Lunar Surface Innovation Initiative (LSII) Status

- Space Technology Industry-Government-University Roundtable (STIGUR)

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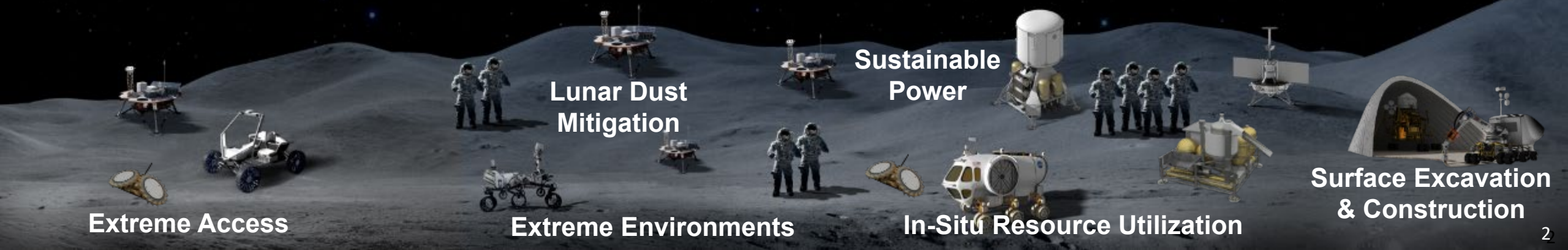
The Lunar Surface Innovation Initiative (LSII)

LSII works across industry, academia and government through in-house efforts and public-private partnerships to develop transformative capabilities for lunar surface exploration

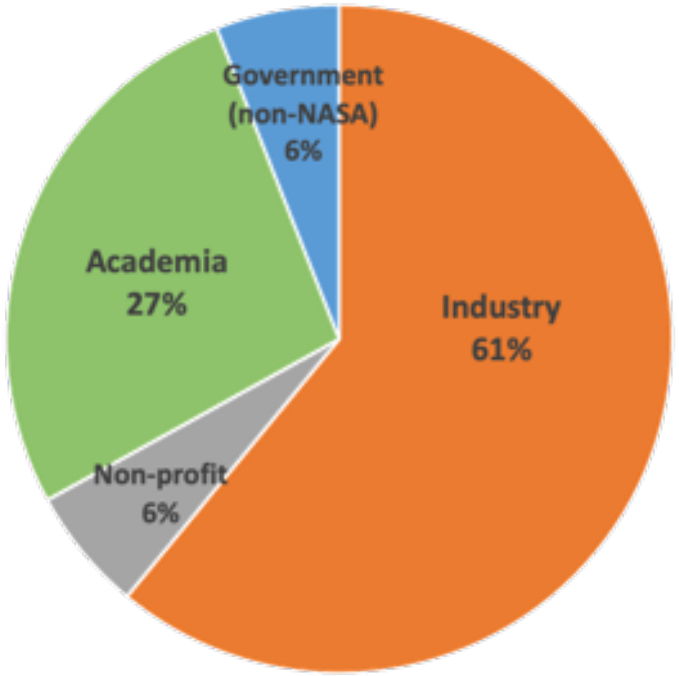
- Formulate and integrate technology maturation activities across the TRL pipeline and Space Technology programs
- Leverage innovative partnering and procurement approaches to expedite technology development
- Utilize early uncrewed lunar surface flight opportunities to inform key technology development
- Establish the Lunar Surface Innovation Consortium (LSIC) comprised of academia, industry, non-profits and other government agencies



LSII continues to grow….

LSII has engaged 500 organizations across 49 states to advance the technologies needed to explore the lunar surface in new ways and stimulate a lunar surface economy.

