JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

LSIC Surface Power Telecon

August 25, 2022

Begins at 11:03

Lunar Surface Innovation
CONSORTIUM

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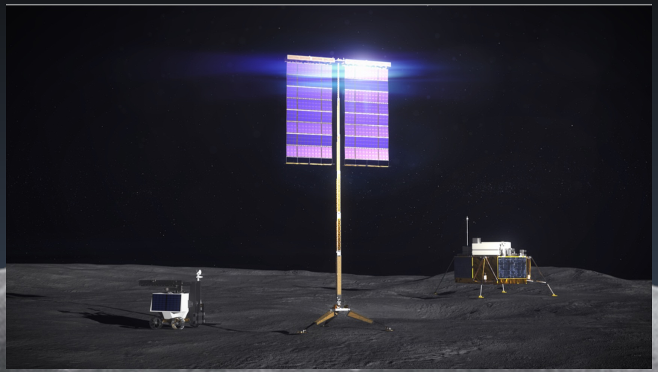
LSIC | Agenda

- Community Updates
  - Solicitations and Awards
    - VSAT, Watts on the Moon
    - Break the Ice (Excavation and Construction)
    - Big Idea Challenge (ISRU)
  - Conferences/Workshops:
    - Your input on the CLPS survive the night workshop
  - Artemis Landing sites
    - Should we do a deep dive? What do you want to do next with this information?
- Ben Bussey: Data buys
- Low-Temperature workshop debrief – Julie Peck
- Rapid Networking

LSIC | VSAT Phase 2 Awards!

The agency will award a total of $19.4 million to three companies to build prototypes and perform environmental testing, with the goal of deploying one of the systems near the Moon's South Pole near the end of this decade. The designs must remain stable on sloped terrain and be resistant to abrasive lunar dust, all while minimizing both mass and stowed volume to aid in the system's delivery to the lunar surface. The awards include:

Astrobotic Technology of Pittsburgh, Pennsylvania: $6.2 million
Honeybee Robotics of Brooklyn, New York: $7 million
Lockheed Martin of Littleton, Colorado: $6.2 million



LSIC | Watts on the Moon Phase Two

NASA'S WATTS ON THE MOON CHALLENGE

The Phase 2, Level 1 winners are:

- Electric Moon, Columbus, Ohio
- Orbital Mining Corporation, Golden, Colorado
- Philip Lubin's Team, Santa Barbara, California
- Michigan Technological University PSTDL
- Skycorp, Santa Clara, California
- Virtus Solis Technologies Inc., Troy, Michigan
- X-Wheel Inc., Hialeah, Florida

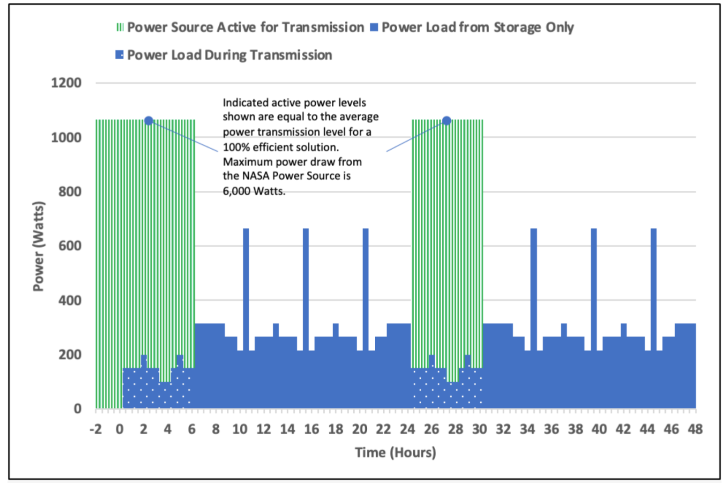


FIGURE 1. Watts on the Moon Challenge Phase 2 Load Profile

Phase 2, Level 2 challenges these seven teams to develop and test key parts of their solutions. Up to four teams will win equal shares of $1.6 million and move on to compete in the Watts on the Moon Challenge finals. To close out the challenge, the four finalist teams will have to prove the success of their solution inside a vacuum chamber for two top prizes worth a total of $1.5 million.

