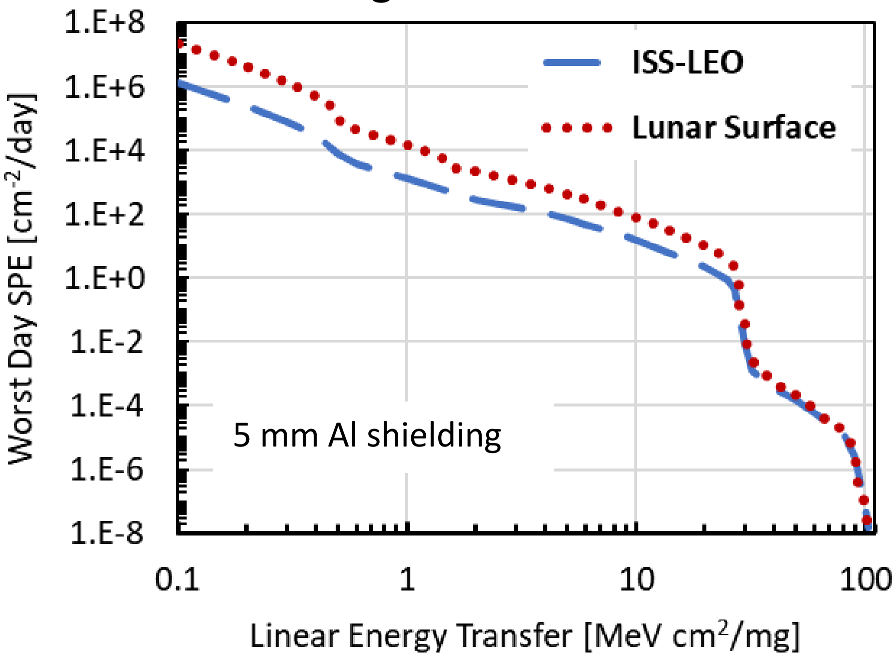
Lunar Radiation Environments

Total Ionizing Dose

Orbit	~1-year TID (2.5 mm Al) krad(Si)
Jovian	1000
GEO	150
Lunar Orbit	4
Lunar Surface	2
ISS LEO	2
Earth Surface	< 0.001



Single Event Effects



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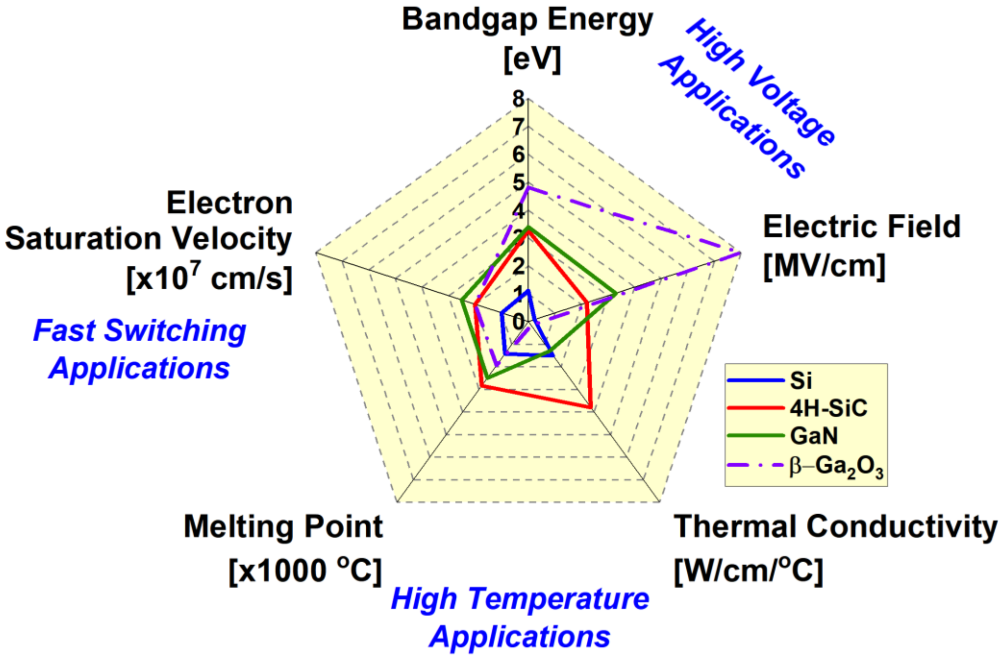
Power Electronics Materials



Graphic: courtesy J.-M. Lauenstein, NASA/GSFC

"Achilles' Heel" of Wide Band Gap Materials: Single Event Effects(SEE)

