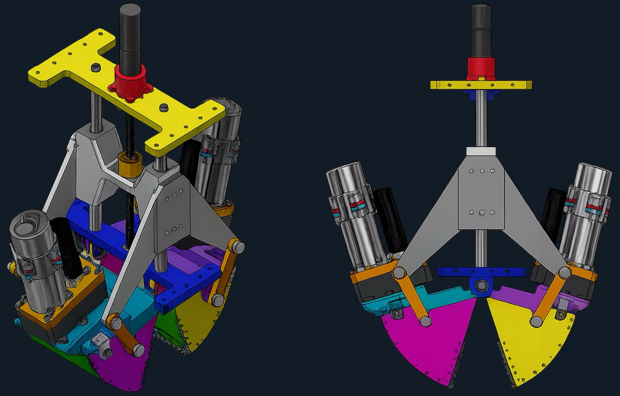
Cislune



PERDEX:

Percussive **D**rum **Ex**cavator to Minimize Sublimation

Preserving Lunar Resources Through Precision Excavation

in collaboration with:

UCF UNIVERSITY OF CENTRAL FLORIDA

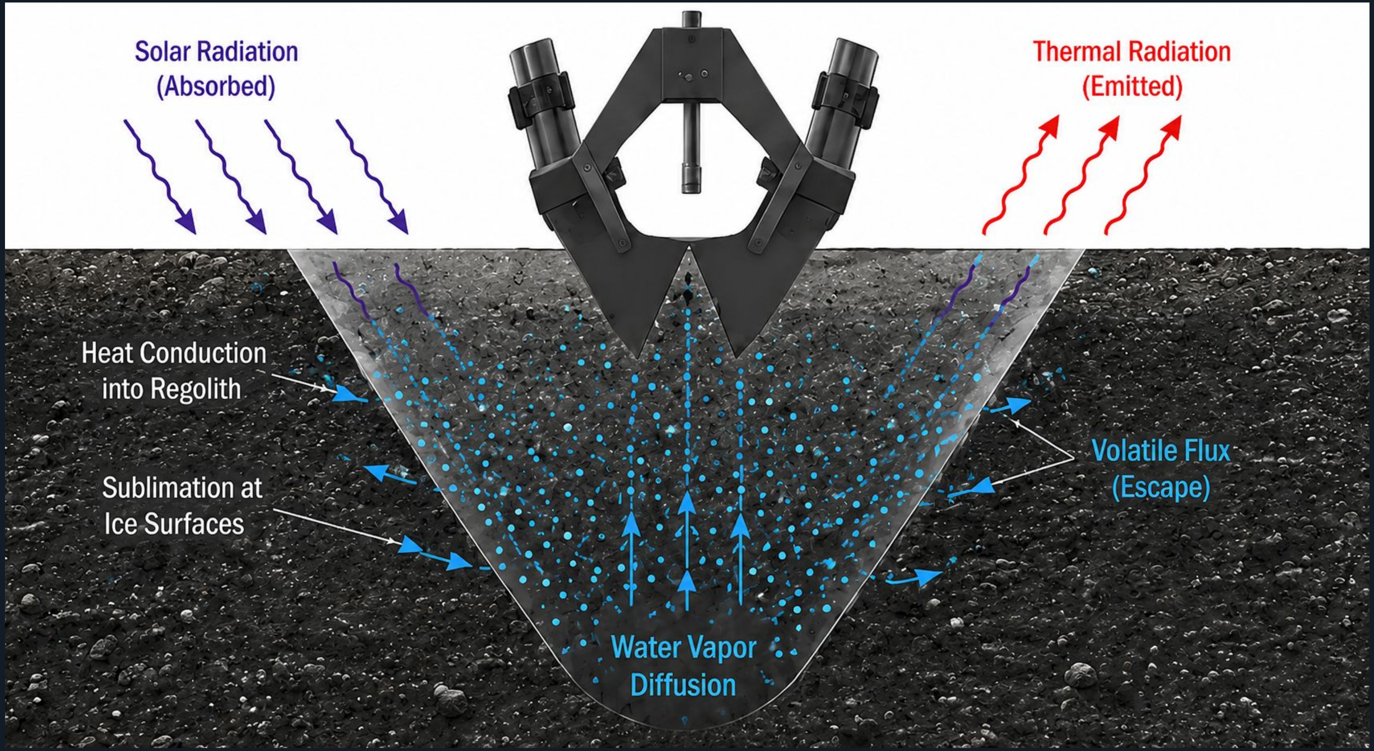
McMurchie Engineering

HONEYBEE ROBOTICS

What are we talking about today

- Why are we conserving sublimating water during excavation?
- PERDEX vs. State of the art
- Design
- Physical Verifcation: CLSM
- Simulations Modeling
- Future steps

Sublimation and Volatile Transport During Excavation



Why Retain Sublimating Water?

