# 2025 Lunar Development Conference

book of abstracts, 250716

# Program:

| Day 1 (Friday 18/7): Exploration | Day 2 (Saturday 19/7): Habitat and life | Day 3 (Sunday 20/7): Mining and |
|---|---|---|
| Ben Smith | Colin Lennox & Mikayla McCord | Peter J. Schubert |
| Briar Frisk | Frieda B Taub | Jim Sloan |
| Frank L'Italien | Ben Smith | Andrew Kuess |
| Gary Barnhard | David G. Schrunk | Margaret Boone Rappaport |
| H Niroumand & L Balachowski | Niklas Järvstråt | Victor O Tenorio et al. |
| Lars R Vadjina | Stuart Nelson | Madison C Feehan |
| Mettle Jones | Ulf E Andersson | Øystein R. Borgersen |
| Veronica Chariavelli | Adam Williams | Niklas Järvstråt |
| | Kimberly Binsted | |
| **Workshop** (Start ca UTC 18:00) | **Workshop** (Start ca UTC 18:30) | **Workshop** (Start ca UTC 18:00) |

| | Day 1 (Friday 18/7): Exploration and structure (Times and order may change) | | |
|---|---|---|---|
| Time | Presenter | Affiliation | Presentation title |
| **UTC 14:00** PDT 7am CEST 1600 | Ben Smith | **Moon Society** | Moon Society: At the Crossroads |
| | Briar Frisk | ArcologyX | Goal Seeking in Semiotic Systems: Value to Space Colonization |
| **UTC 15:00** PDT 8am CEST 1700 | Frank L'Italien | ArcologyX | The Arkseed Protocol & ARKxSTEPs Asset Inventory |
| | Gary Barnhard | XISP-Inc | Off-world Anthropological Space Infrastructure Setlement (OASIS) |
| **UTC 16:00** PDT 9am CEST 1800 | Hamed Niroumand & Lech Balachowski | Gdansk University of Technology | Advancing Lunar Exploration: Evaluating the Physical and Mechanical Properties of Lunar Soil in Moon Geotechnics and Space Geotechnics |
| | Lars R Vadjina | Future Dreams GMBh | The Lunar Testbed: Why the Moon Is Our Ethics Sandbox for Interplanetary Innovation |
| **UTC 17:00** PDT 10am CEST 1900 | Mettle Jones | SinguClarity and ArcologyX | Symbolic AI for ICE Environments: Psycho-ecological Resilience Tools for Lunar Habitat Health and Governance |
| | Veronica Chariavelli | MultiplanetaryX | MultiplanetaryX: Preparing Humans and AI for Lunar Leadership and Resilience |
| **UTC 18:00** PDT 11am CEST 2000 | Niklas Järvstråt & All present | **Workshop** | Exploration and structure |

| Day 2 (Saturday 19/7): Habitat and life support (Times and order may change) | | | |
|---|---|---|---|
| Time | Presenter | Affiliation | Presentation title |
| **UTC 14:00** PDT 7am CEST 1600 | Colin Lennox & Mikayla McCord | EcoIslands LLC and ArcologyX. | Wetlands in space! Self-organizing wetland bioreactors (sowbs) for biological lunar regolith processing and cycling. |
| | Frieda B Taub | School of Aquatic and Fishery Sciences, University of Washington | Overcoming the yuck factor of converting human wastes to human needs (O2 and food). |
| **UTC 15:00** PDT 8am CEST 1700 | Ben Smith | Moonbase Lappträsk | Bio-filtering of human-produced atmospheric volatile organic compounds |
| | David G. Schrunk | The Science of Laws Institute | The Planet Moon Project |
| **UTC 16:00** PDT 9am CEST 1800 | Niklas Järvstråt | Moonbase Lappträsk | Biosphere 1 evaluation |
| | Stuart Nelson | ArcologyX | Engineering the Shell of a Lunar Arcology: Regolith-Insulated Roof and Multi-Layer Transparent Perimeter System |
| **UTC 17:00** PDT 10am CEST 1900 | Ulf E Andersson | Swedish Space Society | More resources in a circular economy on the Moon – and on Earth |
| | Adam Williams | OAEC, The Off Earth Agriculture Company | Lunar Agriculture: Transformation of Lunar Regolith into Soils to enable space agriculture |
| **UTC 18:00** PDT 11am CEST 2000 | Kimberly Binsted | HI-SEAS | HI-SEAS: Rehearsing for Mars in Hawaii |
| **UTC 18:30** PDT 11.30am CEST 2030 | Ben Smith & All present | **Workshop** | Habitat and life support |

| Day 3 (Sunday 20/7): Mining and manufacture (Times and order may change) | | | |
|---|---|---|---|
| Time | Presenter | Affiliation | Presentation title |
| **UTC 14:00** PDT 7am CEST 1602 | Peter J. Schubert | Green Fortress Engineering, Inc. | Transmutation of lunar thorium for baseload power and nuclear rockets |
| | Jim Sloan | Information Universe | Lunar homesteading in the era of Helium3 mining |
| **UTC 15:00** PDT 8am CEST 1702 | Andrew Kuess | ArcologyX | The Allmatter Machine |
| | Margaret Boone Rappaport | The Human Sentience Project, LLC | Sociological Components of Engineering Solutions for Lunar Mining |
| **UTC 16:00** PDT 9am CEST 1802 | Victor O. Tenorio & Marc dos Santos et al. | School of Mining Engineering & Mineral Resources, University of Arizona Dos Santos International | Extraction of Icy Regolith from a Crater at the Permanently Shadowed Regions of the Lunar South Pole using a Sandwich Conveyor System |
| | Madison C Feehan | Space Copy | Extrusion on the Moon: Validation of Regolith-Based Fused Deposition Modelling in Low Gravity Environments |
| **UTC 17:00** PDT 10am CEST 1902 | Øystein R. Borgersen | Solsys Mining | Extraction Strategies: Space Resource Beneficiation and Lithologically Complex Simulants |
| | Niklas Järvstråt | **Moon Society** | Announcement and call for nominations: Moonward Prize |
| **UTC 18:00** PDT 11am CEST 2002 | Victor O. Tenorio & All present | **Workshop** | Mining and manufacture |

# Moon Society: At the Crossroads

Ben Smith - Moon Society (ben@moonsociety.org)/Moonbase Laptrask

## Summary

The Moon is receiving more attention now than in the decades following the Apollo program. Since 2022 there have been 21 missions to Luna, with another 8 planned into 2028. As a 25-year-old international organization focused solely on the Moon, The Moon Society is uniquely qualified to take a leadership role in Lunar settlement. However, we are not there yet.

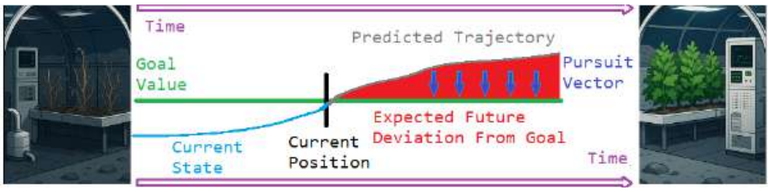
The Moon Society needs YOU if we are going to make this happen. We need our members to help us define what we want the Society to do and accomplish. We need leaders in key positions and running projects. We need doers to make those projects successful. We need advocates and ambassadors to excite people about Lunar settlement and how amazing the future could be. If you want Lunar settlement, then YOU need to help make it a reality.

# Goal-Seeking in Semiotic Systems: Value to Space Colonization

**Briar Fisk**
Arcology Solutions • briarfisk@gmail.com

**Intro:** Autonomous systems in space must be explainable, adaptive, and completely self-reliant. If pressure, a critical factor in CELSS, swings out of range, the crew needs to know why, not just see an abstract alarm. Root causes must be visible so they can be addressed on the spot. If a sensor goes down in the greenhouse the system needs to adapt in place, not freeze. At the bottom of a lunar crater there is no openai access, no phoning home, no lifeline.