120 V 6 kW source, 3 km range to 77 K with load profile as above (24-32 VDC)

LSIC | STMD Solicitations

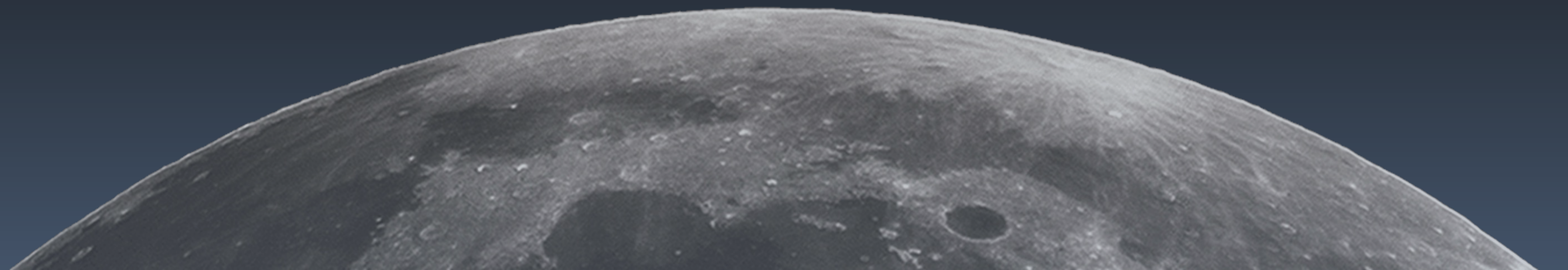
Space Tech Solicitations (https://www.nasa.gov/directorates/spacetech/solicitations)

NASA SBIR Ignite 2022 Program Solicitation
Proposals due: September 1, 2022 (5:00 p.m. ET)

Break the Ice Lunar Challenge Phase 2
Registration close: September 30, 2022
Submission deadline: November 4, 2022

NASA Space Technology Graduate Research Opportunities (NSTGRO) solicitation – September 2022

NASA Innovative Advanced Concepts (NIAC) 2022 Phase II Call for Proposals – October 2022



NASA's BREAK THE ICE LUNAR CHALLENGE

Phase 2 Overview

The goal of Phase 2 is to further the development of technologies that can excavate and transport large quantities of icy lunar regolith and can continuously operate for 15 days. Phase 2 will not focus on ice/water delivery hardware or equipment. Through a prototype demonstration, teams must show that their solutions address the reliability, durability, and traversability challenges these systems must overcome to operate for long durations.

The specific NASA technology gaps that Phase 2 aims to address include:

- Excavate large quantities of icy regolith
- Delivery of large quantities of acquired resources
- Hardware and equipment that is lightweight and energy efficient
- Hardware and equipment that is reliable and durable

LSIC | Upcoming Meetings and Workshops

- **Advanced Power Systems for Deep Space Exploration**
  - Aug 30-Sept 1 https://www.usasymposium.com/deepspace/default.php
- **International Astronautical Congress**
  - September 18-22, Paris
- **AIAA ASCEND**
  - October 24-26, Las Vegas + Online
- **LSIC Fall Meeting**
  - November
- **CLPS Survive the night workshop**
  - December
- **More complete calendar on LSIC website, email with additional events!**

Upcoming Meetings (ISRU)

Some upcoming IRSU related meetings to be aware of:

- Lunar Surface Science Workshop. Sept. “Lunar Resource Evaluation Campaign - Implementing”
- **LSSW Prospecting follow-on workshop will be in October**
- **NASA TechRise 2022; Entries Due Oct. 24: https://www.futureengineers.org/nasatechrise**
- ~~**Break the Ice Challenge due Sept. 30**~~
- **2023 NASA BIG Idea Challenge (grads/undergrads)**
  - **Lunar Forge: Producing Metal Products on the Moon**
  - **E.g., storage vessels for liquids and gases, extrusions, pipes, power cables, and supporting structures**
  - **See website for schedule, NOI due Sep 30!**

LSIC | LSIC Fall Meeting

- **November 2-3, 2022**
- University of Texas-El Paso
- Focus will be on how the 6 Focus Areas relate to Excavation and Construction.
- Abstract deadline has passed, registration opening soon!