LSII Representation

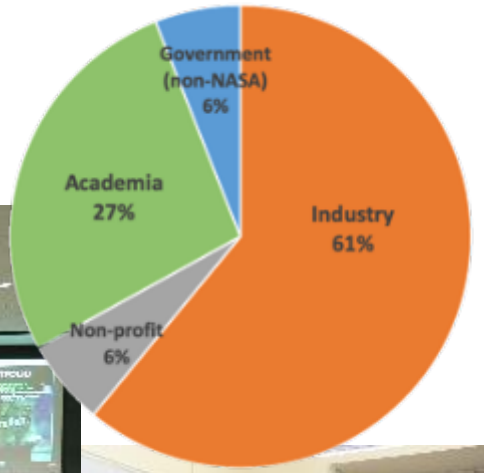


Lunar Surface Innovation Initiative (LSII) Collaboration Highlights

More than 1,500 active participants from over 500 organizations across 49 states, increasing monthly

- **Lunar Surface Innovation Consortium (LSIC) Fall Meeting Nov 3-4, 2021**
  - Hybrid meeting Held at Bowie State University
- APL continues monthly **LSIC Focus Groups** across each of the six LSII capability areas to enable regular interaction across the community.
  - Subgroups have been created at the request of the community
- **LSIC Thematic Workshops**
  - **Dust Mitigation Workshop** – Feb. 2021
  - **Lunar Mapping for Precision Landing Workshop** – March 2021
  - **Power Beaming Workshop** – July 2021
  - **Excavation & Construction** – Aug 2021
- **Lunar Surface Technology Research (LuSTR) Opportunities**
  - Autonomous Systems for Excavation and Site Preparation
  - Lunar Regolith Mineral Beneficiation
  - Cold-Temperature Analog Integrated Circuits
  - Novel Heat Transfer Fluids
- **Centennial Challenges**
  - Break the Ice Challenge – 13 Phase I Awards (Phase II tbd)
  - Watts on the Moon Challenge – 7 Phase I Awards (Phase II TBD)
  - Space Robotics Challenge – 22 Phase I Awards (Phase II underway)
- **BIG Idea Challenge**
  - 2021 Lunar Dust Challenge
  - 2022 Extreme Terrain Mobility Challenge
- **NASA Tournamentt Lab Challenge**
  - Honey I Shrunk the NASA Payload Challenge – 4 Phase I Awards (Phase II underway)

LSII Representation



Johns Hopkins Applied Physics Lab is the lead for the LSIC and overall System Integrator for LSII

Please visit lsic.jhuapl.edu for information on joining the LSIC

Lunar Surface Innovation Initiative (LSII) Projects as of 9/30/21

Approximately half of the Technology Maturation portfolio is comprised of LSII projects.

Surface Power

- *Advanced Alkaline Reversible Cell – ACO/PH Matter*
- *Advanced Modular Power & Energy System – TP/Infinity*
- *Flexible Solar Arrays qual Protocols – ACO/MAXAR*
- *Bifurcated Reversible Alkaline Cell for Energy Storage – TP/PH Matter*
- *Metal Oxidation Warming System Fuel Cell – TP/Masten*
- *Ultra Fast Proximity Charging – TP/Astrobotic*
- *Propellant Fueled Solid Oxide Fuel Cell – SBIR Ph. 3*
- *Vertical Solar Array Technology (VSAT) 5 contracts*
- Breakthrough Distributed Power Architecture for In Situ Lunar Missions
- Chemical Heat Integrated Power Source (CHIPS)
- Micro-grid Definition and Interface Converter for Planetary Surface
- Regenerative Fuel Cell (RFC)
- Tethered Power Systems for Lunar Mobility and Power Transmission

Excavation & Construction

- *ACO - Relevant Environment Additive Construction Technology – SpaceFactory*
- ISRU Pilot Excavator
- Lightweight Surface Manipulation System (LSMS)
- Moon-to-Mars Planetary Autonomous Construction

In-Situ Resource Utilization (ISRU)

- *Carbothermal Oxygen Production Reactor Demonstration – TP/Sierra Nevada Corporation*
- Polar Resources Ice-Mining Experiment (PRIME) CLPS Demo
- Carbothermal Reduction Demonstration (CaRD)
- Dirty Lunar Surface Simulation
- Fundamental Regolith Properties, Handling, and Water Capture
- Laser Spectrometers for Impurity Analysis
- Light Water Analysis & Volatile Extraction (Light WAVE)
- Lunar Auger Dryer ISRU (LADI)
- Molten Regolith Electrolysis Tech Maturation
- Plasma Reduction for Oxygen from Regolith
- Regolith Valve Development
- Lunar Simulants

Extreme Access

- *Lunar Underactuated Robotic Arm – TP/SSL Robotics*
- Cooperative Autonomous Demonstration for Robotic Exploration (CADRE)
- LunarCam
- LunarNav
- Miniature Efficient Heat Pump
- Smart Video Guidance Sensor (SVGS)