**Semiotic Field Theory**: Semiotics is the study of meaning, signs, and symbols. The AI built on SFT remembers the patterns it sees, and can search those memories for similar ones. It builds memory from raw bits, layer by layer, into complete, interpretable patterns. Because memory is structured, it is traceable and human-auditable.




GaiaOS operates in six steps:
1. The current state is sensed (light-blue line).
2. Gaia projects a deterministic future trajectory (grey line).
3. Deviations from user-defined goals (green line) are quantified (red area).
4. The deviation field is inverted to form a pursuit vector (dark blue).
5. The vector, plus current and goal anchors, queries memory for traces whose symbolic deltas match the desired change.
6. Returned traces are filtered; valid traces are superimposed, control signals are extracted, yielding a corrective projection that is explainable, transparent, and entirely local.

**Value to Colonization:** GaiaOS delivers a public-domain, edge-friendly controller that:
- Runs on embedded hardware - no clouds, no network needed
- Explains every inference, decision, and action in symbolic form
- GaiaOS can reconfigure around missing data by reasoning over symbolic memory traces, making it fault-tolerant by design.

Conclusion:
By combining SFT with goal-seeking inference, GaiaOS offers lunar habitats an auditable autopilot for life-support, power, and thermal loops.

**Briar Fisk** is an independent researcher with ArcologySolutions.com, and SinguClarity.org, focusing on semiotic AI for autonomous systems in harsh and resource-constrained environments.
Contact: briarfisk@gmail.com

# THE ARKSEED PROTOCOL & ARKxSTEPs ASSET INVENTORY

## THE ARKSEED PROTOCOL

Plugging, coating and pressurizing a lunar lava tube would create a settlement on the moon with minimal launch mass. In situ resource utilization and modular systems can allow humanity's expansion into AI-managed biomes of vast proportions beneath the lunar surface. This could be achieved with existing technologies, mainly hardening polymers, large inflatable modules and robotic labor. Our work suggests a scalable pathway toward permanent, economically viable lunar settlements — and perhaps the first true cities beyond Earth.

*Image 1: Deployed Arkseed Module*

## THE ARKSTEP ASSET INVENTORY

ARKxSTEPs is one of the key Arcology Solutions technologies and turns any surface into farmland using available 3D printers. Modular, scalable, and endlessly adaptable, it transforms empty space, walls and ceilings, into living, growing ecosystems.

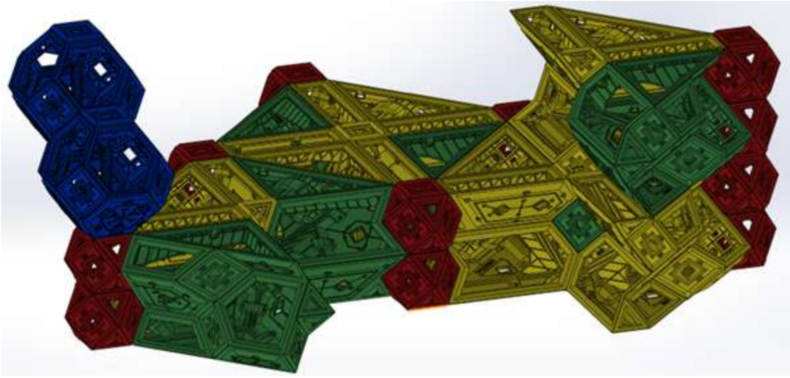


*Image 2: ARKxSTEPs Mesh*

Frank L'Italien is the chief designer of Pure Nature Agro Solutions, developing AI-driven farming embodiments meant to eliminate soil compaction as well as grassroots tools for combating desertification. In his free time he likes to explore the interface between culture and technology, empowering 3D printer owners across the globe so humanity can reach it's full potential as steward of the biosphere.

**Sustainable Lunar Settlement Design Charrette:**
**Off-world Anthropological Space Infrastructure Settlement (OASIS)**
**Lunar Development Conference Abstract**

**Gary P. Barnhard ● gary.barnhard@xisp-inc.com ● +1 301 229 8012**

The Off-world Anthropologic Space Infrastructure Settlement (OASIS) project is a Kepler Space University (KSU) initiative to develop a prototype simulation analog for a sustainable lunar settlement buildable within a ten-year time horizon. The OASIS project began as an ideation exercise to ask and begin to answer fundamental questions concerning how science, systems engineering, and architectural design would drive a program where the desired outcome is a sustainable, scalable lunar settlement where the inhabitants would thrive, not just survive, thereby maximizing the probability of mission success.

The OASIS postulate is that the signatories to the Artemis Accords achieve a confluence of interest whereby:

(1) Developing sustainable offworld human settlements is deemed a priority outcome.

(2) The endeavor to accomplish the same is best served by fostering cooperation, collaboration, and competition.

(3) Our evolving understanding of science, systems engineering, and architectural design fosters our ability to survive and thrive as a species.

(4) We must translate all we learn into being the best stewards of our Earth and life as we know it.

The OASIS Project consists of three phases:

- Phase 0 -- OASIS Earth and flight analog testing for required elements & distributed systems
- Phase 1 -- OASIS in-situ checkout and evaluation of required elements & distributed systems
- Phase 2 -- OASIS Main Buildout & Operations

The process of suspending disbelief, learning how to build the future, and the relevance of different perspectives are integral to the design process. The definition and flow down of the Program and Systems level requirements to the elements and distributed systems must be accomplished. The overall management of the program's cost, schedule, technical risk, and the orchestration of all available program resources to maximize the probability of mission success (a.k.a., “herding” cats) are critical workflow considerations. Interface accommodation requirements, as well as interface standards, must be defined, tested, and applied as an integral part of the design, build, and test processes to ensure the integrated system can function properly (i.e., in a manner that meets or exceeds the requirements in terms of performance, availability, and safety/security). The resulting flow down and definition of verifiable functional requirements into the elements and distributed systems and the flow up of the evaluated efficacy of their implementation by testing, verification, and validation are part of orchestrating the systems engineering processes. This paper provides a top-down introduction and overview of the OASIS project.

**(396 Words)**

# ADVANCING LUNAR EXPLORATION: EVALUATING THE PHYSICAL AND MECHANICAL PROPERTIES OF LUNAR SOIL IN MOON GEOTECHNICS (MoG) AND SPACE GEOTECHNICS (SpG)

**Hamed Niroumand**[1], Lech Balachowski [2]

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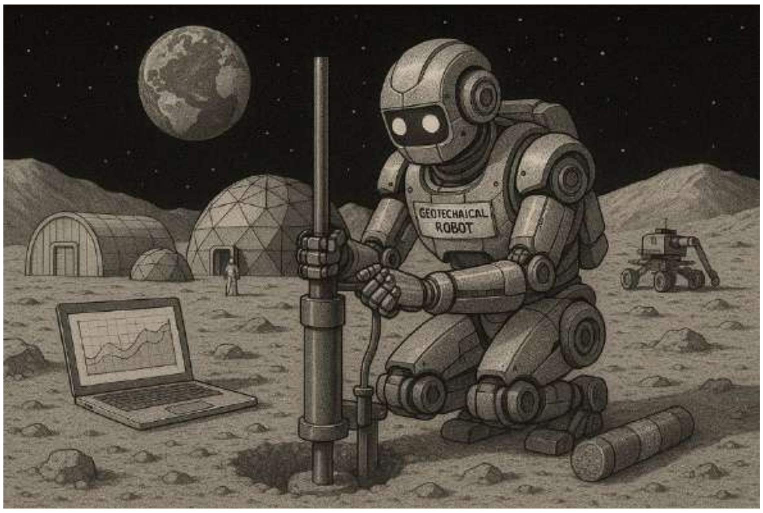
[2]Professor, Department of Geotechnical and Hydraulic Engineering, Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Gdańsk, Poland



Studying lunar soil, or bedrock, is fundamental to advancing lunar exploration, especially with the increasing interest in establishing a long-term human presence on the moon. Lunar rock has unique physical and mechanical properties due to the Moon's low gravity, lack of atmosphere, and constant exposure to solar and cosmic radiation. These characteristics affect every aspect of lunar missions, from the design of landers and rovers to the feasibility of constructing lunar habitats and using in situ resources. This review combines existing knowledge of the physical and mechanical properties of lunar soil with a focus on recent findings from missions such as Apollo and Change, as well as the development of high-fidelity lunar simulators like JSC-1A and LHS-1. As lunar missions continue to evolve, understanding these properties will become more critical for advanced exploration and exploitation of in situ resources. Whether extracting oxygen and metals or building habitats from rock-based materials, the ability to effectively work with lunar soil will determine the success of long-term lunar settlements. Therefore, in this paper, the physical and mechanical properties of lunar soils and related simulants are evaluated as a short evaluation in geotechnical engineering, and the moon is considered as Moon Geotechnics (MoG), a type of Space Geotechnics (SpG).

