Lunar Surface Innovation
CONSORTIUM

LSIC Surface Power Focus Group July Meeting

July 23, 2020

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Today's Agenda

UPDATES

- LSIC community
- Communication updates
  - Google docs
  - LinkedIn group
- Content from STMD
  - STMD capability developments for context
  - LuSTR update

DISCUSSION

- Reference missions
- Formation of surface power subgroups
  - Structure and activities
- Focus Group Goal

- Next telecon:
  - Discussion of inter-relationships between focus groups (prepare questions for other focus areas)

LSIC Community

1. Harness the creativity, energy and resources of academia, industry and government in order for NASA to keep the United States at the forefront of lunar exploration
2. Identify lunar surface technology developments most in need of sponsor support and communicate those to NASA
3. Provide a central resource for gathering and disseminating information, results, and documentation

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Communication

- Slack, Mattermost are out for NASA
- APL Confluence wiki is in progress

- For now, Google docs for dynamic communication
  - Comment using your full name
    - e.g., **Wes Fuhrman**: Generic comment content.
  - Email me to create new documents
- LinkedIn group with an internal message board
  - Connect to broader LSIC community
  - May be appropriate for pairing for solicitations
  - https://www.linkedin.com/groups/13861869/
- Email always an option
  - Wesley.Fuhrman@jhuapl.edu
  - LSIC_POWER@LISTSERV.JHUAPL.EDU

STMD LSII Capability Development

LSII capability development spans the Technology Readiness Level (TRL) Pipeline

ISRU

- ISRU Scaled Pilot Plant Demonstrations
- Demonstrate systems for collecting and purifying water on the lunar surface, capable of scaling to tens of metric tons per month, operating with little to no human involvement.
- Methods for size sorting granular lunar regolith.
- Methods for measuring mineral properties/oxygen content before and after processing

Surface Power

- Surface Fission Power
- Adaptable Lunar Surface arrays
- Energy Storage including Regenerative Fuel Cells
- Power Beaming
- Chemical Heat Integrated Power Source
- Power Distribution Architectures
- Advanced Rover Energy Storage

Dust Mitigation

- Dust tolerant textiles
- Filtration
- Dust Mitigation Structures
- Electromechanical & Magnetics
- Surface Stabilization
- Nanomaterials & Coatings
- Adaptation of Terrestrial Technologies
- Dust Classification & Best Practices Guide

Extreme Environments

- Enable rovers, manipulators, and other systems to operate in the lunar environment including lunar noon (150 °C), night (down to - 180 °C), day/night cycles, and permanently shadowed regions (down to -240 °C).
- Develop & publish Lunar Surface External Environments User's Guide

Extreme Access

- Sustained Surface Activities
- Extended Ops in Permanently Shadowed Regions
- Ingress, Exploration, & Egress of Voids
- Hazard Detection in all lunar environments & conditions
- Autonomous Operations
- Navigation with minimal infrastructure

Excavation & Construction

- Excavation of hard regolith/ice material
- Travel & traverse to mining locations
- Reliability & Maintainability during ops
- Material & Construction of requirements & standards.
- Increased Autonomy

STMD Opportunities for Academia and Industry

STMD anticipates awarding ~$600M to academia and industry supporting 2020 solicitations & awards

- **STMD Tipping Point Multiple Awards:** *Jan – Mar 2020* — $250M
- **Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) Phases I, II, II-E, Civilian Commercialization Readiness Pilot Program (CCRPP), Sequential:** *Phase I Solicitation Jan – Apr 2020* — $212M
- **Announcement of Collaborative Opportunity (ACO):** *Jan – Mar 2020* — $10M
- **Flight Opportunities Tech Flights:** *Feb – May 2020* — $10M
- **Early Career Faculty (ECF):** *Feb – Apr 2020* — $6M
- **Early Stage Innovations (ESI):** *Apr – Jun 2020* — $9M
- **NASA Innovative Advanced Concepts (NIAC) Phases I, II, III:** *Phase I Solicitation Jun – Jul 2020* — $4M
- **Space Technology Research Institutes (STRI):** *Jun – Aug 2020* — $30M
- **NASA Space Technology Graduate Research Opportunities (NSTGRO):** *Sep – Nov 2020* — $19M
- **SmallSat Technology Partnerships (STP):** *Sep – Nov 2021* — $3M
- **Centennial Challenges:** *Varied release dates* — $8M
- **NextSTEP Broad Agency Announcements (BAAs):** *Varied release dates* — *Varies*
- **Lunar Surface Technology Research (LuSTR) Opportunities:** *Coming soon!!!* — $30M