Extreme Environments

- *Deployable Lunar Hopper – TP/Intuitive Machines*
- *LTE Proximity Operations – TP/Nokia*
- *Shape Memory Alloys for Regulating TCS in Space – TP/Paragon*
- *Space Science & Technology Evaluation Facility - First Flight – TP/Alpha Space*
- *Health Sensors for Inflatable habitats – TP/Luna*
- Bulk Metallic Glass Gears (BMGG)
- Cold Operable Lunar Deployable Arm (COLDArm)
- Motors for Dusty & Extremely Cold Environments
- Planetary and Lunar Environment Thermal Toolbox Elements (PALETTE)

Dust Mitigation

- *Dust Mitigation for Flexible Solar Arrays – ACO/SSL*
- Electrodynamic Dust Shield (EDS) CLPS Demo
- Electrostatic Controlled Spray for Lunar Dust Suppression
- Dust Mitigation Best Practices Guide
- Dusty Environments Classification & Testing
- Dust Tolerant Mechanisms
- Lo-DuSST
- Lunar Dust level sensor & Affects on Radiators
- Lunar Dust Removal Tool
- Patch Plate Materials Compatibility Assessment

Technology Maturation - LSII Technology Demonstration Timeline

2022 — 2029

ISRU

- Polar Resources Ice Mining Experiment (PRIME-1)

- ISRU Subscale Demo

- Lunar Auger Dryer for ISRU (LADI)

- ISRU Pilot Plant with Excavator

Surface Power

- Regenerative Fuel Cell (RFC) Power
- Vertical Solar Array Technology (VSAT)
- Wireless Charging for Lunar Surface Demo
- Chemical Heat Integrated Power Source (CHIPS)
- Fission Surface Power Demo

Dust Mitigation

- Electrodynamic Dust Shield (EDS)

- Lunar Dust Smart Sensor for Crewed Environments
- Lunar Dust Removal Tool (LDRT)

Extreme Environments

- COLDArm w/ Bulk Metallic Glass Gears

- LunarCam
- Planet & Lunar Environment Thermal Toolbox Elements (PALETTE)
- Lunar Night Material Survivability

Extreme Access

- IM Deployable Hopper

- Nokia LTE/4G Proximity Comm
- Stereo CAmeras for Lunar Plume Surface Studies (SCALPSS) 1.1
- Surface Robotic Scouts (CADRE)

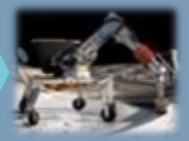
- PSI Mini-Suite
- SPLICE-1

- Lunar LIDAR for Navigation
- Smart Video Guidance System (SVGS)
- Day/Night Lunar Rover Obstacle Avoidance
- SPLICE-2
- Autonomous Robotics Demo

- Deployable Hopper
- Autonomous Exploration of Lunar Pits

Excavation & Construction

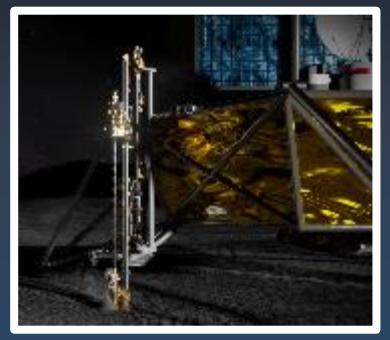
- ISRU Pilot Excavator (IPE)
- Lunar Surface Scaled Construction Demo 1
- Lunar Surface Construction Demo 2



2022-2024 STMD Lunar Surface Tech Demos

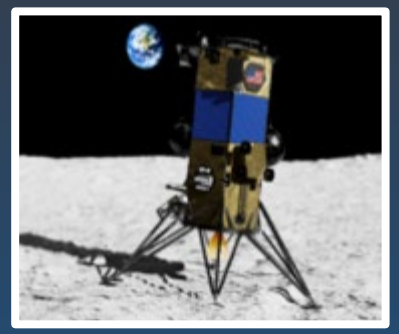
Early lunar surface demonstrations, via the Commercial Lunar Payload Services (CLPS) initiative, are unique opportunities to mature the key capabilities required for for NASA and industry.