Dr. Hamed Niroumand is a faculty member and associate professor in geotechnical engineering at Gdansk University of Technology. He is 40 years old and has been working in his field since 2008. He has published various books, journal and conference papers, and patents. His research topics include foundations, space geotechnics (Moon and Mars geotechnics), simulants, 3D printing houses, earth anchors, and nanotechnology.

# The Lunar Testbed: Why the Moon Is Our Ethics Sandbox for Interplanetary Innovation

by Lars R. "Jones" Vadjina, FUTURE DREAMS GmbH, Email: vadjina@future-dreams.com

As humanity moves closer to a sustained presence on the Moon, the conversation tends to focus on propulsion systems, regolith utilization, and surface infrastructure. These are essential but incomplete. What we build off-Earth will not only be a reflection of our technological capabilities, but also of our cultural assumptions, our ethical blind spots, and the way we imagine human life in extreme and unfamiliar environments.

This presentation proposes a provocative reframing of lunar development: The Moon as a systems-level sandbox, not just for engineering and logistics, but for prototyping interplanetary ethics, governance models, and co-living strategies before we replicate flawed systems off-world. In other words: if we get it wrong on the Moon, we may get it catastrophically wrong on Mars.

This talk builds on principles of strategic foresight, human-machine interaction, and ethics in emerging technologies, with a focus on why lunar habitats offer a controlled, low-latency environment to simulate and stress-test socio-technical systems before they become embedded in longer-range missions.

Key questions we will explore:

- How do we design adaptive, inclusive, and non-authoritarian governance models in small lunar settlements?
- How can the Moon help us model AI-assisted decision-making, without undermining human agency and dignity?
- What values do we encode into infrastructure, from airlocks to algorithms?
- Can we use the Moon to rehearse planetary-scale cooperation in an age of fractured geopolitics?

The argument is simple, yet urgent: The Moon is not just a technical destination, it's a mirror. It will reflect back to us the kind of civilization we're exporting into space.

This presentation also introduces the concept of "ethical prototyping" where systems are evaluated not just for efficiency or performance, but for their capacity to preserve adaptability, fairness, and long-term resilience in high-stakes, low-error environments.

Crucially, the Moon gives us a second chance: to slow down, design intentionally, and ensure our extraplanetary future doesn't repeat the hierarchical, extractive, and short-termist paradigms of our Earthbound past. This isn't about some kind of utopia but rather about survivability.

What's at stake is not just lunar success, but the blueprint for interplanetary civilization.

This presentation is grounded in interdisciplinary research and innovation strategy, informed by a background in AI & ethics, foresight frameworks, and space innovation ecosystems. It is designed to speak to engineers, policymakers, technologists, and anyone invested in building a future we won't regret.

Let's treat the Moon not only as a launchpad but as a lesson.

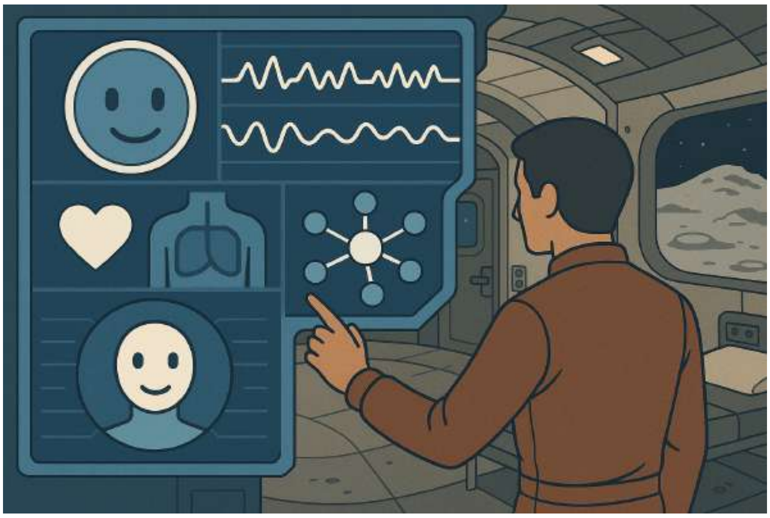
## Short Bio

Lars R. "Jones" Vadjina is a certified innovation manager and interdisciplinary strategist with a background in American Studies (BA), business administration (MBA), advanced coursework in computer science and applied ethics. His work sits at the intersection of space technology, artificial intelligence, and long-range foresight, with a particular focus on how ethical innovation frameworks can shape sustainable multiplanetary futures. Lars has presented at international conferences in 2025 including *Spacecom* and *Digital Dilemmas*, and his current projects explore the cultural, political, and ethical architectures of off-world development. With experience in both consulting and think tank environments, he brings a unique, human-centered lens to complex technological frontiers, asking not only how we build in space, but why, and for whom.

**Symbolic AI for ICE Environments:**

Psycho-ecological Resilience Tools for Lunar Habitat Health and Governance

Mettle Jones, SinguClarity



The psychological and interpersonal dynamics of Isolated, Confined, and Extreme (ICE) environments are an increasingly critical infrastructure in long-term habitation. The Anatta Engine introduces a novel symbolically grounded AI system engineered to support emotional regulation, cognitive metabolism, and interpersonal coherence within closed ecosystems such as lunar habitats. Rather than modeling AI as a replacement for human cognition, the Anatta Engine offers an integrative scaffold - capable of metabolizing cognitive dissonance, surfacing psychoemotional waste, and supporting individual and collective resilience. This paper situates the Anatta Engine within the ICE framework, proposing a new paradigm of psycho-ecological AI infrastructure tuned to the unique constraints of lunar environments.

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Mettle Jones, lead architect of SinguClarity AI, is a symbolic systems theorist and architect focused on behavioral forensics, symbolic modeling, and phase-state dynamics. Their work bridges cognitive science, nonlinear systems theory, and symbolic AI to build diagnostic and adaptive tools for extreme environments. They are the originator of the Anatta Engine—a layered predictive companion AI —and a contributor to decentralized resilience frameworks.

They are a co-founder of GobTek, an interactive art-tech group exploring decentralized resilience and infrastructure through experimental festivals and field prototypes. They are also a core contributor to Arcology Solutions, a decentralized collective advancing scalable living systems and mutual-aid architecture. Their research is self-directed and interdisciplinary, combining insights from biology, thermodynamics, and behavioral systems.

**MultiplanetaryX: Preparing Humans and AI for Lunar Leadership and Resilience**

**Author**: Veronica Chiaravalli
**CEO, Emerging Technologies Sweden | Space Innovator | Analog Astronaut-in-Training**
**LinkedIn**: veronica-chiaravalli-1861831b

As humanity moves toward sustained lunar presence, engineering and infrastructure often take center stage—yet psychological readiness, human-AI collaboration, and emotional resilience remain critical and underexplored.

**MultiplanetaryX** addresses these gaps by combining AI-driven support, immersive training environments, and space psychology into an innovative preparation framework. At its core is **MELP** (Multiplanetary Entrepreneurship & Leadership Program), which equips analog astronauts and space professionals with tools to lead under stress, manage emotional strain, and collaborate effectively with sentient AIs and responsive robotics.