Credit: UTEP

https://lsic.jhuapl.edu/Events/Agenda/index.php?id=350

LSIC | CLPS Survive the Night

NASA’s Science Mission Directorate (SMD) and the Space Technology Mission Directorate (STMD) are pleased to announce a workshop to facilitate collaboration between lander and rover providers and technology developers to share technologies that can enable survival through the lunar night.

- Obvious importance/relevance to our FG - please consider submitting an abstract!
- How can our recent inform this workshop? (think about this as we do the out-brief)
- What’s your take on what the scope should be for the technical program?

https://www.hou.usra.edu/meetings/clps2022/

Community Interest in Data Buys

NASA is interested to learn more about the interest in the LSIC community of NASA conducting data buys from commercial providers

1. Data acquired as a by-product of landing on the Moon
2. Dedicated data that require a specific instrument to be flown

Does NASA buy an entire data set and put it in PDS?
Do users buy data directly from the providers?
What data would YOU want?

https://forms.gle/tuhzwAUaQLDivQ2D7

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LSII | Data Buys

- NASA is interested to learn more about the interest in the LSIC community of NASA conducting data buys from commercial providers

- There are two types of data to consider
  - Data acquired as a by product of landing on the Moon
  - Dedicated data that require a specific instrument to be flown

- What kind of data access is required?
  - Does NASA buy an entire data set and put it in the Planetary Data System (PDS)?
  - Do users buy data directly from the providers?

LSII | By-Product Data

- Data acquired as a by product of landing on the Moon
  - Environmental Data
    - Radiation, thermal, illumination, dust
  - Descent & Landing Imagery
    - Images of terrain during descent, surface panorama after landing
  - Landing & Post-landing effects
    - Plume/surface interactions
  - Technology/System Performance
    - Navigation performance, comm performance

- **Are there additional data sets you would want?**
- Are there data sets the lander will naturally acquire, but perhaps you need a variation of those data, e.g. a certain data set to be acquired at a higher cadence?

LSII | New Data Sets

- What data would enhance your ability to plan lunar surface operations?

- Data sets that require a dedicated instrument to be flown
  - E.g. New topography, or mineral map data sets
  - Could be either an orbital of surface data set

  - Monitoring Data for Situational Awareness
    - Rover locations and movement
    - Charging operations
    - Search and Rescue for lost rovers

LSII | General thoughts/questions

- Are there any Data privacy, Intellectual Property or Distribution Concerns
- Are these data global or regional in nature?
- Is there a different financial value for different data qualities, e.g. spatial or spectral resolution?
- How do you put a value on a data set?
- If you are a potential provider, what level of funding, if successful, is required for you to consider acquiring these data?
- Is the data you want a one-time acquisition? Every landing?
- Do you need it only for a particular region