- Future ISRU resources
  - Oxygen, Hydrogen, etc.
  - Life support, radiation shielding, mining, propellant
  - Reduces energy cost per kg of recovered water

- Understanding lunar and planetary evolution
  - Cometary and asteroidal volatile delivery
  - Solar wind implantation processes
  - Ancient lunar volcanic activity
  - Volatile migration and accumulation within permanently shadowed regions (PSR)

PERDEX Relative to State-of-the-Art Lunar Excavation

Traditional Excavation Systems Cause Volatile Loss

PERDEX Captures Intact Icy Material

Validated Through Modeling & Cryogenic Testing

Optimized for PSR Excavation

>50×

reduction in modeled volatile loss after capture

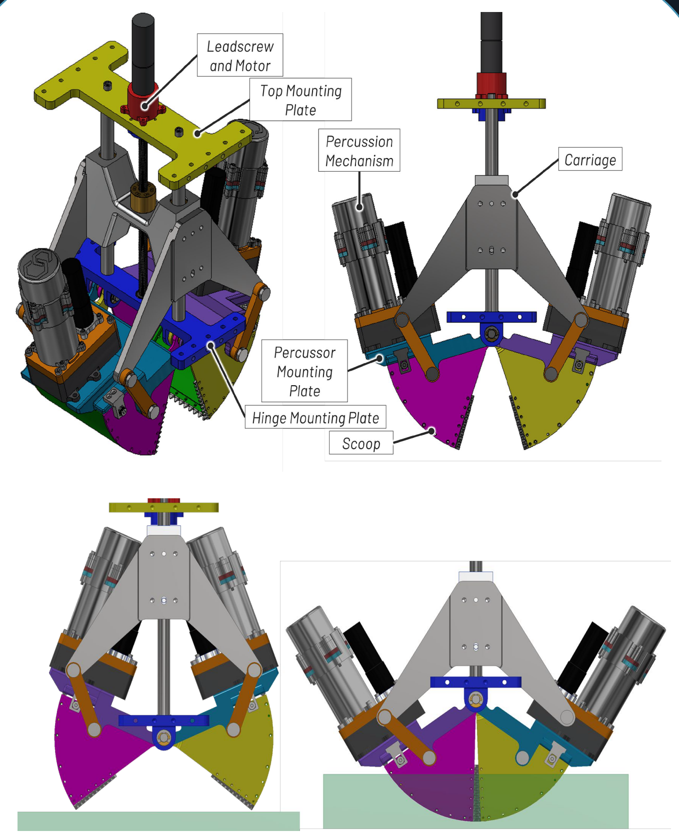
1.5 MPa

excavation system sized for high-strength cementitious icy lunar regolith

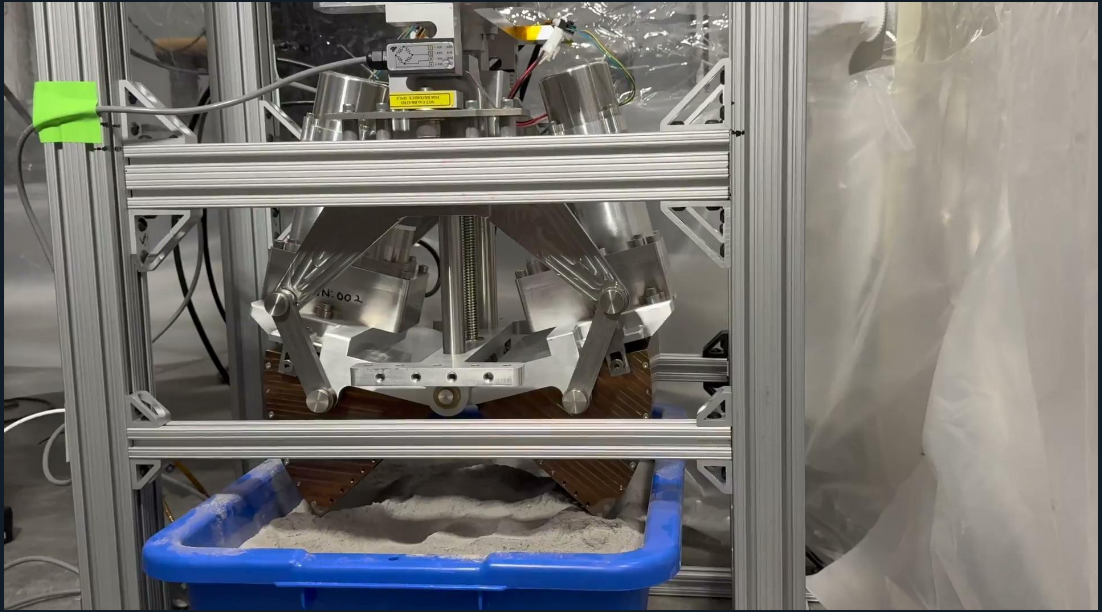
40–260 K

multi-species thermal and vapor-pressure simulation under PSR conditions

PERDEX Percussive Clamshell Excavator Architecture:



- **Dual clamshell-style dredger buckets fracture and enclose large intact icy regolith fragments, minimizing exposed surface area and suppressing sublimation-driven volatile loss during excavation.**
- **Independently actuated percussion mechanisms penetrate consolidated cementitious icy regolith while reducing excavation resistance and limiting lateral reaction forces imparted into the vehicle.**
- **Kinematically optimized scoop geometries and modular excavation interfaces support scalable lunar ISRU excavation across ambient, cold-soak, and cryogenic TVAC validation environments.**



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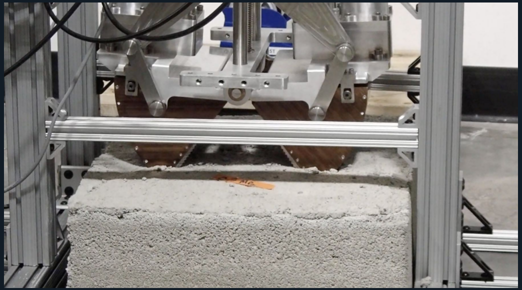
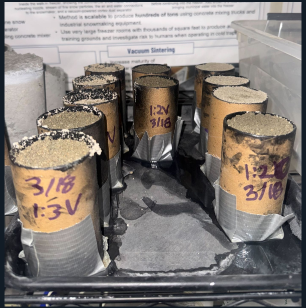
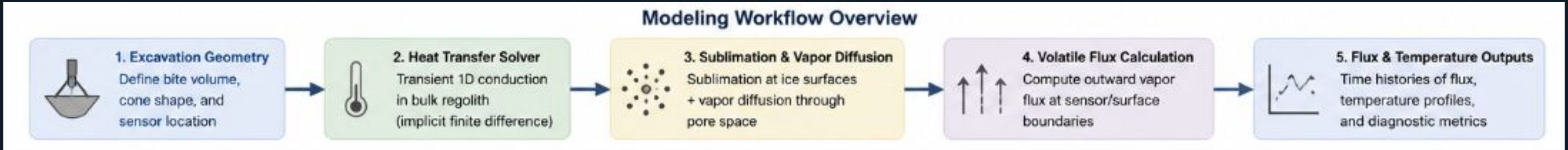
Compacted Icy Regolith Simulant Production

- Repeatable, cost-effective, ambient-condition testing
- Controlled Low-Strength Material (CLSM)
    - Aerocrete: high-porosity concrete
    - Target yield strength: 1.5MPa
- Recipe experimentation
    - Manipulated ratios of aerocrete liquid to cement powder and aggregate
- Final product: mechanism test brick