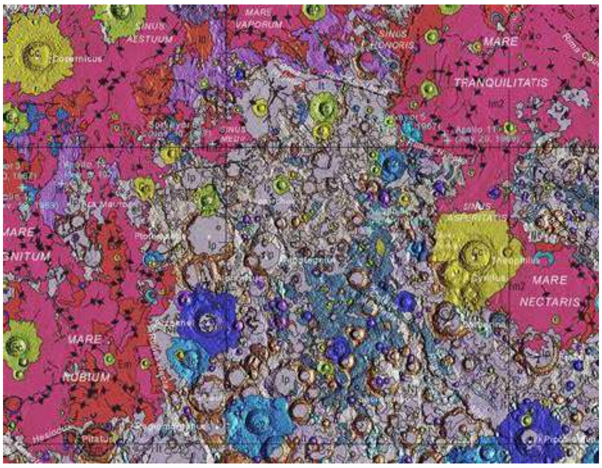
Trainees engage with AI entities like *Aurion* (a strategic humanoid assistant) and *Laika* (a robotic dog supporting emotional well-being), while operating in virtual lunar habitats and simulation-based decision loops. MELP blends storytelling, emotional resilience training, and scenario-based learning to replicate the pressure and isolation of lunar missions.

This approach not only enhances preparedness but also promotes ethical AI integration, self-awareness, and adaptive leadership—vital for long-term mission success.

# Day 1 Workshop:
# Lunar Exploration for Development

Moderator: Niklas Järvstråt, Moon Society (niklas@moonsociety.org)

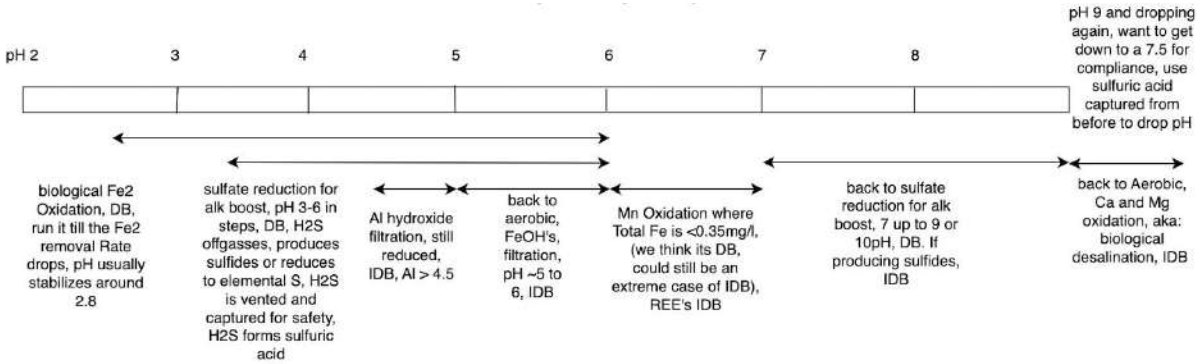
Join our workshop and help us brainstorm what we need to find out about the moon to survive there. Everyone is invited to contribute and there are no bad ideas (although some may not make the final cut). The goal is to create an exhaustive list that researchers can use to plan their next project and to help identify knowledge gaps. All participants will be acknowledged in the paper (if desired).



# Wetlands in space!

**Self-organizing wetland bioreactors (sowbs) for biological lunar regolith processing and cycling.**

Colin Lennox, *EcoIslands, Altoona, PA,* colin@ecoislandsllc.com
Mikayla McCord, ArcologyX, mikaylamccord16@gmail.com




Self-organizing wetland bioreactors (SOWBS) provide a designer of mine influenced water (MIW) treatment systems with a tool to harness ubiquitous microbiological processes in methodical and novel layouts for a variety of MIW load reclamation and beneficiation. SOWBs efficacy comes from the ability to grow and maintain very high masses of attached biofilms that are self selecting dependent on the MIW load entering any portion of a SOWB treatment system. As the MIW load is sequestered or remediated, the net water biochemistry changes, developing new and ever changing selective pressures on the predominant, but ever shifting, biofilm metabolisms found throughout the treatment train. Depending on the MIW's load, influences such as iron, aluminum and manganese are either directly or indirectly remediated by the self organized biofilms. Direct bioremediation (DBR) is when a microbe uses the influence in its metabolic triplet to respire, grow and reproduce. Indirect bioremediation, or IBR, are processes such as biofilms "stickiness" and the tendency to colonize and coat all surfaces in the SOWB, including precipitating matter, that leads to capture and sequestration in the SOWB of influences that are not part of a metabolic triplet. This paper provides designers with a rudimentary framework to apply self organization by elucidating mine influence specific DBR and IBR. This knowledge can be applied to other waste streams beyond mining. The experiences herein are not learned through classical experimental design using controls and variables, but on iterative trial and error, so this study is, by definition, long and involved.

Mikayla McCord, ArcologyX
Altoona, PA
mikaylamccord16@gmail.com
Mikayla is a recent graduate of Johns Hopkins University with a Masters in BioTech and has several years of microbiology laboratory experience.

Colin Lennox, CEO and PI of EcoIslands
Altoona, PA
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Colin has been building and investigating self-organization in open and semi-enclosed ecological systems for 15 years.

# Overcoming the yuck factor of converting human wastes to human needs ($O_2$ and food).

**Frieda B. Taub**

School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington 98195, USA

taub@uw.edu

The potential use of urine, feces, sweat, wash water, and other waste products has been slower to develop than techniques for converting $CO_2$ to $O_2$ and for storing and producing food. An effective method of recycling must be developed if the Lunar Surface is not to become an enclosed human habitation, with an ever-increasing waste storage facility, and perpetually resupplied with the chemical elements sequestered in the waste. Odor, recalcitrant organics, potential need for anaerobic processes, color, and our training are among the challenges of dealing with human Sh....

Effective conversion of human wastes could be the greatest gift of the space program to Earth. Currently, cities process human waste minimally, aiming to reduce $O_2$ demand, convert $NH3$ to $NO3^-$, and achieve some limited recovery of P. Treated sewage is then released into the nearest aquatic environment, such as a lake, river, or ocean. As a result of the aquatic enrichment of N and P, algal blooms, some toxic, have become common. We still treat waterborne wastes as if "Dilution is the Solution to Pollution." Solid waste is buried in landfills, covered with soil to reduce odors, flies, and birds. Rural areas have even less waste processing or recovery.

My "retirement project" has been the study of small (250 ml to 1 liter) liquid and gaseous "Closed Ecological Systems" consisting of photosynthesis (3 species of green algae), grazing (*Daphnia magna*), and recyclers (undefined) microbes. Surprises included (1) very high atmospheric pressures, (2) very alkaline conditions (pH > 11), and (3) high O2 levels, which could occur because these systems are closed off from Earth's atmosphere. Although the algal-grazer systems seemed to achieve a "steady state" for weeks, they eventually diminished. We presume that essential elements become unavailable because of the accumulation of recalcitrant organic compounds. Inadequate nutrient recycling becomes the limiting factor in sustaining a healthy aquatic community. This seems to be the fate of most ecological systems if resupply is limited.

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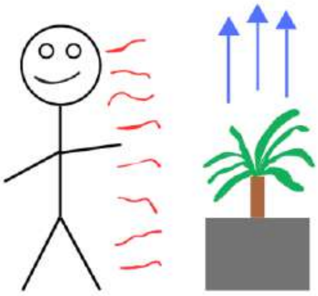
Frieda B. Taub is an Emerita (theoretically retired) Professor, having earned her PhD in 1959 by studying the ecology of salamanders in a forest, for which most processes were too complex to estimate.

"Closed Ecological Systems" seemed to offer fewer unknowns than complex natural ecosystems. In 1959, she joined a modest project funded by the Boeing Aircraft Company to study the use of freeze-dried human fecal material as food for fish (Tilapia) at the University of Washington. The fish eagerly ate the flakes of human feces, which appeared very similar to aquarium fish flakes, although they were nutritionally inadequate. This research was discontinued in 1961, when it became apparent that long-term life support systems were decades away, but the future is now.

