Project Olympus: Off-Planet Construction

Evan Jensen
Vice President of Strategic R&D
ICON Technology, Inc.
evanjensen@iconbuild.com

January 2024

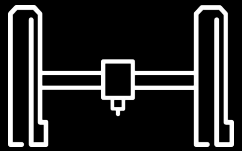
LSIC Monthly Meeting

ICON's Terrestrial Operations

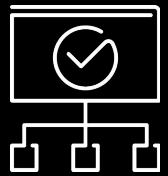
For Context...

TERRESTRIAL CONSTRUCTION

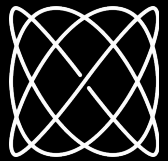
ICON is a construction technologies company



Robotics



Software



Adv. Materials

Architecture

TERRESTRIAL CONSTRUCTION

It's been sticks and bricks for hundreds of years, but everything is about to change

1200s

Middle Ages

Early standardization of carpentry and architecture techniques.

1880s

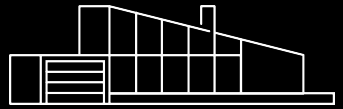
Industrial Revolution

Climate control and industrial production of building materials.

1950s

Power Revolution

Power tools enable homes to be built faster.



The Future

3D Printing

Advancements in robotics, software, and materials create *10x improvements* in speed, quality, resiliency & sustainability.

ICON Projects

The Chicon House: Printed March 2018 within 48 hours. 350 sq. ft. structure: 2 Bdrs, 1 Bath, Kitchen

CFV Welcome Center: Printed May 2019 within 24 hours. 500 sq. ft. structure: 1Bdr, Office, Kitchen, Living

Community First Village (CFV): Total 6 homes printed in March 2020. 400 sq. ft. structures: 1 Bdr, Kitchen, Living

New Story: Total 6 homes printed in Tabasco, Mexico in May 2019. 500 sq. ft. structures: 2 Bdrs, 1 Bath, Kitchen, Living

Camp Swift Barracks: Printed in August 2021, 3,800 sq. ft. structure set to house 72 soldiers

House Zero: Printed in Winter 2021 within 10 days. 2,000 sq. ft. structure: 3 Bdrs, 2.5 Bath with a 350 sq. ft. ADU

TERRESTRIAL CONSTRUCTION

Wolf Ranch, 100 homes, Georgetown, TX

ALL RIGHTS RESERVED | PROPRIETARY & CONFIDENTIAL
THIS DOCUMENT OR ANY USE OR SHARING OF THIS MATERIAL WITHOUT
PERMISSION OF ICON TECHNOLOGY, INC. IS STRICTLY PROHIBITED.

