

# Science priorities for non-polar lunar sites: A DARPA perspective

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Presented to NASEM Applied Sciences Panel

August 12, 2025





A quick background on the DARPA perspective



## H1/Metrics: LunA-10



# It is the year 2035, and a thriving lunar economy exists on the Moon. How did we get there?

- Push from Individual self-service (Exploration Age) to <u>commercial multi-service</u> (Industrial Age)
- Push from government as a sponsor to <u>commercial</u> as a <u>customer</u>
- For a given lunar service or unit: What are the <u>inputs/outputs/limitations</u>?

Does it close to a sustainable lunar economy?

What DARPA-hard technical challenges
must be surmounted to create this by 2035?

#### **Performers**



#### **Government Integration Team**











H2: LunA-10



## The current paradigm:

Individual scientific efforts within isolated, self-sufficient systems

#### Power:

NASA investment in SFP for wired power

#### **Transportation:**

Human Landing System
Rovers for limited
cross-mass

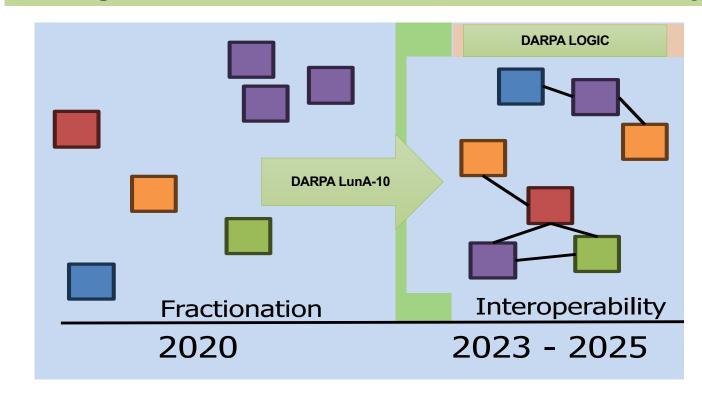
#### Communications:

Not commercially proven

# Lunar Market Analysis:

Highly speculative and company-specific

## **Driving from era of fractionation to era of connectivity**

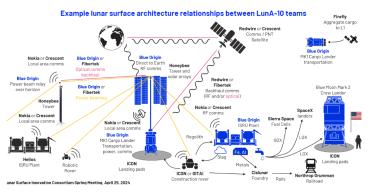


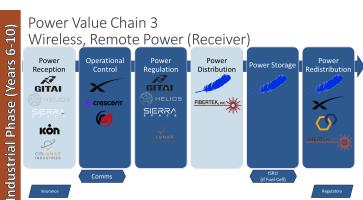


## **Value Chains that feed an Analytical Framework**



### 13 Company-centric Architectures, 61 Value Chains, 8 Analytical Frameworks





Industrial Age— Economy
Honeybee Lunar Oasis
\$770k/Mr Wired Power
\$360k/kg Hosted Payload
\$1,10k/kw/h themal Dissappation
\$130/kwh Thermal Energy Delivered
\$130k/km Industrial)
\$1,000/kwh Beamed Power (Fibartel)
\$1,000/kwh Bea

PNT: Position, Navigation, & Timing RF: Radiofrequency

MTI: Multi-Target Identification

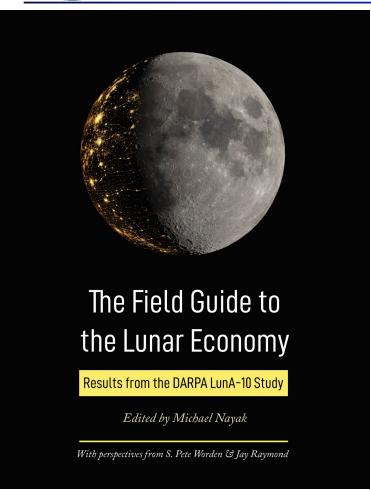
LOX: Liquid Oxygen DTE: Direct to Earth

DOR: De-oxygenated Regolith



## New H2 after LunA-10: Field Guide to the Lunar Economy





#### A deep dive into LunA-10's results

Book 1: Historical and Framing **Perspective** 

From Flags & Footprints to a Commercial Lunar Economy LunA-10 Study Framing & Overview

Book 3: Lunar Power **Enabling** Lunar Mining **Perspectives** Metal Ecosystem on the Moon