# Bio-filtering of human-produced atmospheric volatile organic compounds

Ben Smith - Moon Society (ben@moonsociety.org)/ISRUtech

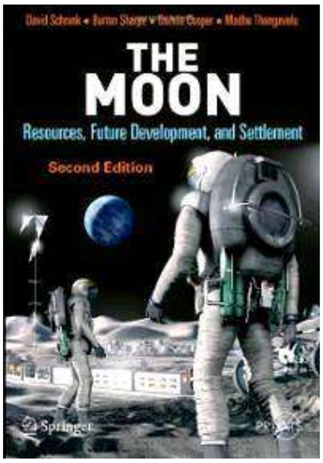


Every human produces hundreds, possibly thousands, of atmospheric volatile organic compounds (VOCs) every day. These VOCs include toluene, benzene, methanol, styrene, and acetone. Some of these are exhaled into the surrounding atmosphere. Others are volatilized from skin secretions. While human-produced VOCs are present in very low concentrations (parts per billion), they represent a hazard in sealed environments if allowed to accumulate. This presentation will briefly cover the problem of human-produced VOCs, how they are currently dealt with, why plants are a better long-term solution, and what research still needs to be done.

Ben Smith is an independent Lunar settlement researcher. He is the founder of Lunar Homestead (currently on a pause) and former Moon Society Treasurer, Membership Coordinator, and leader. Ben is also a working partner with ISRUtech. Ben will be on a 100-day road trip up the Pacific Coast Highway (west coast of the United States) during LDC 2025; having an adventure and figuring out the nomadic lifestyle

# THE PLANET MOON PROJECT

David G. Schrunk, Science of Laws Institute



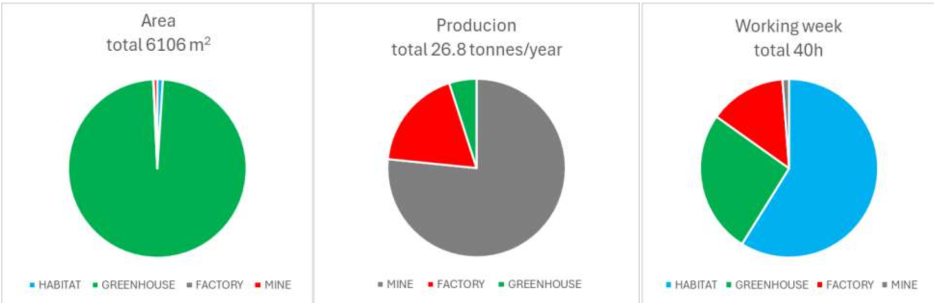

Humankind now has the motivation, tools, and resources required to establish permanent settlements on the Moon. This presentation discusses the “Planet Moon Project,” an international plan to exploit the significant advantages of ancient lava tubes as sites for the development of large-scale human settlements in this century. In the coming decade, lava tubes will be explored robotically, and a suitable site will be selected and prepared for human habitation. After initial automated missions have delivered essential materials and equipment to the lava tube site, human crews will arrive to oversee further development, and permanent human presence will then be realized. With the use of robotics and resource utilization, human presence on the Moon will be expanded to include multiple lava tubes, and a rail system will connect mid latitude locations with the polar regions. The functioning “Planet Moon” will then gain access to the unlimited resources of Space, permanent bases will be established on Mars, and large-scale scientific, exploration and development projects will be conducted throughout the solar system.

David G. Schrunk is an aerospace engineer, medical doctor, and coauthor of the book, The Moon: Resources, Future Development, and Settlement. The “Moonbook” describes the steps that can be taken to transform the Moon into an inhabited sister planet of the Earth by the end of the 21st century, and thus improve the material wellbeing of humankind. Over the course of his career, Dr Schrunk has authored multiple articles on space development in the scientific, legal, and aerospace literature. Dr. Schrunk has written many articles in the scientific and legal literature dealing with humankind's evolution as a space faring civilization.

# Survival on the moon – is it even possible?

Niklas Järvstråt, ISRUtech Sweden AB

**What do ALL OF US do to keep YOU alive?** To answer that, we mapped 42 materials through the complete Earth economy using a four-process framework, then divided by 8 billion people. Humanity on Earth is self-sufficient but only through an intricate world-spanning web of interacting processes. We simplified to the four categories MINE (making resources available for use), FACTORY (making stuff), GREENHOUSE (growing things and cleaning air and water) and HABITAT (daily living and people stuff).




We found that agriculture use 98% of all land: 6,000 $m^2$ per person. Mining moves most resources, mainly into factories which refines those into useful things. If you are one of the working people, from a 40-hour week, you would spend 24h helping people live their lives, 10h growing stuff, 6h making stuff and less than 30 min in the mine. If you live in a developed country, you use even less time growing and making things as effectively all the average high-wage persons work goes into making lives easier.

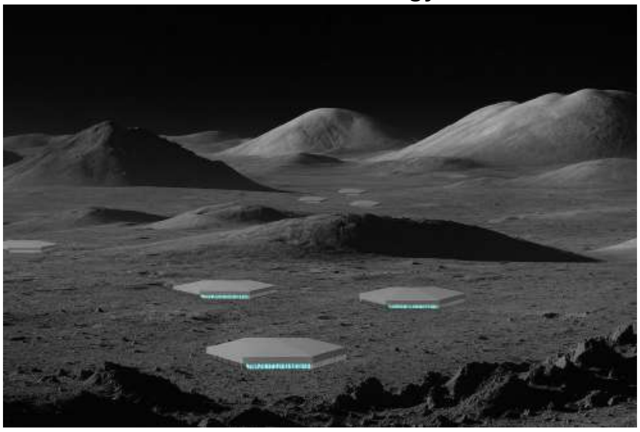
The real system constraints when considering scaling the global production network down to settlement level are complexity, knowledge maintenance across multiple domains, and operational resilience. However, accounting for coordination advantages over global trade chains, the scaling challenge becomes making conscious choices to trade some scale advantages for flexibility while maintaining essential capabilities. Fundamentally, small-scale self-sufficiency requires deliberate effort and planning rather than simply scaling down Earth's specialized systems. The question shifts from "is it possible?" to "are we willing to make the effort and accept the trade-offs?"

Niklas Järvstråt is a materials scientist and rocket engineer specialising in high-temperature materials behaviour, with experience in superalloys, steel and aluminium alloys, and wind turbine composites. As founder of ISRUtech Limited and director of the Moonbase Lappträsk Analogue facility, a first systematic approach to using proven Earth technologies to create small scale self-sufficiency at a small-town scale specifically aiming for permanent Lunar settlements.

# Engineering the Shell of a Lunar Arcology:

## Regolith-Insulated Roof and Multi-Layer Transparent Perimeter System

Stuart Nelson, Arcology Solutions



stuart.nelson@arcologyx.space

This presentation proposes a lunar adaptation of the innovative shell structure originally designed for Martian arcologies: a pressurized membrane roof covered with regolith, anchored at the perimeter and paired with transparent multi-layer Mylar windows. This approach offers an elegant solution to radiation shielding, micro-meteoroid protection, and breach robustness—if a leak occurs, the regolith mass continues to maintain air pressure as it gradually settles toward the floor.

The proposed lunar shell leverages internal air pressure to support a thick regolith blanket, providing robust shielding from cosmic radiation and meteorites without the need for heavy structural support. The structure avoids the need for underground habitation and enables psychologically beneficial "outdoor" living within a sealed volume. Transparent perimeter walls composed of layered Mylar allow for a view of the lunar landscape while minimizing radiation exposure and pressure loss risk.

This presentation will include plots and calculations correlating regolith thickness to internal air pressure under lunar gravity, and assess the relationship between Mylar layering and atmospheric retention. We will examine the engineering implications, performance in failure scenarios, and the overall livability and resilience of such arcologies.