Freedom of Form



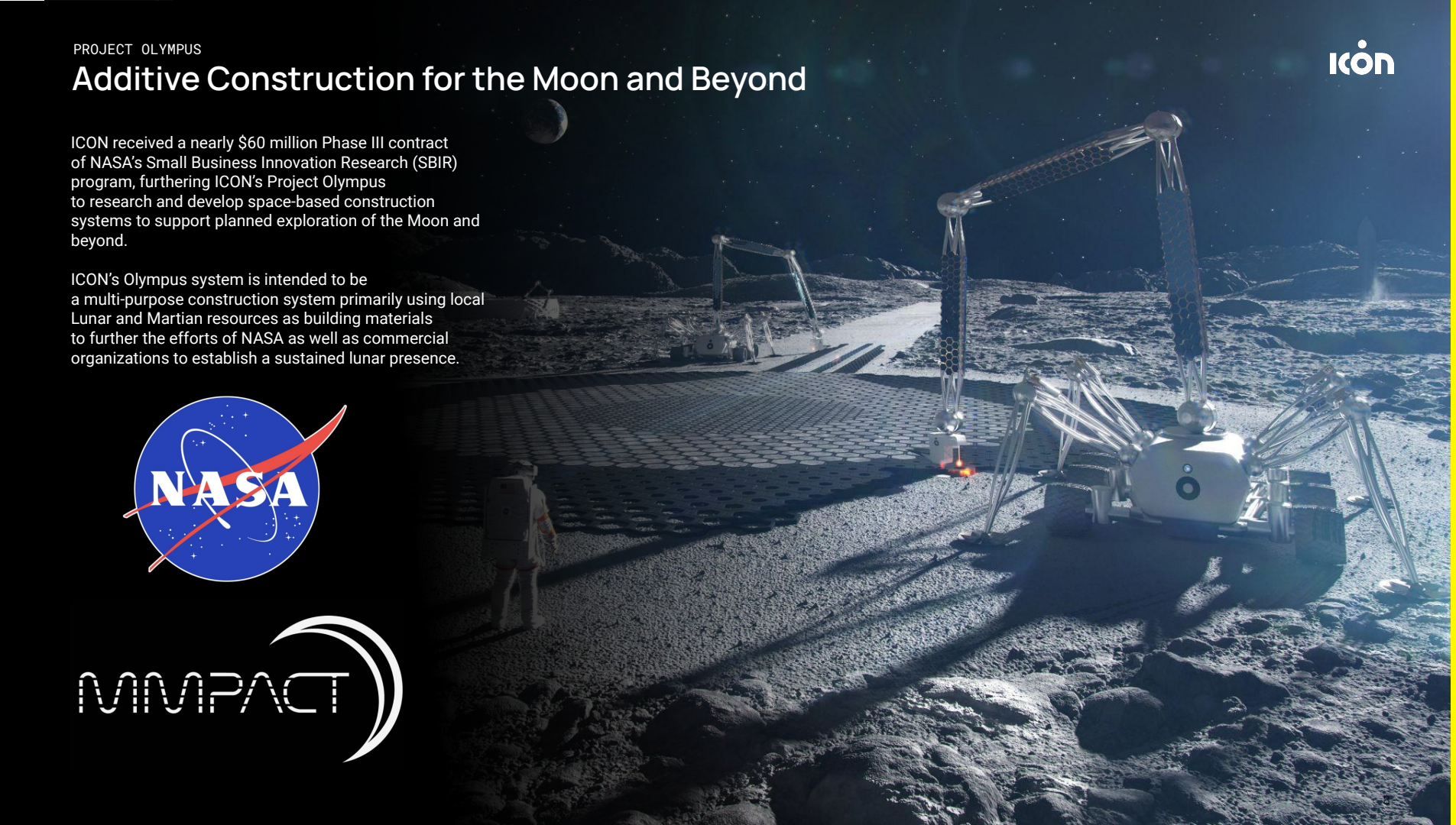



PROJECT OLYMPUS

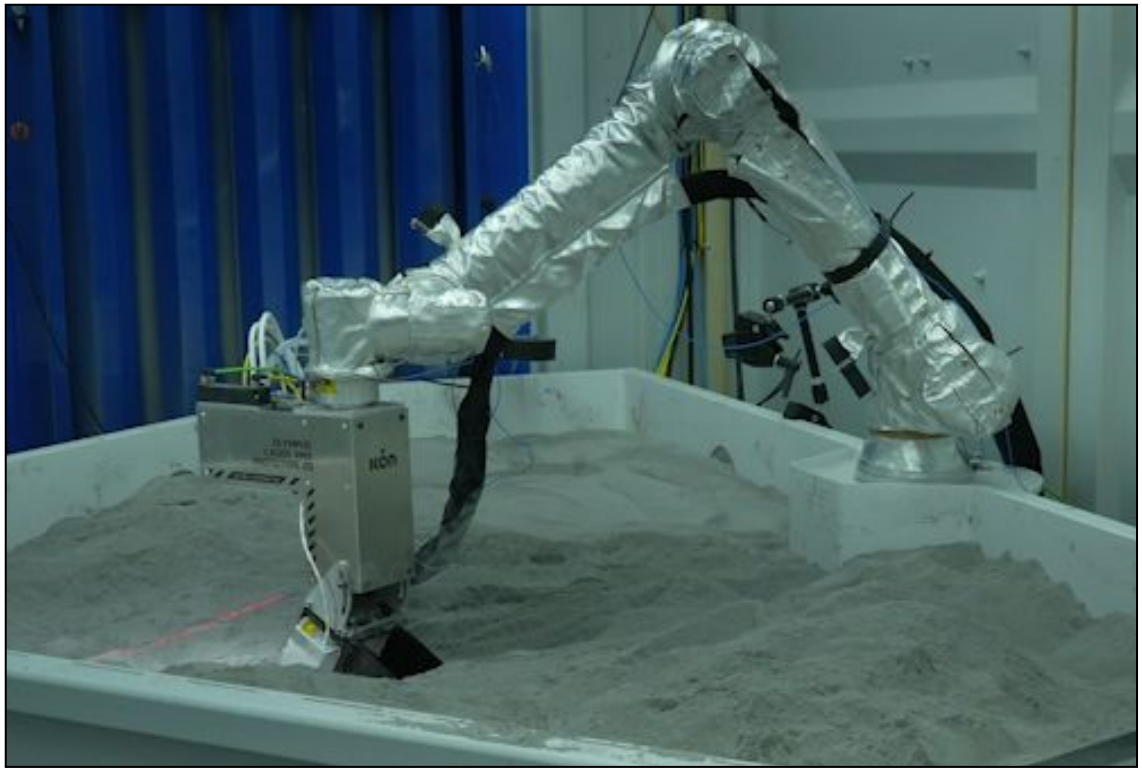
Additive Construction for the Moon and Beyond

ICON received a nearly $60 million Phase III contract of NASA's Small Business Innovation Research (SBIR) program, furthering ICON's Project Olympus to research and develop space-based construction systems to support planned exploration of the Moon and beyond.

ICON's Olympus system is intended to be a multi-purpose construction system primarily using local Lunar and Martian resources as building materials to further the efforts of NASA as well as commercial organizations to establish a sustained lunar presence.



Making Off-planet Construction a Reality...



ICON's Prototype Laser VMX toolhead in atmospheric lunar regolith simulant test bed at ICON's Off-Planet Systems lab in Austin, TX.