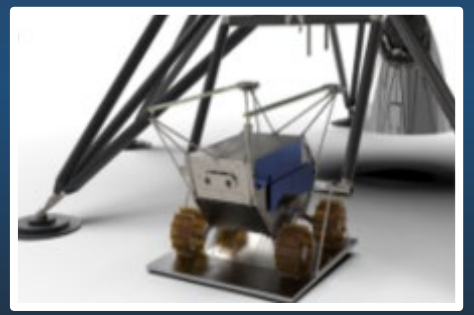
CLPS PRIME (Intuitive Machines 2) Winter 2022



Deployable Lunar Hopper (STMD Tipping Point)

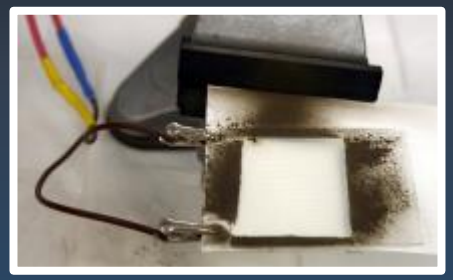
Polar Resources Ice-Mining Experiment (PRIME-1)



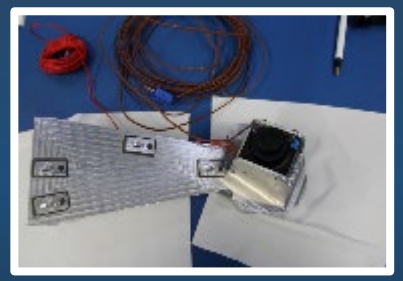


Nokia 4G/LTE Proximity Comms (STMD Tipping Point)

CLPS 19D (Firefly Aerospace) Summer 2023



Electrodynamic Dust Shield (EDS)



Stereo CAmera for Lunar Plume Surface Studies (SCALPSS 1.1)

CLPS CP-11 (Intuitive Machines 3) Winter 2023

Cooperative Autonomous Distributed Robotic Explorers (CADRE)

CLPS CP-12 (TBD Provider) Spring 2024

Cold Operable Lunar Deployable Arm (COLDArm)

Flight Evolution & Demonstration Strategy

ISRU, Excavation and Construction

Reconnaissance, Prospecting, Sampling

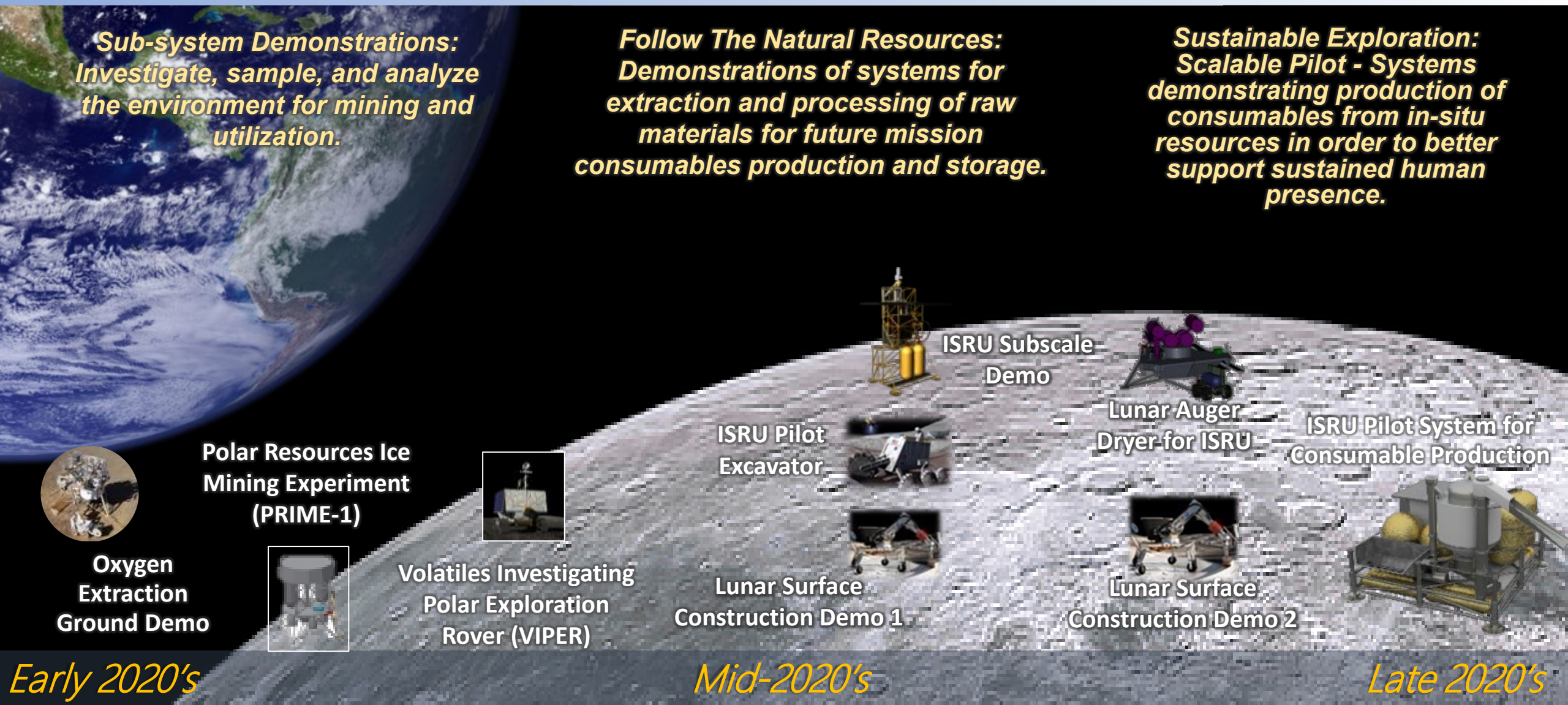
Sub-system Demonstrations: Investigate, sample, and analyze the environment for mining and utilization.