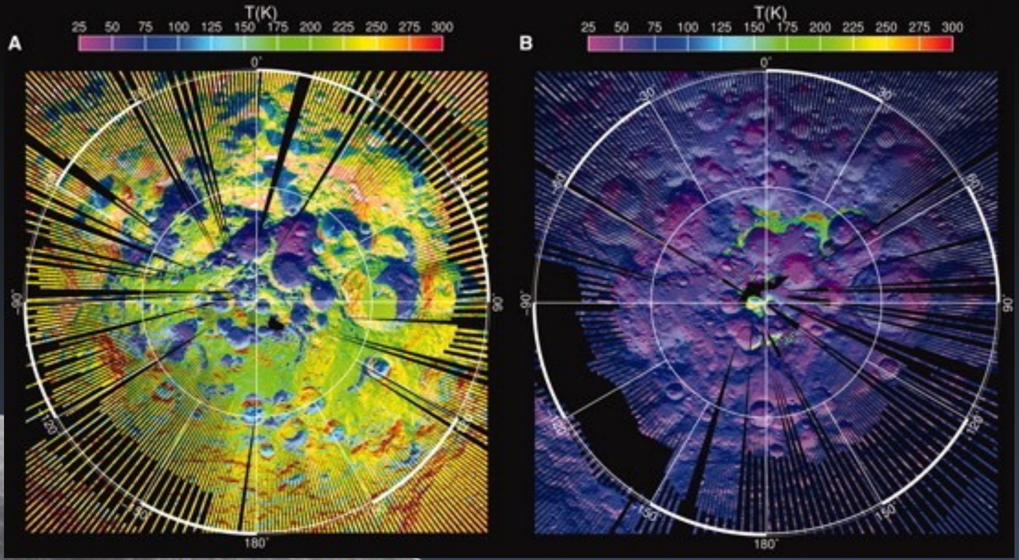
LSIC Workshop: Low Temperature Power and Energy Storage

This workshop, held July 28 2022, was an investigation into near-term solutions for power during the lunar night and in extremely cold environments at the sub-kW regime. The ~6-hour virtual workshop included:

- Overview of lunar thermal environments
- Panel discussion with representatives from various industry and academia perspectives
- Lightning talks to rapidly survey new technologies
- Presentation on low-temperature batteries from Dr. Marshall Smart at JPL
- 3 breakout discussions targeting specific scenarios at different power regimes

Attendance Statistics:

- Registered: 204
  - Academia: 33 (16%)
  - Government: 60 (29%)
  - Industry: 88 (43%)
  - Nonprofit: 21 (10%)
  - Other: 2 (1%)



Diviner-measured daytime (left) and nighttime (right) bolometric brightness temperatures

Overview of Lunar Thermal Environments (Ben Greenhagen, APL)

The Extreme Environments focus group is an excellent resource for all aspects of the lunar environment, and started out this workshop by presenting a well-organized overview of thermal considerations. Ben's talk deftly considered the lunar thermal environment in two categories:

Global Environment

- Equatorial daytime maximums: 387-397 K
- Equatorial nighttime minimum: ~95 K
- Long periods of no direct solar illumination even at mid-latitudes (~14.75 Earth days of lunar day/night)
    - Other sources of illumination at night (Earthshine, Lyman-alpha, zodiacal light) provide rough equivalent of a 60-Watt bulb 2-3 meters overhead

Poles as Special Environments

- Permanently shadowed regions (PSRs) are always cold
- Areas that get even small amounts of illumination warm and cool rapidly
- Terrain can have drastic effects – higher areas get more light!

Panel Session

Panelists included:

- Richard Oeftering, NASA GRC
- Pamela Clark, Morehead State University
- Joshua Ruedin, Nanohmics Inc.
- Chris Morrison, USNC
- Ian Jakupca, NASA GRC
- Mike Provenzano, Astrobotic

The panelists explored near-term technologies for system solutions, including RTG systems, parabolic radiators/reflectors, cryo-electronics, RHUs, thermal switches, and more. A consensus was reached that there is no single solution that will apply, rather, s**ystems will need to incorporate multiple technologies** to achieve desired performance. While *surviving* the night can be done; the current challenge to address is how best to promote *operability* during the night.

Low Temperature Li-Ion Batteries for NASA Applications (Marshall Smart, JPL)

- Marshall Smart gave an excellent summary of the latest state of the art battery technology employed in recent missions, as well as ongoing work that will pave the way for the future
- Different types of Li-Ion electrolytes have been infused into several missions including MER, Phoenix, Juno, Grail, MSL, and InSight
- New technologies have been demonstrated to provide excellent low-temperature characteristics and will be viable for future missions
    - Quallion BTE cells and 12 Ah cells have been demonstrated to operate *continuously* at -60° C and are operational down to -90° C (PUFFER program)
    - 18650-size E-One Moli Li-ion cells operational down to -60° C, and demonstrated over 167 Wh/kg at -40° C with low rates