SiC Diode

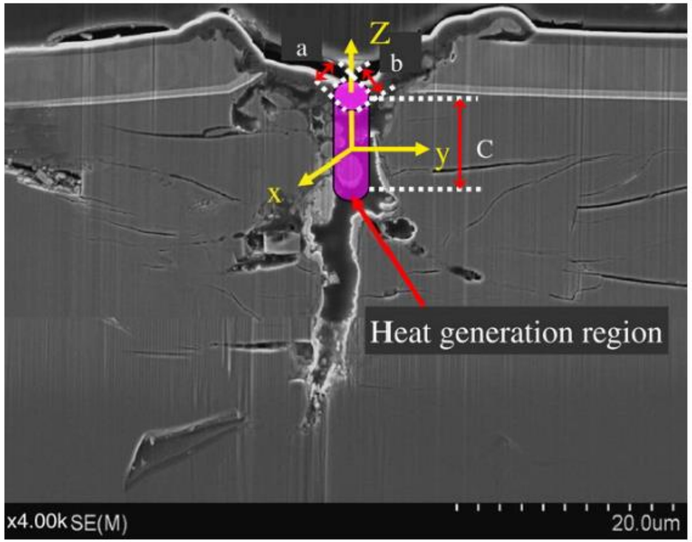
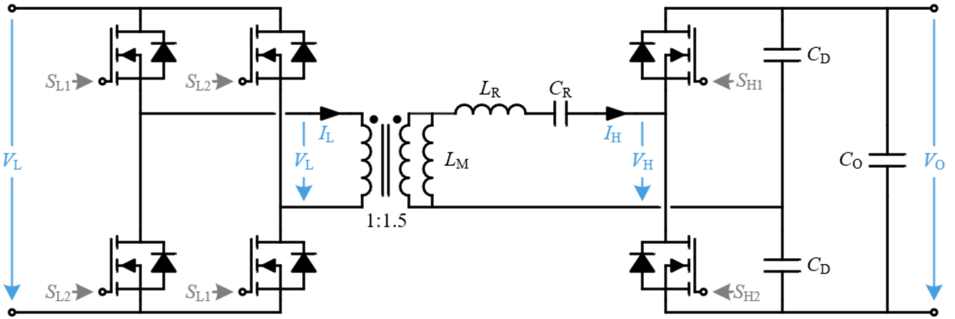


Image: Shoji, et al., © (2014) The Japan Society of Applied Physics, used with permission.

Power Management Circuit Topology

Typical Staged Boost Convertor Module

100 V



300 V

300 V

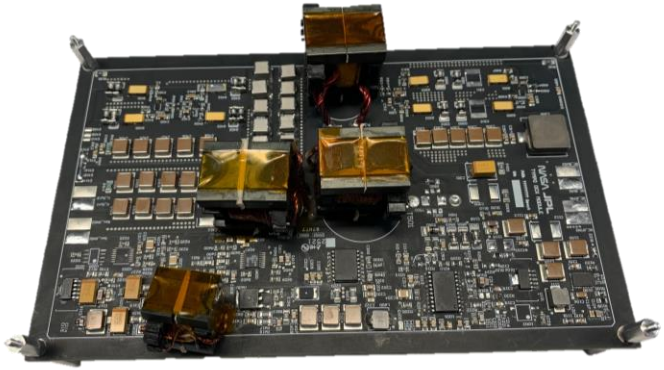
+4 in series

300 V

300 V

300 V

Breadboard PCB



Barchowsky et al, NASA JPL, IEEE Aerospace Conf. 2022

Challenge

Bring to TRL 6 by 2030 a suite of power management, control, and regulation circuits & software operating at up to 1000 V and at maximum specific power and which are maintainable in the Lunar dust environment and 0.99 reliable for 10 years in the relevant Lunar radiation and thermal environments and in the Lunar hard vacuum and Mars atmosphere environments.

NASA Proposal Opportunities:

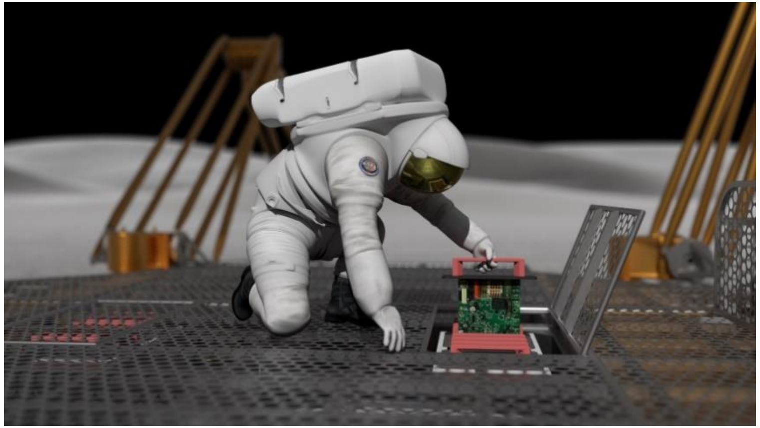
Announcement Links:

2022 STMD Tipping Point Announcement:

https://tinyurl.com/2022TippingPoint

2022 STMD Announcement of Collaboration Opportunity (ACO):

https://tinyurl.com/2022ACO



Next Key Date: Mini Proposals Due: 3/31/2022

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