Resource Acquisition & Processing

Follow The Natural Resources: Demonstrations of systems for extraction and processing of raw materials for future mission consumables production and storage.

Pilot Consumable Production

Sustainable Exploration: Scalable Pilot - Systems demonstrating production of consumables from in-situ resources in order to better support sustained human presence.



Lunar Surface Innovation Consortium (LSIC)

Nationwide alliance of universities, commercial companies, non-profit research institutions, NASA, and Other Government Agencies with a vested interest in our nation's campaign to establish a sustained presence on the Moon.

Johns Hopkins Applied Physics Lab (APL) serves as the LSII Integrator and manages the Lunar Surface Innovation Consortium (LSIC)

LSIC Objectives include:

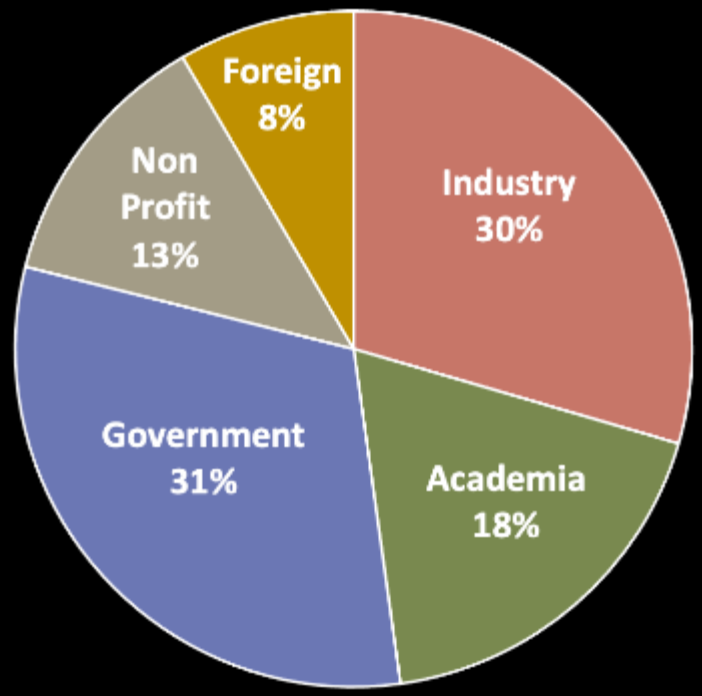
- **Technology Development:** Identify lunar surface technology needs, assess the readiness of relative systems and components
- **Information Clearinghouse:** Provide a central resource for accessing and sharing information relevant to lunar surface technology development, funding, and flight opportunities
- **Community Development:** Foster growth of a diverse community and networking among members

If interested in further information, please visit lsic.jhuapl.edu

LSIC Fall Meeting Highlights

The Lunar Surface Innovation Consortium (LSIC) Fall Meeting was held as a hybrid forum on October 14-15, 2021 with >500 attendees from academia, industry, government and non-profit institutions.