Book 2: **Components of** Commercial Lunar Infrastructure

Comms/PNT Robotics as a Service

Commercial Landing Pads for Heavy Landers

Lunar Infrastructure Hubs

Thermal as a Service

Rail Network for Lunar Logistics

Cislunar Supply Hubs

LunA-10 Analytical Frameworks & Value Chains

Space Treaties & International Law

Responsible Space Economics

Rules-based Frameworks

Case Study: Air Traffic Control in

Antarctica

Biomanufacturing in Space and on the Lunar Surface

The Role of Space Insurance

Lunar Interoperability

Next Steps for the Commercial

Lunar Economy

https://www.airuniversity.af.edu/AUPress/Dis play/Article/4250446/the-commercial-lunareconomy-field-guide-a-vision-for-industry-onthe-moon-in-t/

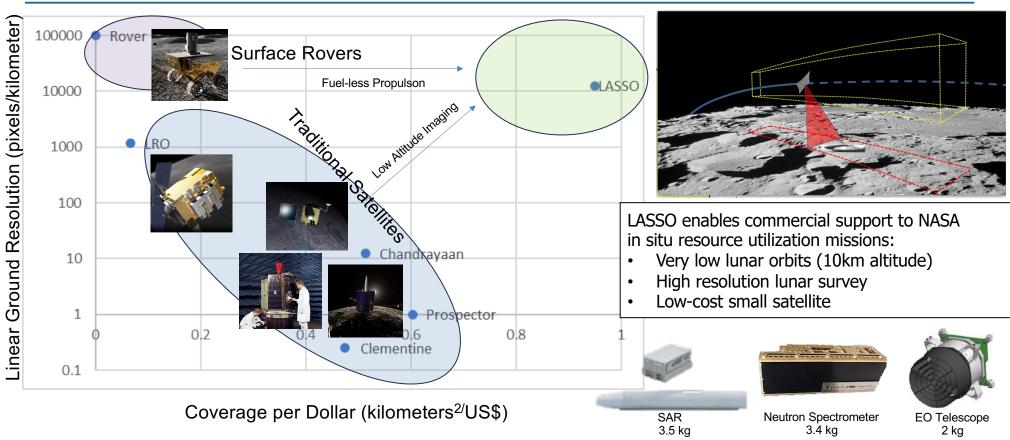
**Published July 2025 from Air University Press** Free access to all: Google "Air University Lunar Field Guide" 135 authors from 46 organizations





# DARPA's next bet – LASSO. Lunar low-altitude prospecting





LASSO achieves long term satellite coverage with high resolution sensing



Specific to the Applied Sciences panel... what practical science enables this future?

(sustained human operations and exploration ...that will enable a future commercial lunar economy)



# Six DARPA-hard hypotheses to Accelerate the Lunar Economy 570





#### Thermal as a service

Heat generation and heat rejection hubs Enable all lunar industry to survive the night Reduce mass to Moon by >50%



## Global subsurface prospecting

Today's economic "anchor tenant" is ISRU (oxygen and water). What is the next "gold rush" resource?



#### Silicon as a service

Silicon (and Si-based microelectronics) are the bedrock of our technological civilization Lunar regolith is 21% Si; 1/6g allows growing larger Si-wafers than possible on Earth



#### Biomanufacturing for construction

Are there new ways for engineered microbes to accelerate construction of structures on the lunar surface?



### Improved low-gravity beneficiation

New ways to efficiently extract resources in the ppm concentration, and make it economically viable



#### Reimagining PNT for lunar surface

Can we do better than "GPS for the Moon"? New insights into reimagined PNT and communications

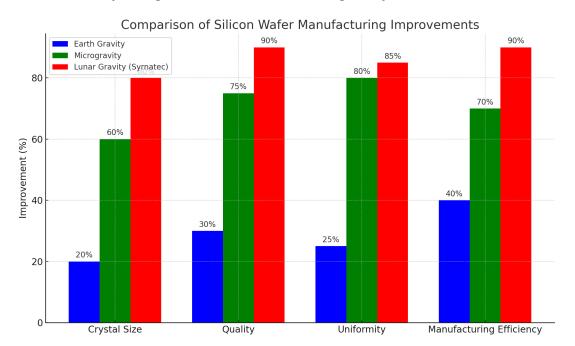
PNT: Position, Navigation, and Timing



## In-situ science investigations with broad and high impact



Science that enables the in-situ manufacture of silicon
 There is a huge difference between 99% and 99.999% pure
 Silicon crystal growth studies in microgravity to reduce defects



Humans onsite Non-polar? required?