Note: Funding awards are approximate and subject to change

- Open Solicitations as of June 5, 2020
- Solicitations were/will be open *in the timeframe specified in italics*

LuSTR

- Lunar Surface Technology Research (LuSTR)
  - Academic (US) lead research with industry support (40%)
  - LuSTR topic areas included two topics in ISRU and **four topics in Power**
  - Solicitation web link: https://tinyurl.com/NASA-2020LuSTR

- Four Power Topics:
  - Flexible Power Distribution for Difficult-to-Reach and Mobile Applications
  - Advanced, Radiation-Tolerant Power Electronics
  - Low-Temperature Batteries
  - Advanced Power System Control for Interoperability

- Questions regarding topic areas can be submitted at: hq-LuSTR@mail.nasa.gov

Discussion Section

- Any questions before moving to the more discussion-oriented portion of the telecon?

Reference Missions

To further develop our potential architectures and road map, can we identify some reference missions for context. These can be based on resources, readiness, and/or need. Open to suggestion (i.e. **let's discuss**)

- Lunar south pole outpost
  - Continued priority
  - Easily related to recent solicitations

- Your ideas (or we can solicit from other focus groups)

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Subgroups

These are open to suggestion. We can continue discussion within the google doc.

- Architecture and road mapping (including reference missions)

- Power generation (nuclear, solar)
- Power management and distribution (transmission, standards, modularity)
- Energy storage

- Related to other focus-groups:
  - Power demands (ISRU, Excavation and Construction, etc.)
  - Environmental considerations (Extreme environments, extreme access, dust mitigation, etc.)

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Focus Group Goal

Each focus group is charged to define a **single 1-year goal**.

NASA needs power systems which can survive the lunar night and enable lunar exploration. The first-year goal of the surface power focus group is to:

Provide specific recommendations and a staged road map to NASA for maturing the power-related technologies needed to enable sustained presence, ISRU, excavation and construction, in the context of (TBD reference mission).

Next telecon

- What you can do before the next Focus Group meeting, by email, Google docs, etc.
  - Weigh in on Google docs:
    - Subgroups (including cross-FG coordination)
    - Year-one goal
    - Reference missions
  - Suggest additional Google Docs for other topics of interest
  - Engage on LinkedIn (e.g. for LuSTR partnerships)

- Coming up next meeting
  - Circle back on above topics
  - Hear from other focus groups
  - More on STMD funding opportunities

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STMD LSII Capability Development (cont.)