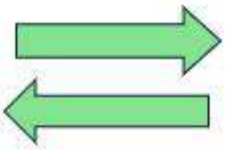
By combining accessible construction techniques with abundant lunar materials and simple physics, this system demonstrates a scalable, repairable, and livable shell for future lunar communities. The approach supports the long-term vision of thriving, self-sufficient arcologies on the Moon—without requiring people to live underground.

**Stuart Nelson** is a designer and systems thinker focused on sustainable infrastructure and habitat design for extreme environments. His work combines structural geometry, local manufacturing, and adaptive reuse to develop low-mass, reconfigurable building frameworks suitable for martian, lunar and terrestrial applications. Stuart integrates architectural innovation with ecological and industrial strategies to support long-term human presence beyond Earth.

# More resources in a circular economy on the Moon – and on Earth

*Ulf E Andersson, Swedish Space Society*

What types of technologies and smart systems do we need to have a permanent human presence on the Moon? For providing those working and living there with food, water, air and greenery? That answer is very similar to the tech and systems we need to have for creating sustainable cities on Earth, based on a circular economy and resource abundance. Those who work for the circular economy and sustainability on this planet can learn a lot from those who work for crewed bases and future settlements on the Moon. But the space sector should learn much more from the vastly larger number of people working for sustainable circular solutions for more food, water and other resources on Earth – solutions that might be applied for the benefit of the humans that soon will work and live on the Moon.



Ulf E Andersson is Vice President of the national NGO Swedish Space Society (Swedish: Svenska Rymdsällskapet) – working to promote the space sector and space settlement. We arrange seminars, technical visits, publish a newsletter, and publish opinion materials in newspapers and in social media. http://www.svenskarymdsallskapet.org/.

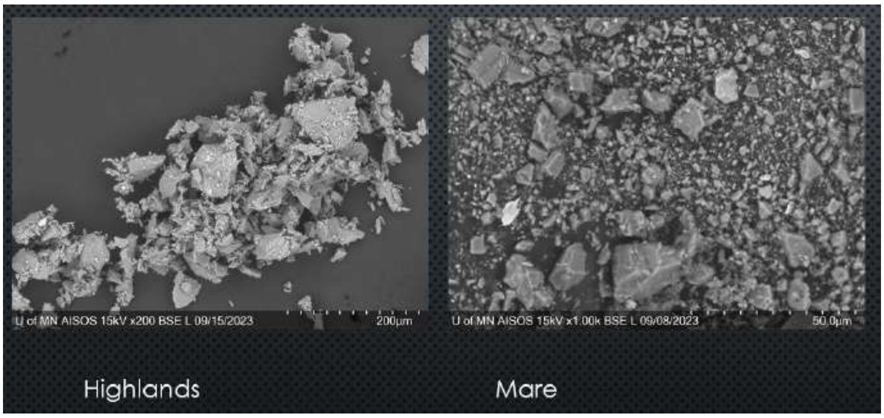
He is also CEO of the consultancy Swedish Future Scanning (Swedish: Svensk Framtidsbevakning) – focusing on urban food production, wastewater recycling and urban greenery. We are scanning the world for good tech, biological solutions and smart systems in these areas. Personal mail ulferikanderssson@gmail.com

# Lunar Agriculture:

## Transformation of Lunar Regolith into Soils to enable space agriculture

Adam Williams, University of Minnesota, adam@oeac.space

Astropedology and Astro-Agriculture: Transforming Lunar Regolith Simulant by Accelerating Mineral Weathering to Create Soils to Support Off-Earth Agriculture. This presentation will explore the current state of the Lunar Regolith transformation research, explore upcoming projects, and present new findings since the LDC 2024 presentation. Topics covered will include key factors for lunar regolith and agriculture. Transformation strategies. Test Results including Soil, Carbon, Nitrogen, pH. It will also explore pioneer plant species and promising results.




Adam Williams is a PhD Candidate and professional engineer. 15+ years' experience as an engineer specializing in test and product development. Adam's PhD research is focused on Lunar Agriculture, In addition to that Adam has: Bachelors in Economics and Philosophy, Masters in Software Engineering, Masters in Bioinformatics (agriculture robotics focused), Grad Certificate in Space Resources from Colorado School of Mines, and a Masters in Space Resources from Colorado School of Mines (focus on lunar geology and agriculture)

Adam also is an active volunteer including community service organizations as well as serving as a Space Ambassador for the National Space Society.

# HI-SEAS: Rehearsing for Mars in Hawaii

Kimberly Binsted, HI-SEAS

**HI-SEAS (Hawai'i Space Exploration Analog and Simulation)** is a habitat on an isolated Mars-like site on the Mauna Loa side of the saddle area on the Island of Hawaii at approximately 8200 feet above sea level. At HI-SEAS, we conduct NASA-funded research with the goal of reducing or removing some of the barriers to human space exploration.

Our specialty at HI-SEAS is conduction long-duration simulated missions. We have conducted two four-month missions, two eight-month missions, and one twelve-month mission. A journey to Mars and back would take 2.5-3 years, so we need to understand and address the issues that can arise when humans spend long periods in space.

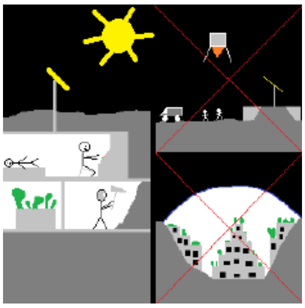
Like Olympus Mons on Mars, Mauna Loa is a shield volcano, and the two mountains share many geological features, such as lava tubes and flows. The site has a cool dry climate that varies very little over the year, enabling long-duration missions. Also, it is visually isolated, with no visible plants, animal life, or human activity in the area.

Our crew members are very astronaut-like, in their education, professional background, and psychology. They have to be mentally and physically tough. Resources are limited: for example, each crew member gets only eight minutes of shower time per week, and there is no fresh food (all food items must be shelf-stable). Like it would be on a Mars mission, communication is high latency, taking twenty minutes each way. Space is also limited, with only about 1000 square feet between six people. EVAs are in simulated space suits, on a pre-approved sortie plan.

We are currently planning upgrades to the HI-SEAS facility so that it can support a wider range of mission simulations under a variety of conditions: different crew sizes, different habitable volumes, and so on. In this talk, I will describe these planned modifications and solicit feedback.

# Day 2 Workshop:
# Lunar Underground Habitat Parameters

Moderator: Ben Smith, Moon Society (ben@moonsociety.org)

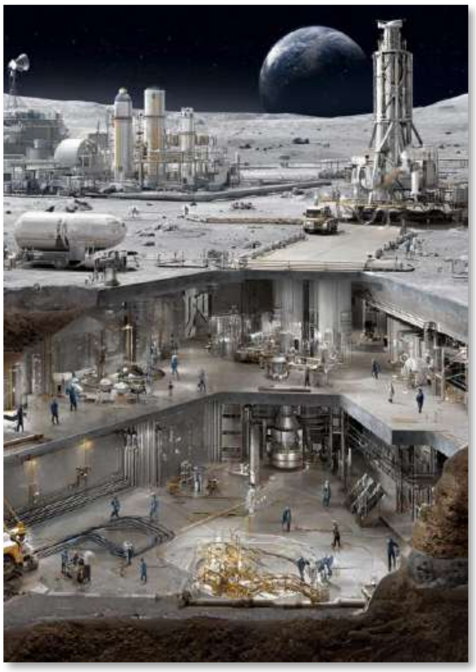


Join our workshop and help us brainstorm as many parameters (measurable factors that define a system or sets the conditions of its operation) as possible for the design of habitats used in a permanent underground settlement on the Moon. Everyone is invited to contribute and there are no bad ideas (although some may not make the final cut). The goal is to create an exhaustive list that researchers can use to plan their next project and to help identify knowledge gaps. All participants will be acknowledged in the paper (if desired).