- The Fall LSIC Forum was led by APL and hosted by LSIC partner Bowie State University:
  - Virtual address by NASA Deputy Administrator Pam Melroy
  - Space Tech Associate Administrator Jim Reuter provided Space Tech highlights
  - Next Generation Lunar Scientists and Engineers Presentation
  - Investing in Cutting Edge Technology: Building a Space Economy Panel
  - Fostering Innovation in Industry and Academia Panel
  - Community-contributed technical lightning talks and poster presentations
  - Introduced a Surviving the Lunar Night Study and Survey Introduction
  - Panel discussions on Autonomy, Robotics and planned flight demonstrations
  - Breakout sessions on utilizing autonomy and robotics to establishing, operating and maintaining a presence on the Moon



- A summary report, including an initial assessment of the breakout group findings, will be posted publicly on the LSIC website by the end of November.
- LSIC will build on the breakout group findings to develop focus area goals

Meeting program, abstracts and presentations can be accessed online at: https://lsic.jhuapl.edu/Events/Agenda/index.php?id=148

LSIC | Dust Mitigation Workshop

Lunar Dust is a major concern and dust tolerant/dust mitigation solutions are critical for enabling sustained surface operations.

Over 340 attendees from over 200 institutions attended workshop on February 4, 2020 with the following representation: 20% Academia, 28% Government, 43% Industry, and 9% Nonprofit

High priority challenges and needs Identified:

- Establishing set of tolerances allowing systems to operate “dirty”
- Acquisition of ground truth dust properties and plume/ejecta data from precursor missions to validate modeling tools and designs
- Develop and standardize simulants and testing conditions to better capture real dust problems instead of approximations
- Pathways and mechanism for integrating dust tolerant/mitigation technologies into lunar systems and architecture
- Technology demonstrations on CLPS landers to test in real-world conditions

Technology gaps identified:

- Landing, launch, and surface transport dust ejecta/plume mitigation
- Passive/Active dust removal tools
- Dust tolerant space suits/fabrics
- Habitats and Vacuum/Filtration
- Dust tolerant mechanisms
- Dust tolerant joints, wheel bearings, and connectors
- Dust tolerant optical power systems
- Dust detection sensors
- Surface modification solutions

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LSIC Dust Mitigation Workshop Website