Designed in collaboration with NASA KSC, ICON's integrated Scoop/Tamp/Filter system is capable of meeting NASA MMPACT Key Performance Indicators (atmospheric and in vacuum).

PROJECT OLYMPUS

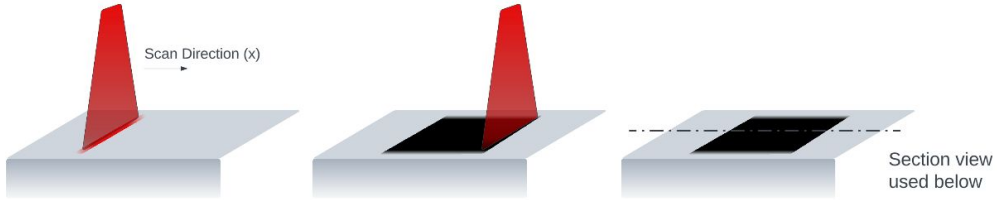
Prototype Laser VMX Regolith Preparation & Laser Construction

ICON's Prototype (atmospheric) Laser VMX toolhead is capable of autonomous site preparation, filtering, compaction, and creation of ISRU-based structural elements.

ICON's Laser Vitreous Multi-Material Transformation (VMX) Process

The Laser VMX Process is a powder-bed fusion(PBF) method of additively constructing horizontal and vertical structures from only lunar regolith. Thin layers of material are progressively deposited and selectively lased - the lasing sequence applies a thermal schedule such that material is preheated, sintered, melted/adhered to the previous layer, and crystallized.