Note: Listed TRLs are end TRLs

Surface Power	**GCD Activities *(Mid TRL)***	• TP-Advanced Modular Power and Energy System (AMPES) [Infinity] – *TRL 7* • ACO-Flexible Solar Arrays qual Protocols (FSAP) [Maxar] – *TRL 6* • Breakthrough Distributed Power Architecture for In-Situ Lunar Missions – *TRL 6* • Chemical Heat Integrated Power Source (CHIPS) for Deep Space Power Systems – *TRL 6*	• Micro-Grid Definition and Interface Converter for Planetary Surface – *TRL 6* • Tethered Power Systems for Lunar Mobility and Power Transmission – *TRL 6* • TP-Flexible Next Generation Radiation-Hardened Switching Power Controller [TallanQuest, LLC] – *TRL 6*	• Vertical Solar Array Technology – *TRL 6* • ACO-Primary Fuel Cell Power System for Lunar Landers [Blue Origin] – *TRL 5* • Regenerative Fuel Cell (RFC) – *TRL 5* • RFC Non-Flow-Through (NFT) Fuel Cell Microgravity (µg) Behavior Analysis
	TDM *(High TRL)*	• Surface Fission Power – *TRL 9*		
	SBIRs *(Low to Mid TRL)*	• Integrated Nuclear Power and Propulsion: ○ Phase II – High Speed Closed Brayton Cycle Turboalternator [Mohawk Innovative Technology, Inc.] – *TRL 4* ○ Phase II – Reduced Shielding, Rugged, Scalable-Electrical Power Converter for Fission-Power Systems [Qortek, Inc.] – *TRL 4* ○ Phase II – Silicon Carbide-Based Power Electronics for Small Fission Reactors [CFD Research Corp.] – *TRL 4* ○ Phase II – A High Temperature Heat Rejection System for Fission Power Generation [ThermAvant Technologies] – *TRL 3* ○ Phase II – Fission Stirling Convertor [American Superconductor Corp.] – *TRL 3* ○ Phase II – Integral Neutron and Gamma Shield Material [MillenniTEK, LLC] – *TRL 3* ○ Phase II – Linear Acoustic Nuclear Conversion Engine (LANCE) [Nirvana Energy Systems, Inc.] – *TRL 2.5* ○ 2 New Recommended SBIR Phase I	• SBIR Sequential – Consolidation of Heat Pipes within a U-8Mo Core for High Efficiency and Long-Term Reliability [Peregrine Falcon Corp.] – *TRL 5* • SBIRs Supporting RFC: ○ Phase III – Membrane Electrode Assemblies (MEAs) into the Cycle I Stack for Test [Infinity] – *TRL 5* ○ Phase III – Regenerative Fuel Cell Electrolyzer [Giner, Inc.] – *TRL 3* • Lunar & Planetary Surface Power Management & Distribution: 4 New Recommended SBIR Phase I
	ECI *(Low TRL)*	• In-Space Assembly of Perovskite Solar Cells for Very Large Array – *TRL 3-4*		
	ECFs *(Low TRL)*	• Batteries for Extreme Cold Environments (4 Awards) [Dartmouth College, Georgia Tech, University of California-San Diego] – *TRL 2-3* • Advanced Wires and Cables (Proposed) – *TRL 2-4*	• Energy/Exergy Models for Integrated System Design (Proposed) – *TRL 2-4* • Surface to Surface Power Beaming/Wireless Power Transfer (Proposed) – *TRL 2-3*	
	Challenge *(Low TRL)*	• "Watts on the Moon" Centennial Challenge – *TRL 2-3*		
	STRG *(Low TRL)*	• Upcoming Surface Power LuSTR – *TRL 2-3*		

Lunar Surface Technology Research (LuSTR) Opportunities

University-led efforts to develop and mature technologies that address high-priority lunar surface challenges

Technical Characteristics:

- Unique, disruptive or transformational lunar surface technologies: *in situ* resource utilization, sustainable surface power, extreme access, extreme environments, surface excavation and construction, and lunar dust mitigation
- Low to mid Technology Readiness Level (TRL): TRL 2-5
- Post-award infusion opportunities

Eligibility

- Organization submitting proposal must be an accredited U.S. university
- PI must be a professor at the submitting university; co-Is are permitted
- ≥ 60% of budget must go to accredited U.S. universities
- Up to 40% paid teaming with other universities, industry and non-profits encouraged

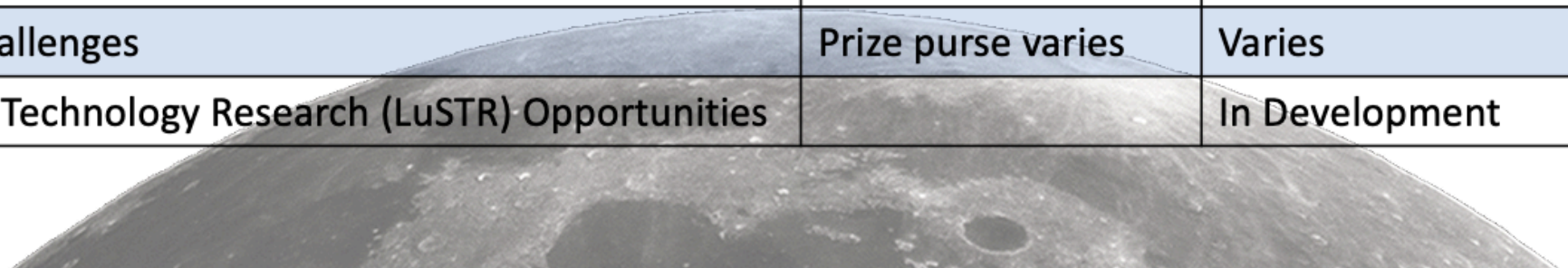
Award Information

- Expected duration: **2 years**
- Anticipated awards (inaugural solicitation): **10-15 awards** valued at up to **$1-2M** each
- Oversight: Annual reviews and semi-annual briefings at LSIC meetings
- Award instrument: Grants
- Release Date: **July 2020**