## Transmutation of Lunar Thorium for Baseload Power and Nuclear Rockets

**Peter J. Schubert**, Ph.D., P.Eng, Prof. Emeritus
Green Fortress Engineering, Inc.
Carmel, Indiana, USA

Lunar scientists, engineers, and settlers crave the ample baseload power offered by nuclear reactors. However, the Outer Space Treaty (OST) discourages launch of fissile material due to the non-zero risk of rocket failure and contamination of our shared biosphere. The answer is obvious: produce nuclear fuel on the Moon. Uranium is scarce and very difficult to enrich. A superior solution is to beneficiate thorium and transmute it into U-233. Two methods for fabrication of fuel pins are presented here, including techno-economic analysis of a first mission. The brute-force methods of the first mission can produce a 2 MWe reactor that can then power a more refined process as a second phase. This work summarizes a corpus of research studies conducted into mining and manufacturing methods developed over the last six years. A third phase of advancement will result in the synthesis of fuel rods that can be inserted into a nuclear thermal rocket (NTR) at a depot in translunar space. The NTR will have been brought up from Earth without any radioactive fuel, thereby complying with the OST. Once fueled and initiated (using the same method as transmutation), NTRs can rapidly deploy to points across the Solar System. Two NTR reference missions are outlined: one being to retrieve platinum group metals from an M-class Main Belt asteroid to pay for the entire development program; and the other to retrieve volatiles and carbon from a C-class asteroid for delivery to the lunar surface. With these resources, a thriving community of souls can live a comfortable existence in the pleasant one-sixth gravity of the Moon.



**Bio-sketch**

Peter Schubert is an emeritus professor, a technical fellow, and a licensed professional engineer with over 50 patents and more than 130 technical publications. One such publication is a textbook titled Space Systems Architecture for Resource Utiliization. Dr. Schubert has managed multiple NASA awards, including an experiment that he flew in the “Vomit Comet” performing lunar gravity (g/6) parabolas. Peter founded a chapter of the Students for the Exploration of Space (SEDS) on his campus, and was the faculty advisor for 12 years.

# Lunar Homesteading in the Era of Helium 3 Mining

*James H. Sloan, Information Universe, Jsloan12@Earthlink.net*

In the 1950s without any hard data we speculated that the Moon was chemically similar to our Earth, that we would find abundant water in the form of buried ice or trapped in mineral formations. In the 1970s we had the Apollo samples through which we shifted to a dry Moon hypothesis. In the late 1980s there was a push to return to the Moon and move on to Mars. This lead to papers arguing that while water was scarce on the Moon that it was not non-existent. These papers outlined how we could mine low levels of volatiles to meet our life support needs. This in turn lead to discussions of the mining of Helium 3.

This paper explores the impact of Helium 3 mining on the supply of elements needed for life support. We can think of these elements as a proven resource based on the Apollo samples while the ice at the Lunar Poles is still an unknown as to what volatiles it contains and in what quantities. The paper addresses the amount of Helium 3 that we will need and the impact this will have on the Moon. The paper will end with issues and solutions in Helium 3 mining.

In 1964 as a ten year old, James H, Sloan looked at the space activity around him and decided that he would join the settlers of the Moon when he reached adulthood. To this aim he received a Batchelor's degree in electrical engineering and joined the growing Air Force Space Program as an Air Force Officer . He was privileged to work in the Air Force's Advanced Plans Office and served on Project Forecast II. The downturn in the aerospace industry led him to a Masters Degree in International Relations. Released from military service in the 1990s, he struggled to return to Federal service as a civilian analyst and retired in 2014 to pursue his passion for space settlement.

# The Allmatter Machine

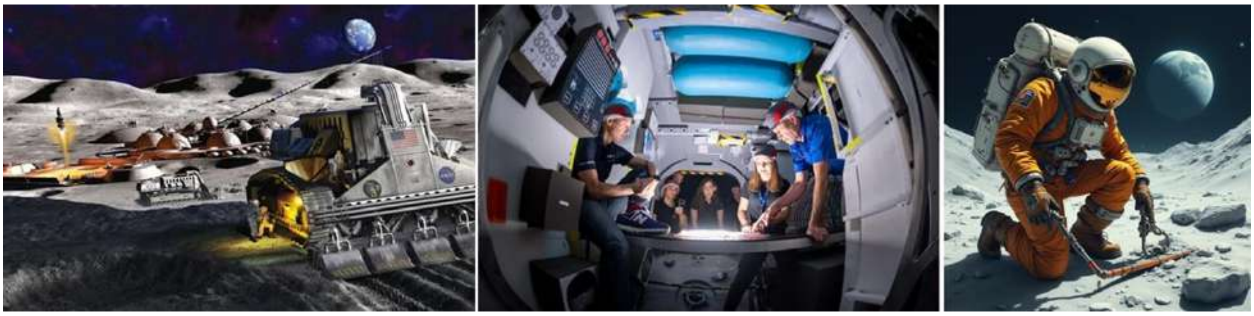
Andrew Kuess, ArcologyX

# Sociological Components of Engineering Solutions for Lunar Mining

Margaret Boone Rappaport Ph.D., Co-Founder,

The Human Sentience Project LLC, Tucson, AZ 85704

Sociological theory is crucial for planners designing facilities and services for miners in off-world base camps on Earth's Moon. This analysis highlights three key aspects: (1) Social Stratification, which involves analyzing human hierarchies essential for supervising difficult work and protecting worker rights in small lunar mining camps where *ad hoc* social arrangements can emerge as in other isolated groups; (2) Socialization Functions: information exchange, greetings, verbal and non-verbal "pulse-taking" via radio, gestures, tone, slang, and in recreation time, humorous storytelling and serious cautionary tales for lunar miners; (3) Social Complexity, extending stratification to include formal and informal roles, specific task experts, training specializations, and important talents in high-tech prospecting, extraction, and storage techniques of valuable products. Sociologist Campa, in *The Human Factor in the Settlement of the Moon* (2021) defines stages of social evolution on the Moon, from Base Phase to Village and City Phases. A mining base camp is a specialized version of Base Phase. Tenorio et al.'s CIPHERS (2024) and OMNI-5 (2025) project designs provide excellent base camp designs from which to extrapolate social solutions for miner well-being. Included in the original designs are training in disaster prevention, wearable sensors to track vital signs, and provision of a "safe location". We expand suggestions to include a security reporting system with suggestions for a clear command structure, clear designation of a base camp commander, and modular inflated habitations giving space to confer on work and socialize in groups, time for social interaction, social support, relaxation, and entertainment including electronic games and communication with family on Earth to maintain morale among miners. These personnel are not likely to be uneducated, but experts in robotic manipulation of heavy equipment, prospecting and testing of rare minerals, extraction techniques, AI programming, planetary science, mining engineering, logistics, materials storage, handling, and transport gases such as He-3, scheduling and shipping. Expertise variety should help to guard against emergence of cliques and gangs, as will rotation of crew to protect from radiation.



**Left image credit: Popular Mechanics, Pappalardo 2020. Middle image credit: NASA Gateway. Right image credit: Victor O. Tenorio, with AI.**

Dr. Margaret Boone Rappaport is a social scientist, and lead Editor of *The Human Factor in the Settlement of the Moon* (Springer, 2021).

# Extraction of Icy Regolith from a Crater at the Permanently Shadowed Regions of the Lunar South Pole using a Sandwich Conveyor System

*Author and Presenter: Victor O. Tenorio, Ph.D., University of Arizona, vtenorio@arizona.edu*
*co-Author and co-Presenter: Marc Dos Santos marc@dossantosintl.com*
*Co-Authors: Muhammad Waqas waqas@arizona.edu, Matthew Patterson mpatterson1@arizona.edu*

Initiating a mining operation at the Moon's South Pole using ISRU Pilot Excavator equipment and a sandwich conveyor system presents significant challenges. Excavating icy regolith in low gravity can be performed reliably, thanks to a counterrotating bucket drum system tested on Earth that provides near-zero reaction force. This system is ideal for excavating icy regolith in the Permanently Shadowed Regions near Shackleton Crater. Additionally, the sandwich conveyor system is well-suited for navigating irregular slopes and efficiently transporting material to the crater rim, while keeping the material hugged securely between two belts.