- · Chip-scale quality control
- Manufacturing process optimization
- Keep crucible sorted/fed with ISRU material instead of requiring expensive robotic ingest



# In-situ science investigations with broad and high impact

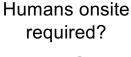


Subsurface investigations of KREEP terrane
 The quantification of REEs in KREEP would be game-changing
 Current estimates are quite thin (20-25 ppm Rb, lanthanum in carbonaceous chondrites)

Investigate the KREEP-rich magma at multiple locations to quantify the geological composition and elemental abundance of REEs.

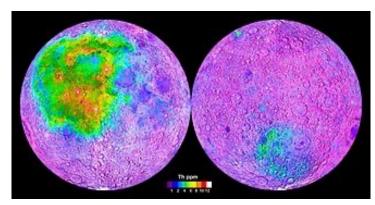


Non-polar?





- Diverse sampling locations
- In-situ geology
- Need coring to get below 1 m depth
- Estimates of mechanical properties of subsurface (1-10 meters)



Lunar Prospector measurements of Thorium Thorium is used as a proxy for KREEP (Potassium, rare earth elements, phosphorus)



## 3: Don't forget biology - biology is an enabler of lunar ISRU



#### **Carbon Sources**

- Local human waste
- Shipped high density carbon



1 kg of pure carbon can be converted into... (upmass savings)

- 2.5kg Glucose (60%)
- 2.0kg PLA (50%)
- 1.3kg Methane (25%)

#### **Lunar Resources**

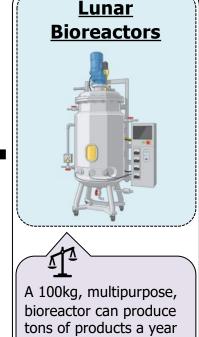
- Water
- Minerals
- Oxygen
- Energy



Energy required for 1kg of regolith brick making

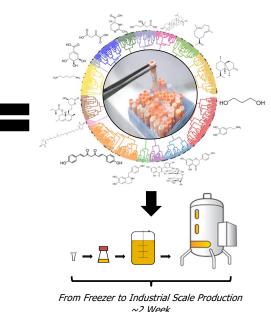
- 1,632 kJ Laser Sintering
- 108 kJ Biological process