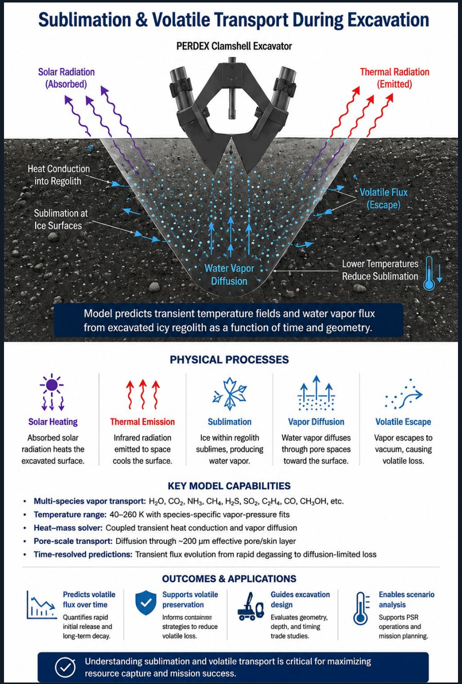


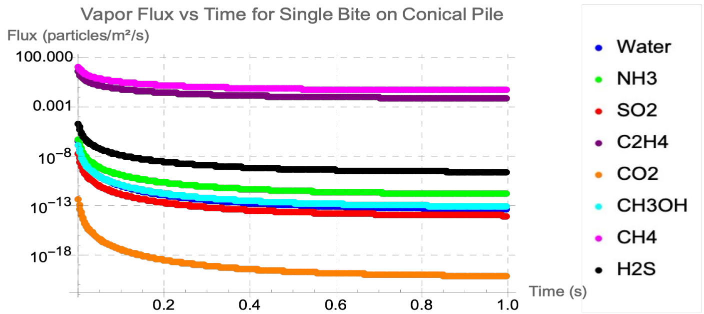


PERDEX Sublimation-Driven Volatile Evolution Simulation Architecture:



- **Physics-based finite-difference simulation framework coupling thermal conduction, vapor diffusion, and sublimation transport within excavated icy regolith.**
- **Multi-physics excavation model developed to predict volatile evolution, thermal gradients, and post-excavation sublimation losses under lunar vacuum conditions.**
- **Numerical solver integrates excavation geometry evolution, cryogenic heat transfer, pore-scale diffusion, and volatile flux transport for PSR excavation analysis.**
- **Implicit transient thermal solver computes temperature evolution through bulk and near-surface regolith layers during excavation exposure events.**
- **Geometry-aware excavation model evaluates volatile escape as a function of excavation depth, bite geometry, exposed surface area, and containment timing.**
- **Simulation architecture supports rapid scenario analysis for excavation operations, volatile preservation strategies, and clamshell containment performance.**





- Multi-species volatile flux evolution following excavation of icy regolith exposed to vacuum conditions under PSR thermal environments.
- Simulated sublimation-driven vapor flux for H_2O, CO_2, NH_3, CH_4, H_2S, SO_2, and additional species during transient post-excavation degassing.
- Initial rapid volatile release transitions into diffusion-limited sublimation as latent cooling develops within the excavated regolith pore structure.
- Modeled vapor transport through pore-scale diffusion layers predicts time-dependent volatile loss following excavation and exposure.
- Volatile species exhibit distinct sublimation decay behavior as a function of vapor pressure, molecular transport, and thermal evolution.
- Heat–mass transfer solver captures transient volatile escape dynamics during excavation, exposure, and containment operations.

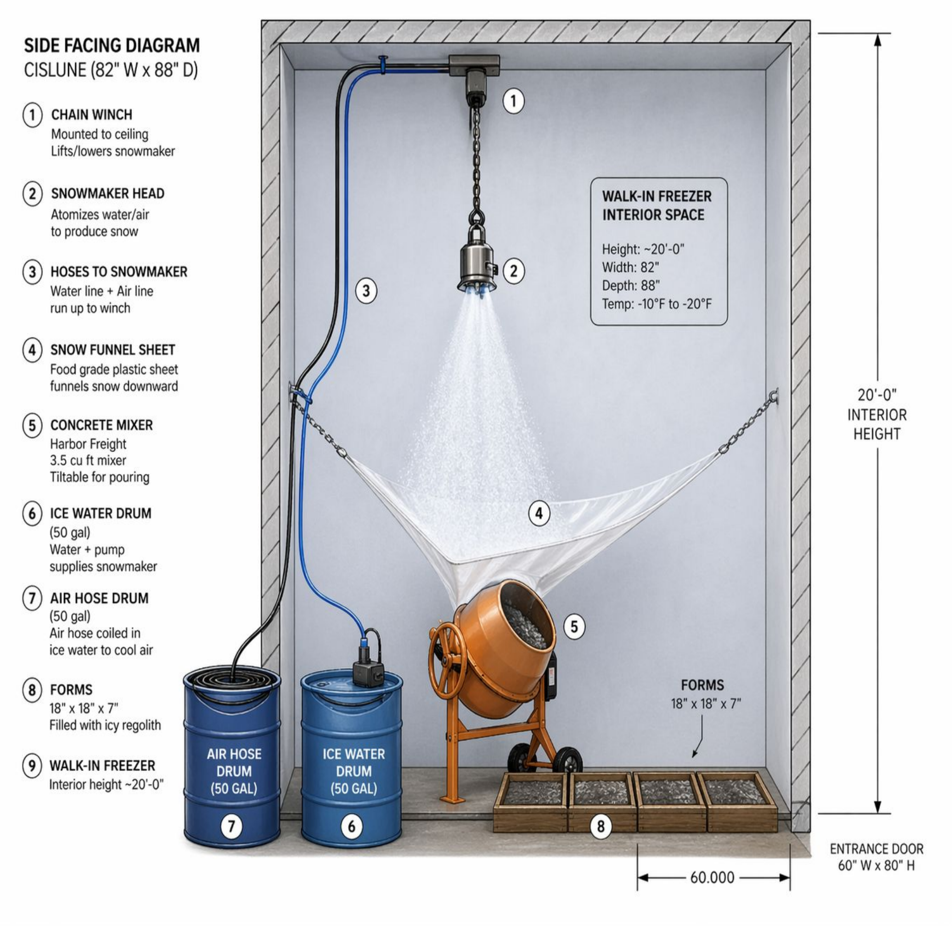
PERDEX Excavation Performance in CLSM & Cryogenic Icy Regolith Simulants:

Test 1/2: 0.5 mPa Concrete (front and back sides)

Test 4: 6% Cemented Freezer Test w/ Freezer Offsets

Test 3:

Test 5: 10% Discrete Freezer Test



PERDEX Future Testing & Technology Maturation:

Dry Regolith Testing in Thermal Vacuum

- Honeybee Robotics

Icy Regolith Simulant Testing in Thermal Vacuum

- McMurchie Engineering

Continuous Volatile Monitoring throughout Excavation Process

- Heat–mass transfer models simulate volatile diffusion, sublimation behavior, and multi-species vapor flux across cryogenic lunar conditions.
- Cold-soak experiments, ultrasonic penetration testing, and icy regolith simulant campaigns validate excavation performance and volatile-retention behavior under representative PSR conditions.

Radiation-Tolerant Avionics

- Designed for permanently shadowed regions where cryogenic temperatures, vacuum exposure, and volatile instability make conventional excavation inefficient.
- Integrated percussion and clamshell containment reduce vehicle loading, limit material disturbance, and preserve volatile-bearing regolith through capture and transfer.

Cislune In-Progress Programs & Technical Development:

TREAD — NASA SBIR Phase 1 H15.02-1007
Development and calibration of DEM/CRM wheel–regolith interaction simulations using PyChrono, LIGGGHTS, and PyDEME for lunar traction and wheel wear degradation analysis, validated against UCF RIDER wheel wear SEM characterization and RIDER experimental testing data.

GRASP — NASA STTR Phase II T7.04-1097
Development of DEM-based regolith compaction analysis using Project Chrono and LIGGGHTS to evaluate wheel-induced terrain densification during autonomous lunar site preparation, enabling comparison across multiple wheel geometries and informing the design and fabrication of a custom Cislune compaction-optimized wheel derived from the highest-performing simulated features.

NASA LunaRecycle Challenge — Phase II Winner and Finalist
Development of lunar recycling and ISRU systems for steel production, oxygen recovery, and processing of difficult-to-recycle polymers and organic waste feedstocks through furnace-based experimental testing, alongside a digital twin framework for closed-loop resource recovery and process optimization.

CARVE
Development and prototyping of a compact modular autonomous excavation rover platform for subsystem integration, robotic excavation testing, terrain-interaction validation, and rapid advancement of scalable lunar autonomy and construction architectures.

CITA/TRUST — NASA STTR Phase II T10.05-1007
Development of immersive cyber-human teaming environments and trust-aware autonomy frameworks within Cislune's SimMoon digital VR lunar environment to study real-time human-machine trust dynamics, uncertainty representation, and autonomous decision-making during space operations.

CISORT — NASA SBIR Phase II Z12.03-1016
Development of lunar regolith beneficiation and particle-sorting systems for separation and concentration of high-value materials, integrating granular flow modeling, resource-processing workflows, and scalable ISRU-oriented material handling architectures.

PERDEX — NASA SBIR Phase II Z12.01-1792
Development of a volatile-preserving percussive drum excavation system for lunar regolith extraction, integrating percussion-assisted cutting mechanics and low-disturbance excavation architectures to minimize sublimation losses and preserve volatile-bearing material during ISRU operations.

Sublimation during