3D view & Coordinate System:
Incident Laser Beam is a Bar
Scan Direction X is typically orthogonal



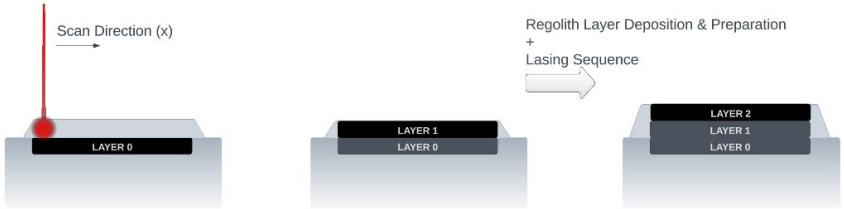
Regolith Layer
Deposition &Preparation Definition:
The (n)th layer is prepared by first depositing prefiltered regolith atop the previous (n-1)th layer, usually in gross excess.

The deposited regolith is scraped flat to a prescribed height.

The regolith is then compacted to increase bulk density.

Lasing Sequence:
The (n)th prepared regolith layer is lased to apply a heating schedule to the material, and the (n-1)th and lower layers are also conductively headed.

The uppermost layer is also referred to as the active layer.

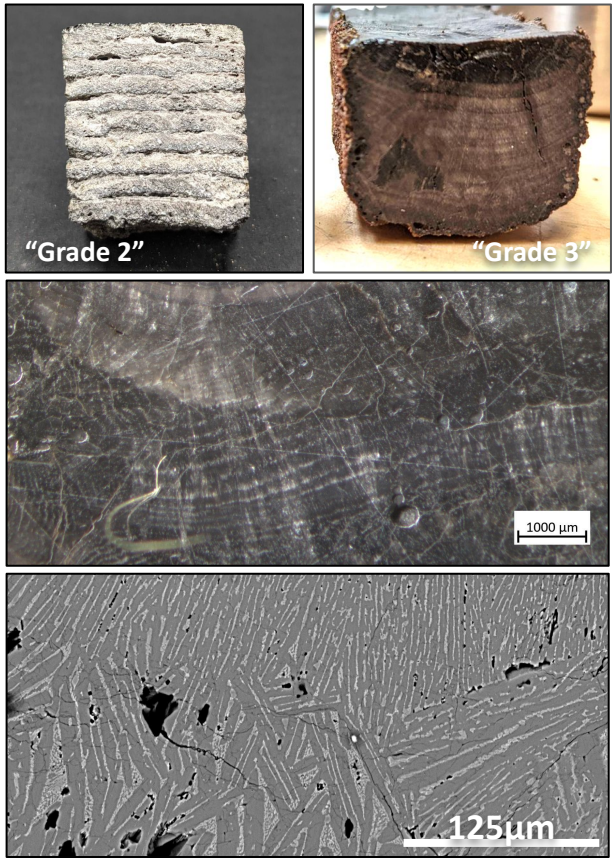


Laser VMX Construction Material:

Laser VMX Materials produced in vacuum underwent 3rd party testing at Kratos Southern Research Engineering (KSRE) during NASA MMPACT's Down-select competition.

Laser VMX "Grade 3" Properties:

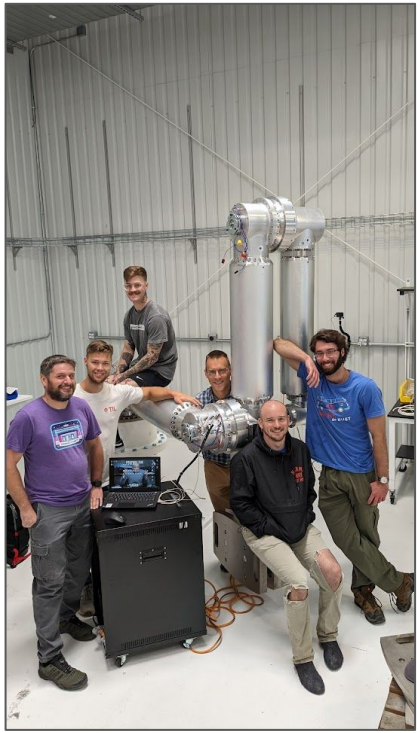
Compressive Strength [ASTM C1424]	**~50,000 psi** @ 25 °C **~48,500 psi** @ 57 °C **~49,200 psi** @ -192 °C **~36,500 psi** @ 1 year lunar TVAC cycles
Layer to Layer Adhesion [ASTM C297]	**~1,260 psi**
FLexural Strength (4-pt) [ASTM C1499]	**~5,500 psi**
Ablation Mass Loss [EW40-0WI-013]	**0.07%** @ 270 BTUs
Thermal Expansion: [ASTM E228]	**3.6E-6 m/m-°C** average over -150 °C to 50 °C @vacuum
Density:	**2.7 g/cm^3**

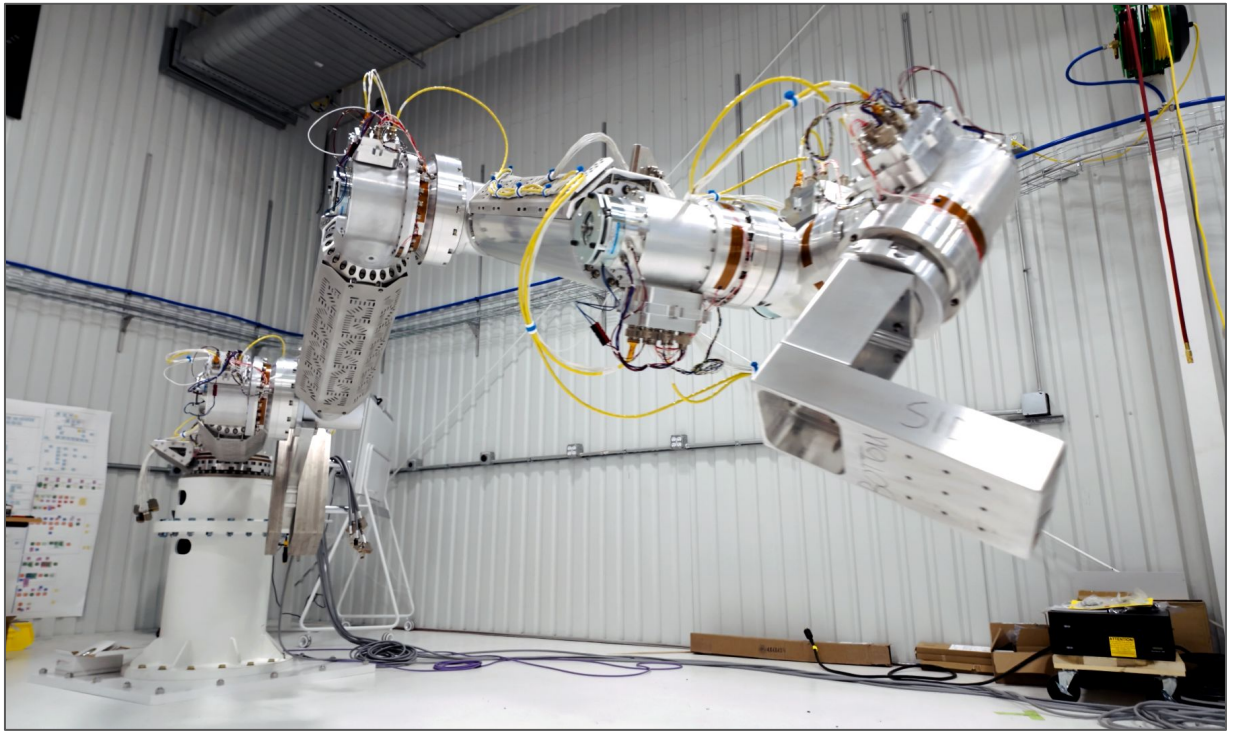


ICON's Laser VMX vacuum-produced material is a high performance building material made from 100% ISRU-based feedstock.