STMD Recurrent Solicitation Opportunities

Opportunity	Solicitation Totals for New Awards*	Solicitation
Tipping Point (TP)	$250M	Jan-Mar
Space Technology Research Institutes (STRI)	$30M	June-Aug alt. years
SBIR/STTR Phase I, II, Phase II-E, CCRPP, Sequential	$212M	Jan-April (Phase 1)
NASA Innovative Advanced Concepts (NIAC) Phase I, II, III	$4M	Jun-Jul (Phase 1)
Announcement of Collaborative Opportunity (ACO)	$10M	Jan-Mar
Early Career Faculty (ECF)	$6M	Feb-April
Early Stage Innovations (ESI)	$9M	April-June
Smallsat Technology Partnerships (STP)	$3M	Sep-Nov alt. years
Flight Opportunities Tech Flights	$10M	Feb-May
NASA Space Technology Graduate Research Opportunities (NSTGRO)	$19M	Sep-Nov
Centennial Challenges	Prize purse varies	Varies
Lunar Surface Technology Research (LuSTR) Opportunities		In Development

*Based on FY 2020 Operating Plan



LSII Technology Demonstration Planning

Capability Area	Activity for Surface Demonstration	Targeted Initial Flight Demo
ISRU	Ice Mining Subscale Demonstrations (includes PRIME)	2 Sub-system Class: PRIME (FY22); Ice-mining Sub-scale Demo (FY24)
	Oxygen Extraction Subscale Demonstration	FY26
	ISRU Pilot Plant System (Includes excavation and power sub-systems)	System Flight Demo FY29 (Full Mission)
Surface Power	Chemical Heat Integrated Power Source (CHIPS)	FY26+ Sub-system Class
	Regenerative Fuel Cell/PV Power Demonstration	FY26+ Sub-system Class
	Wireless Power Transfer for Lunar Surface Demonstration	FY26+Sub-system Class
	Lunar Surface Solar Arrays	FY25+Sub-system Class
	Surface Fission Power Pilot	FY28 – Full Mission
Dust Mitigation	Multiple Lunar Dust Mitigation Demonstrations	3 Sub-system Class: #1 (FY23), #2 (FY25), #3 (FY27; 3 Component Class: #1 (FY22), #2 (FY24), #3 (FY26)
Extreme Environments	COLDArm with Bulk Metallic Glass Gears (BMGG) & LDRT	FY23 Sub-system Class
	Engineering Camera for Lunar Exploration (LunarCam) Demonstration	FY23 Sub-system Class
	Lunar Exposure Platform (Lunar MISSE)	FY22+ Component Class
	Lunar Night and Material Survivability	FY22+ Component Class
	Planet & Lunar Environment Thermal Toolbox Elements (PALETTE)	FY24+ Subsystem Class
	Extreme Environments System Demonstration(s)	2 Sub-system Class: #1 (FY26), #2 (FY28)
Extreme Access	Surface Robotic Scouts Technology Demonstration (CADRE)	FY23+ CADRE Sub-system Class
	Lunar LIDAR for Navigation Demonstration	FY24 Sub-system Class
	Exploration of Lunar Pits Demonstration	FY24+ Sub-system Class
	Micro Video Guidance System (μVGS)	FY22+ Component Class
	Day/Night Lunar Rover Autonomous Obstacle Avoidance and Localization	FY24+ Component Class
	Lunar Surface Communications Demonstrations	FY24+ Sub-system Class
	Lunar Surface Autonomous/Robotics Systems Demonstration(s)	2 Sub-system Class: #1 (FY25), #2 (FY28)
Excavation & Construction	Lunar Surface Construction Demonstration(s) (Scaled Landing Pad Demo)	2 Sub-system Class: #1 (FY26), #2 (FY28)
	Lunar Surface Excavation Demonstration(s)	2 Sub-system Class: #1 Small Pilot Excavator (FY24), #2 FY26; Part of ISRU Pilot Plan (FY29)
Technology Research	LSII Allocation for Technology Research Opportunities (STRG, STTR, etc.)	Component Class: #1 FY23, #2 FY25, #3 FY27, #4 FY29