Several challenges must be addressed. The harsh lunar environment, with extreme temperatures and abrasive dust, demands robust equipment. Constructing and assembling the conveyor system and deploying units on the lunar surface will be complex and costly, necessitating specialized cranes and robotic assistants. Estimating production rates and transportation costs involves considering the logistics of moving equipment from Earth. Supervision will require a mix of human presence and surveillance cameras to ensure smooth operations and promptly address any issues.

Despite these challenges, the potential for successful extraction of icy regolith using advanced systems is promising. The case study incorporates actual lunar contours, design specifications, and a proposed sandwich conveyor system tailored for this demanding scenario.

| | |
|---|---|
|  | Victor Tenorio is a Mining Engineer with a Ph.D. from University of Arizona. His research interest is focused on Smart Mining and Decision Support Systems for optimizing productivity. Worked on several engineering projects in Peru and Chile. Currently Professor of Practice at the University of Arizona. Founder of the Wildcat Moon Miners (2021), a research team dedicated to participating in Space Mining-related projects and competitions |
|  | Marc Dos Santos holds a B.S. in Aerospace Engineering with a focus on Information Technology from MIT. He became a partner at Dos Santos International in 2004, having been integral to the company since its founding in 1997, where he organized the computer and communication systems. He has developed and optimized numerous processes and analytical tools, contributing significantly to the DSI Sandwich Belt High Angle Conveyors, overseeing projects from Australia to the Arctic Circle. |

# Extrusion on the Moon: Validation of Regolith-Based Fused Deposition Modelling (FDM) in Low Gravity Environments

Madison C. Feehan, Space Copy Inc. © 2025, madison.feehan@spacecopy.com


As lunar surface operations transition from exploratory to infrastructural, the demand for in-situ resource utilization (ISRU) techniques capable of fabricating structural components with minimal Earth-dependence has intensified. This study presents the first validated implementation of regolith-based Fused Deposition Modelling (FDM) from Space Copy Inc., under ambient conditions, with real-time projections on the impacts of low-gravity conditions via thermal simulation, leveraging beneficiated lunar simulant processed into a printable slurry matrix.

The feedstock comprises mechanically and thermochemically refined regolith (OPRH2N) integrated with >20% by mass of high-temperature thermoplastic binders (PEEK variants sourced from recycled ISS food packets) to achieve rheological stability and interlayer adhesion. The extrusion system was adapted for lunar-relevant conditions, incorporating a variable-pressure micro-extrusion nozzle with a varied aperture, internal helical flow channels, and active thermal regulation to mitigate clogging due to particulate agglomeration and binder phase separation.

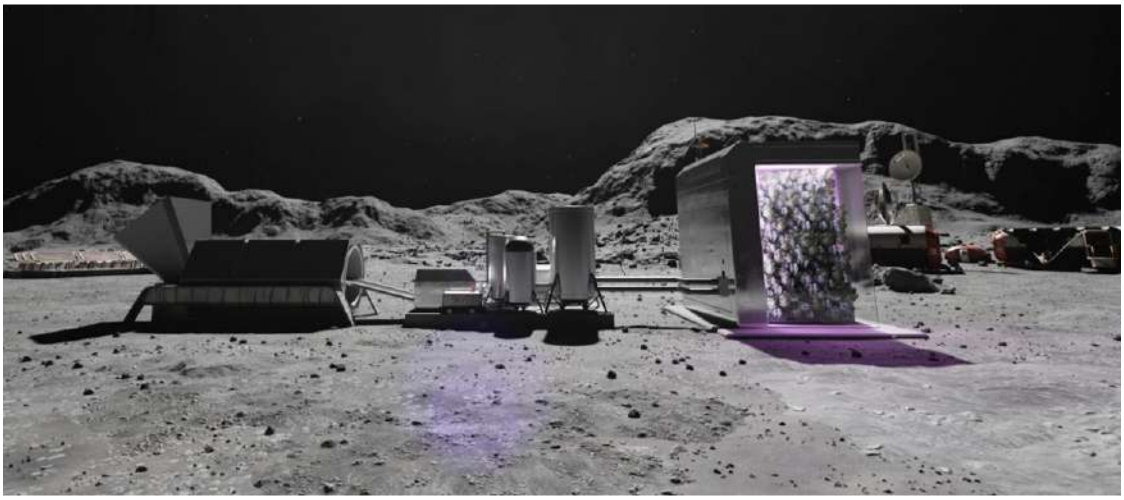
Key parameters, including extrusion temperature, layer height, deposition rate, and interpass cooling intervals, will be chronicled through an exploration into iterative testing. Results demonstrated consistent layer fidelity, minimal delamination (<10% interfacial void fraction), and compressive strengths exceeding expectations.

This work establishes a foundational framework for autonomous, additive construction of critical lunar infrastructure, such as radiation shielding, thermal enclosures, and landing pad substructures, using ISRU-enabled materials and gravity-adaptive FDM systems. This study will highlight future work that will extend to in-situ binder synthesis and robotic toolpath adaptation for regolith heterogeneity.

**About The Author:** Madison C. Feehan is the founder and CEO of Space Copy, an international logistics and manufacturing company advancing in-situ resource utilization (ISRU) technologies for space. Based in Canada, she brings a background in lunar instrument development and early-stage innovations for NASA's Planetary Science, Heliophysics, and Astrophysics divisions. With a foundation in Commerce and a Harvard Business School certification in Entrepreneurship and Innovation, Madison also serves as the G100 Region Chair of Space Technology and Aviation for Alberta and Chair of the Lunar Chamber of Commerce. Her work spans STEM education, international policy for small science-driven businesses, and global collaboration through organizations including the United Nations, and the Lifeboat Foundation.

# Extraction Strategies: Space Resource Beneficiation and Lithologically Complex Simulants

Øystein R. Borgersen – Co-founder & CTO, SolSys Mining (oystein@solsysmining.com)



Efficient in-situ resource utilisation (ISRU) depends on beneficiation chains that transform raw lunar regolith into usable concentrates. With support from ESA and the Norwegian Space Agency, SolSys Mining has advanced this concept through three linked efforts:

- ELISA combined dry beneficiation with acid/alkali leaching to recover plant nutrients from commercial simulants and molten-oxide-electrolysis slag, but also exposed how pre-processed simulants overstate separation efficiency.
- LuNOR, a new family of simulants made entirely from crushed terrestrial rocks, preserves grain structure, hardness contrasts and dust behaviour, offering a more realistic analogue for beneficiation, regolith handling and dust-mitigation studies.
- URECa narrows the objective: pairing regolith simulant with source-separated urine to liberate nutrients and deliver a balanced, low-toxin, low-mass fertilizer. CIRiS will validate the product by hydroponically cultivating multiple crops. Where ELISA was a combination of minerals processing and agriculture, URECa additionally links these with the ECLSS node.

SolSys Mining will be presenting both the company and current activities, as well as the case for extraction strategies and lithologically complex simulants related to space resource beneficiation at the 2025 Lunar Development Conference.

Øystein R. Borgersen is co-founder and CTO of SolSys Mining. With extensive experience in system engineering, process, and product design, Øystein brings broad knowledge and innovative thinking to the company. He has been instrumental in SolSys Mining's space resource beneficiation and lunar regolith simulant production programs. Although most experienced in the fields of mining and minerals processing, he has also held various engineering and managerial positions across industries, ranging from additive manufacturing and hydropower to aerospace and defense. Øystein has a background in Mechatronics Systems Engineering and has furthered his expertise through the Space Studies Program at the International Space University. His career reflects a passion for innovation and a commitment to advancing technology.

# Day 3 Workshop:
# Lunar Mining and Manufacure

Moderator: Victor O. Tenorio, Mining and Geological Engineering, UArizona

Join our workshop and help us brainstorm what we need to mine and make on the moon to survive there. Everyone is invited to contribute and there are no bad ideas (although some may not make the final cut). The goal is to create an exhaustive list that researchers can use to plan their next project and to help identify knowledge gaps. All participants will be acknowledged in the paper (if desired).