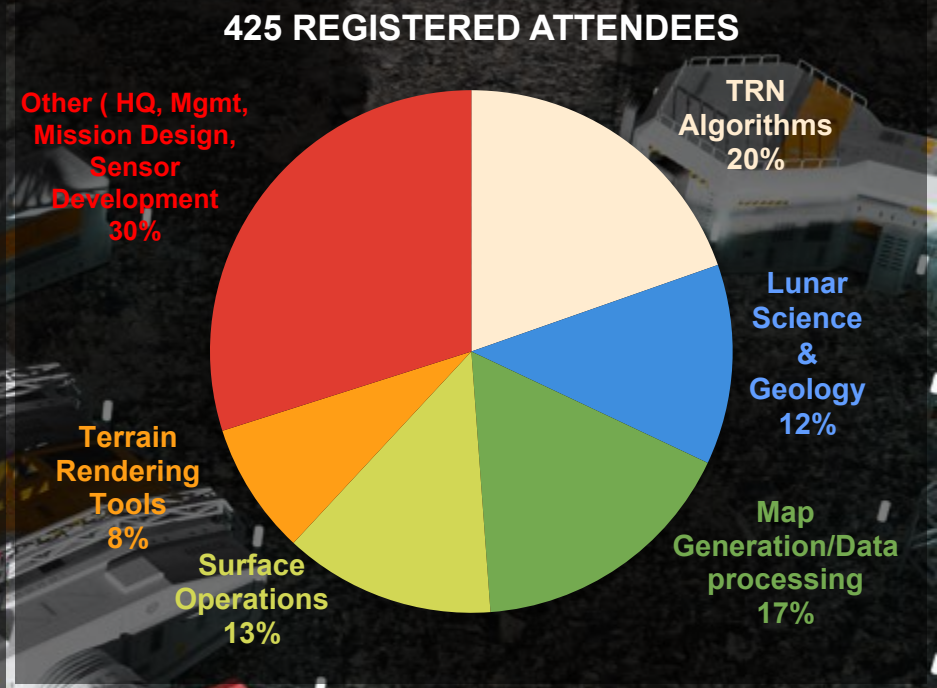
APL

LSIC | Workshop on Lunar Mapping for Precision Landing

Precision landing and hazard avoidance systems are necessary to enable access across the lunar surface. Communication between lunar data providers and data users is necessary and, to date, has been inefficient.

Workshop held March 2-4, 2021

425 attendees from over 138 institutions: 18% Academia, 34% Government, 34% Industry, and 12% Nonprofit



High priority challenges and needs identified:

- Terrain Relative Navigation (TRN) systems need lunar maps with unique characteristics.
- Industrial partners and navigation engineers are not fully utilizing existing lunar data.
- Standard data sets and controlled maps would be beneficial for testing algorithms.
- Current flight processor capability may be insufficient for advanced TRN algorithms and map processing.
- Targeted new missions and instrumentation would fill gaps in data needed for TRN systems.
- Standardized rendering tools, data verification and validations metrics, and metadata are desired.

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LSIC | Power Beaming for the Lunar Surface Workshop

This workshop, held July 22-23, 2021, was a response to an explicit request from the community during a regular monthly telecons. Every registration-suggested topic was covered over the 2-day, 10-hour workshop, which consisted of plenary talks, breakout sessions, networking, and panel discussion. Presenters included stakeholders from DoD, NASA, and industry partners and startups. Day one plenary talks provided succinct insight to beginners and on current SOA, while day two had deeper technical discussions.

- Webinar had 184 unique attendees, and a steady ~120-130 participants day 1, ~100 on day 2. 40+ participated through the breakouts both days, with strong conversation 1+ hour into networking session. Surveyed respondents self-reported:
  - Understanding (before → after) Mean 3.5 → 4.5 Median 3 → 5
  - Diversity: Mean 4.4, Median 4
  - Inclusion: Mean 4.5, Median 5

- **High priority challenges and needs identified:**
  - Power beaming is a plausible solution especially for PSR prospecting and exploration. Marginal cost of extending range is trivially small for laser PB. Could also be used to connect complementary regions.
  - Current PB hardware not space-qualified but could be rapidly advanced(e.g. upcoming SWELL demo on ISS)
  - Power Beaming Figure of Merit currently under consideration for Watts on the Moon is not ideal
  - PB offers different failure modes/complexity compared to cabled-power for exploration
  - Thermal management will complicate design of high-power systems, but waste heat may be beneficial