Modeling done by Unv Mississippi and Space Factory; SHALE FA4 Response



Modeling done by Unv Texas at Austin, B-SURE performer

## Unparalleled aperture for on demand chemical diversity

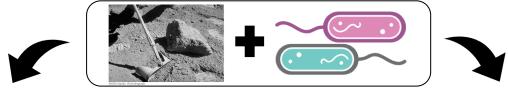


Bioreactors: a critical enabler of the lunar economy. Make It, Don't Take It

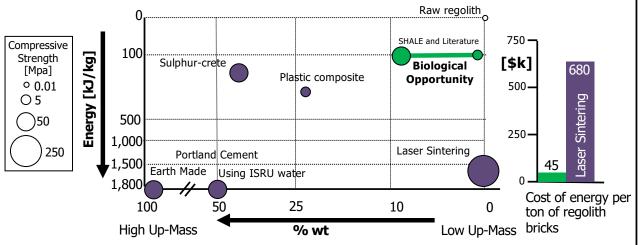


## **DARPA** 3: Biological ISRU for REE extraction and regolith construction

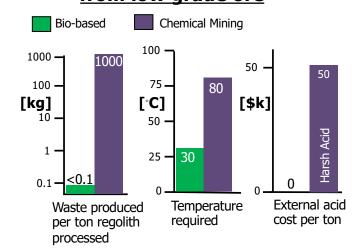




## **Grow Regolith binders for surface structures**



# Metal Harvesting and concentration from low grade ore

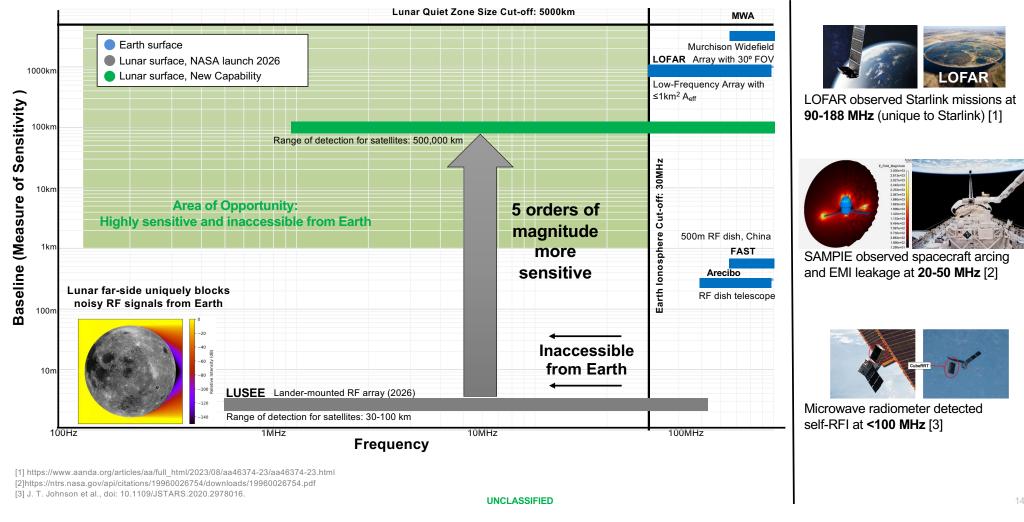


Biological S&T should be part of Decadal Science Objectives on the lunar surface, and directly require humans to enable





## 4: RF emissions from low-frequency regime inaccessible from Earth





## In a decade when Starship exists... The next generation of radio science becomes possible with VLBI



#### Today's State of the art: \$1M/kg to the Moon



#### **NASA LuSEE**

Antenna size: 3m m<sub>LUSEE</sub>=128kg; m<sub>system</sub>=178kg Mission cost: \$178M

Scaling to km-scale interferometers from CLPS rovers not possible



Near-future State of the art: \$1,000/kg to the Moon

SpaceX Starship 2027+: 100 tons to the lunar surface

100,000 dipoles (100 km interferometer): 40% of single Starship capacity

LuSEE: Lunar Surface Electromagnetics Experiment Large system deployments at low costs possible with Starship, but other issues exist

#### **Technical Challenge for Very Large Interferometers: Data** Science Volume



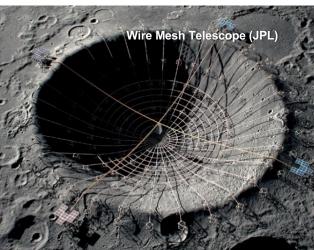


N=100.000 dipoles requires 10<sup>10</sup> interferometry baselines (N<sup>2</sup>)

Cannot be modeled today. even with world's largest supercomputers 4,000 petabytes of data generated in a 24-hour period

### **Technical Challenge for Very Large Dish Telescopes:**

**Mechanical Tolerancing** 



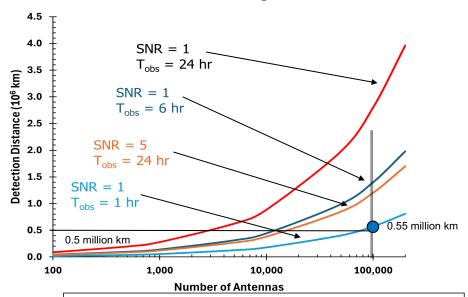
**Extreme temperature changes cause** structural failures due to thermal variation



# For a VLBI of a given size on the near and far side of the Moon, there are significant planetary defense applications

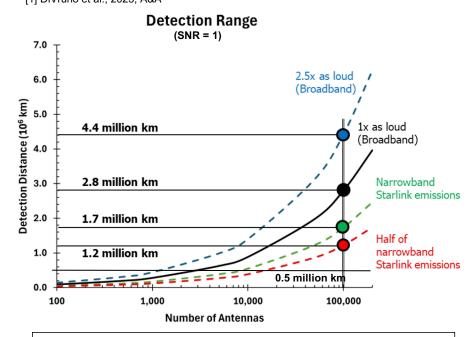
100,000 dipoles distributed over 200 km<sup>2</sup> 24 hour integration period Center frequency 40 MHz Bandwidth 20 MHz Emitter flux density 1.3x10<sup>-23</sup> W/m<sup>2</sup>/Hz, scaled from 500 km Starlink LOFAR obs

#### **Detection Range**



Decrease from 24 hr to 1 hr observation reduces max range to 20% ( $\sqrt{1/24}$ )

100,000 dipoles at 14 km max baseline 24 hour integration period Center frequency 40 MHz Bandwidth 20 MHz [1] DiVruno et al., 2023, A&A



Even at 5x decrease in emitter strength, detectable at the distance of Earth-Sun L2



Summary



# In-situ science investigations with broad and high impact



	Non-polar?	Humans onsite required?
1. Science that enables the in-situ manufacture of Si	<b>√</b>	
2. Subsurface investigations of KREEP terrane	<b>√</b>	
3. Radically new human-lunar biological applications (pharma, ISRU)		
Very long-baseline interferometric radio science     (and planetary defense)		<b>√</b>