ICON TVAC Robot that Executes Laser VMX [6-DOF Arm + End Effector]

The VMX Process is intended to be executed by a robotic system that consists of a 6-DOF robotic arm used to manipulate a swiss-army knife end effector capable of executing the entirety of the open-bed 3D-printing operations required to produce VMX materials.





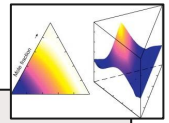
ICON TVAC Robot that Executes Laser VMX [6-DOF Arm + End Effector

The VMX Process is intended to be executed by a robotic system that consists of a 6-DOF robotic arm used to manipulate a swiss-army knife end effector capable of executing the entirety of the open-bed 3D-printing operations required to produce VMX materials.

ICON's Thermal Cryo-vacuum rated robotic arm is functional in TVAC at subsystem scale, with testing at full scale in lunar-like conditions at NASA MSFC V20 next month.

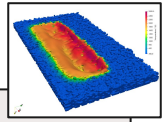
PROJECT OLYMPUS

Integrated Computational Material Engineering (ICME): The Laser VMX Process Simulated in a Lunar Digital Twin



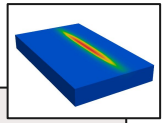
Sub-Microscale
- Scale of constituents
- No specific discretization
- Thermocalc
- Discrete constituent material phases
- Capture phase change, enthalpies, energies, and products

CALPHAD (Standalone)



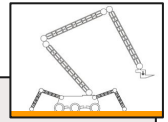
Microscale
- Scale of regolith grains
- Discretization of 5-1000 µm
- Project Chrono, OpenFOAM
- Discrete powderbed with porosity and laser with ray tracing
- Capture melt pool, porosity changes, heat flow

DEM → Ray Tracing → CFD



Mesoscale
- Scale of laser bar path
- Discretization of 1-2 mm
- OpenFOAM, CalculiX
- Capture thermal stresses/ strains, heat flow, large-scale melt pool/flow

CFD (Standalone) | FEM ↔ CFD



Macroscale
- Scale of print features
- Discretization size TBD
- TBD Software
- Capture thermal stresses/strains, structural deformation