LSIC Workshop: Low Temperature Power and Energy Storage

Lightning Talks

The community had the opportunity to view 12 pre-recorded lightning talks reviewing the latest advancements in low-temperature power technology:

Richard Ambrosi (University of Leicester)	European Radioisotope Power and Heat Solutions for Lunar Applications
Gary Barnhard (XISP-Inc)	Surviving The Lunar Night: Power and Ancillary Services Beaming as Part of an End-to-End Power System V1-1
John Bucknell (Virtus Solis Technologies, Inc)	Highly Efficient Thermoelectric Storage for Lunar Small-Scale Consumers
David Bugby (JPL, CalTech)	Passive Thermal Management Technologies for Lunar Day/Night Survivability
Nathan Davis (OxEon Energy)	A SOXE-PEM Hybrid Energy Storage System for Continuously Powered Lunar Operations (HESS-CPLO)
Shanti Garman (University of Washington)	Wireless Power Transfer as a Thermal Management Solution for Mobility Energy Storage: CubeRover Lunar Night Survival Study Using Magnetically Coupled Resonators
Christopher Greer (Penn State)	Surviving the Lunar Night Using Metal Oxidation Warming Systems with Electricity Cogeneration
Alex Ignatiev (Metox Technologies)	Using Lunar Superconducting Magnetic Energy Storage (LSMES) for NASA Artemis Program
Randall Kirschman	Electronics for Cryogenic Temperatures – Real and Ready
Richard Oeftering (NASA GRC)	Battery and Electronics Technologies for Lunar Power Hibernation
Nick Rolston (Arizona State University)	Improving Thermomechanical Reliability of Li-Ion Batteries to Withstand Freeze-Thaw Process (Thermal Cycling)
Arjit Sengupta (Vanderbilt University)	Operation of Silicon Carbide Power Devices under Lunar Surface Temperatures

LSIC Workshop: Low Temperature Power and Energy Storage

Breakout Scenario Takeaways

CLPS-scale	PSR Prospector-scale	Mini-Rovers

• Thermal Isolation:
  ◦ Must be considered from both the environment and other parts of the lander
  ◦ Weak points are in the interfaces: wiring, optics, sensors, etc.
• Separating power generation from avionics to make weight distribution work out complicates thermal design
• Should payloads and the bus be self-sufficient through the night or share thermal resources?
	• Regulatory approval is needed for novel RPS, but this is the most obvious solution for non-solar, non-tethered power
	  ◦ Minimal mission may be useful to test the regulatory framework
	• Autonomous operations for traversing terrain necessary to avoid complicated CONOPS required by VIPER
	• Power beaming solution possible, but needs demonstration/space qualification
		• Three options for operational modes:
		  ◦ Hibernation during lunar night
		  ◦ Part-time operations in lunar night/cold
		  ◦ Full operation in lunar night/cold
		• RHUs will be a good, compact tool to support this scale of low-temperature operation
		• Wireless charging, such as that designed for Astrobotic's CubeRover will be highly impactful for operation at night/in PSRs

LSIC Workshop: Low Temperature Power and Energy Storage

General Themes

- There is a need to probe the regulatory framework for launching alternative radioisotopes. The technology is understood and will be impactful once it clears regulatory hurdles.
- Delivering anything beyond modest levels of continuous power (10’s of We) through the lunar night will be hard in the near/mid-term.
- Minimal operational modes/survival would be viable at these and lower levels, and efforts towards achieving this will deliver high-value in the near term
- If payloads can draw on small-scale power through the night and expect full power and comms to return, the scope of the possible opens up dramatically. This is possible in the near-term

LSIC | Networking!

Speedy networking event: Go around the room: each person picks the next person to speak. Introduce yourself by saying

1. Name
2. Institution
3. What you work on
4. What you need to know next

Then, if there's still time, discuss any topics that spark your interest or anyone:

- Something you think the group might not know

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