- STMD Technology Demonstrations on CLPS flights will be a combination of payloads co-manifested on SMD-led CLPS Missions and STMD-led CLPS missions.
- The '+' sign by flight dates indicates the earliest year that the technology could be ready for flight. If CLPS missions are not available and architecture needs can be met, can consider later flight year.

LSII Technology Demonstration Candidates

Candidate flight technologies are funded for TRL maturation.
Technologies listed are scheduled to reach at *least TRL 6 by the dates shown in italics unless otherwise noted.*

ISRU	**O_2/Metals Extraction**	**$H_2O/LH_2/LO_2$ Production**	**Inlet/Outlet Valves**	**Sensors**
	Carbothermal Reduction Demonstration (CaRD) *FY23*	TP – Lunar Ice Processing Tipping Point (Ice) [OxEon] *TRL 5 FY21*	Regolith Valve Development *FY23*	Laser In-Situ Resource Analysis (LIRA) *FY24*
	Plasma Reduction for Oxygen Extraction from Regolith *TRL 5 FY24*	Light Water Analysis & Volatile Extraction (Light WAVE) *FY22*		
	Resource Recovery with Ionic Liquid for Exploration (RRILE) *FY24*	TP – Lunar Propellant Production Plant (LP3) [Skyre] *TRL 5 FY22*		
	Molten Regolith Electrolysis (MRE) *FY25*	Lunar Auger Dryer ISRU (LADI) *FY25*		
Surface Power	ACO – Flexible Solar Arrays qual Protocols (FSAP) [MAXAR] *FY21* Regenerative Fuel Cell (RFC) *TRL 5 FY24* Chemical Heat Integrated Power Source (CHIPS) *FY25*	TP – Advanced Modular Power and Energy System (AMPES) [Infinity] *FY22* Tethered Power Systems for Lunar Mobility and Power Transmission *FY25*	Micro-Grid Definition and Interface Converter for Planetary Surface *FY24* Breakthrough Distributed Power Architecture for In-Situ Lunar Missions *FY25*	

Dust Mitigation	**Sensors**	**Suppression**	**Filtration**	**Passive Mitigation**	**Active Mitigation**
	CPLS Payload for PSI Measurements *FY22*	Electrostatic Controlled Spray for Lunar Surface Dust Suppression *FY25*	Lunar Dust Filtration *FY23*	Patch Plate Materials Compatibility Assessment *FY22*	Lunar Dust Removal Tool (LDRT) *FY23*
	Lunar Dust Lever Sensor & Affects on Radiators (LDAR) *FY22*				Electrodynamic Dust Shield (EDS) *FY23*
	Lunar Dust Smart Sensor for Crewed Environments *FY23*			Dust Tolerant Mechanisms *FY23*	Lunar Occupancy Dust Surface Separation Technology (LO-DuSST) *FY25*
Extreme Environments	TP – Health Sensors for Inflatable habitats (HSI) Tipping Point [Luna] *FY22*	TP – Shape Memory Alloys for Regulating TCS in Space (SMARTS) [Paragon] *FY22*		Miniature Efficient Heat Pump for Lunar Exploration *FY24*	
				Motors for Dusty and Extremely Cold Environments *FY24*	
Extreme Access	Extreme Terrain Access for Lunar Exploration	TP – CubeRover [Astrobotic] *FY22*		Lightweight Surface Manipulation System (LSMS) *FY23*	
		High TRL Rover LIDAR *FY23*			

Excavation & Construction	**Excavation**	**Construction**
	ISRU Pilot Excavator *FY22*	Lunar Safe Haven Seedling Study
	Build & Excavation Autonomous System with Transportation (BEAST) *FY24*	Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) *FY23 (Microwave Manufacturing)*