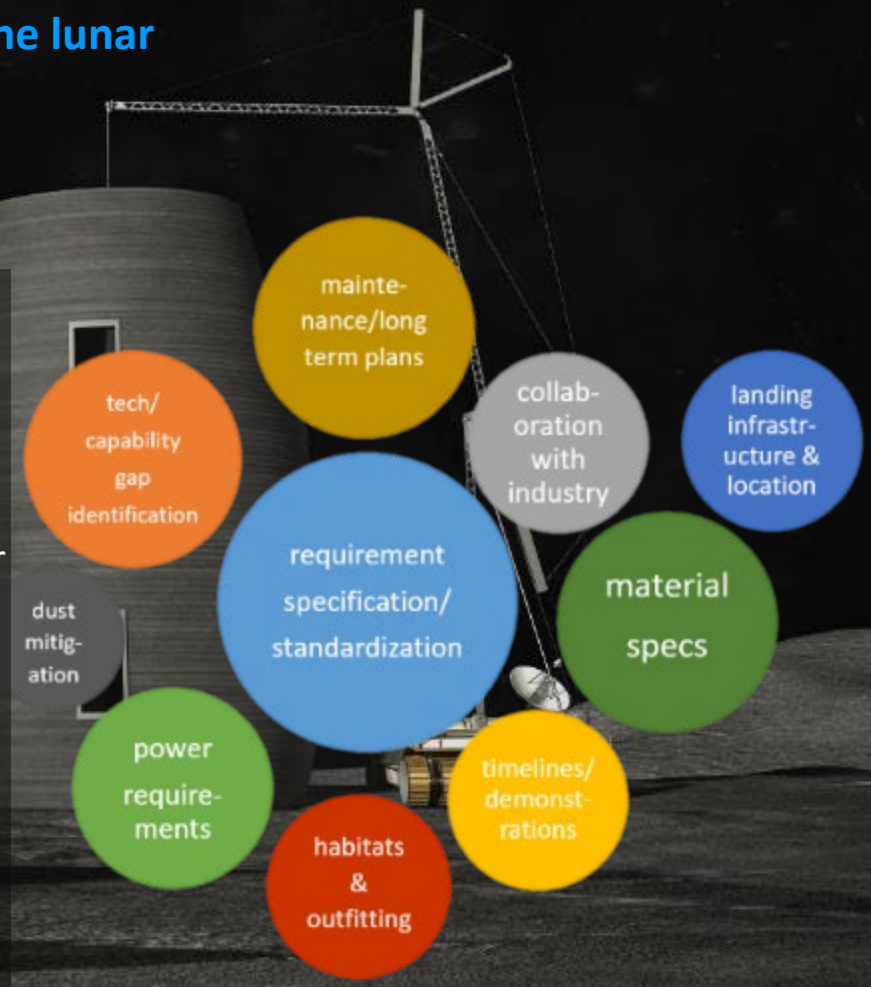
LSIC | Excavation and Construction Workshop

The Excavation & Construction Workshop focused on high-technology readiness level (TRL) excavation and construction tools and methods to support initial development of the lunar surface.

Over 130 attendees attended the workshop on August 20, 2021 with the following representation: 27% Academia, 31% Government, 29% Industry, and 12% Nonprofit.

Key Takeaways

- More guidance from NASA is needed on requirement specification/standardization, tech/capability gap identification, material specification, power requirements, and maintenance/long-term plans.
- More demonstrations on the lunar surface are needed, prominent among them concerning ground lunar survey composition measurements, underground exploration for habitats, laser power beaming demonstration and demonstration of repair bots.
- Technologies developed by the fast emerging Autonomous Construction industry are likely high-TRL technologies that NASA should leverage.
- Automation technologies in the mining industry have made rapid strides (out of necessity) and should be utilized. Some of the other high-TRL technologies available that the community feels can be used for early development work include tele-operation with 2 sec latency and autonomous object detection using AI.
- Details are needed on the timeline for basic infrastructure and the order of construction.
- Guidance on topics relevant to industry's involvement such as (administrative and logistical) mechanisms in place by which industry can get involved, how industry can attract investors and how much new spending is necessary from industry.



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Develop capabilities for sustainable exploration of Moon

LSII Collaboration Highlights

LSII has awarded ~$200M* through STMD Programs to establish collaborations across industry and academia.

Collaborations & Partnerships

Commercial Lunar Payload Services (CLPS) Technology Demonstrations (i.e. PRIME-1 mass spectrometer and drill, Nokia 4G Wireless and Intuitive Machines Deployable Hopper)

$127M – Tipping Points & Collaborative Opportunities (10 TPs & 5 ACOs selected in 2020)

$36M – SBIRs (Ph. I, II, III, CCRPP, Lunar Sequentials)

$14M – Space Technology Research Grants (6 LuSTR Opportunities, ECF, ESI)

$9.9M – NextSTEP BAA (9 ISRU awardees with multiple ground demos)

$3.5M – Vertical Solar Array Technology (VSAT) Solicitation (5 Phase I Awards)

$3M – NIACs (including first Phase 3 award for Exploration of Lunar Pits)

$2M – Breakthrough Innovative Game-changing (BIG) Challenge
2020 Permanently Shadowed Region – 8 teams; 2021 Dust – 7 teams

$1.4M – NASA Tournament Labs (GrabCAD, Yet2, HeroX) Open-source Challenges

$1M – Centennial Challenges ('Watts on the Moon' & 'Break the Ice' Challenges)

APL LSII Integration and Lunar Surface Innovation Consortium

*Since LSII was initiated in 2020

Technology Drives Exploration