ML | FEM

1 nm — 1 µm — 1 mm — 1 m

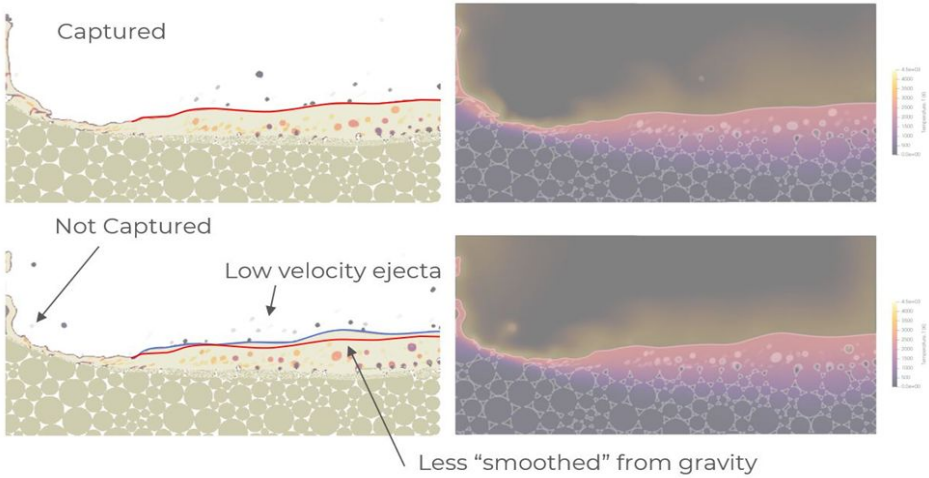
PROJECT OLYMPUS

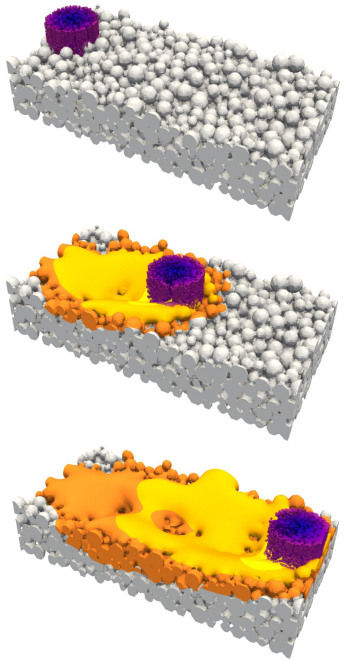
Predicting How Our Process will Behave on the Moon vs. our Space Simulation Chambers

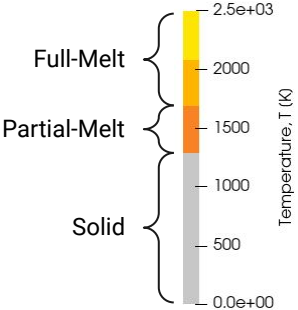
Simulations: 1/6g - hard vacuum - real lunar regolith properties

Earth 9.81 m/s^2

Lunar 1.62 m/s^2



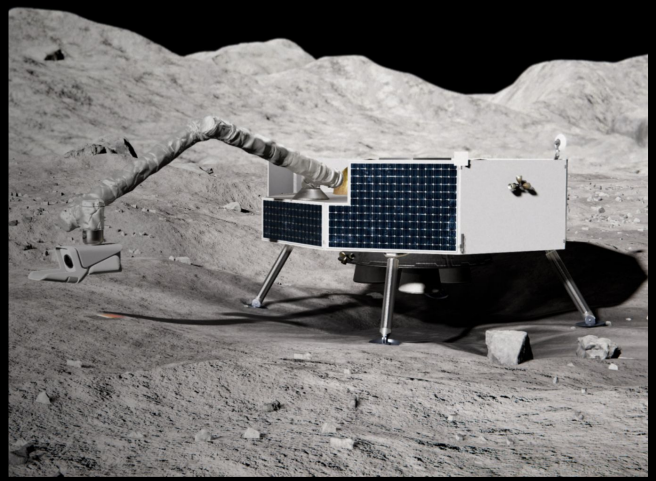




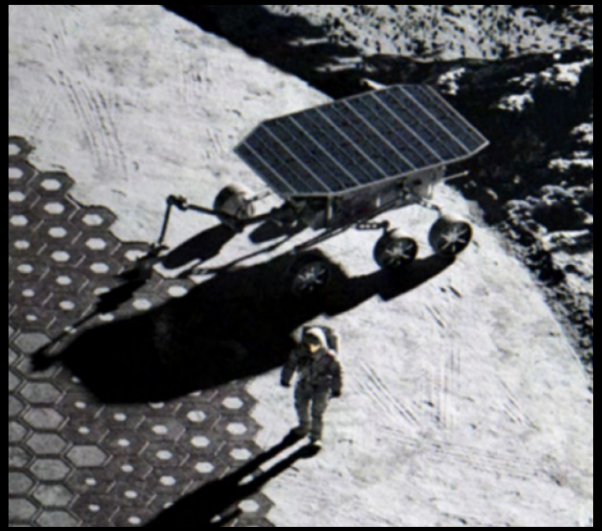
ICON is leveraging integrated computational material engineering to inform how laboratory work will scale to the lunar surface.

PROJECT OLYMPUS

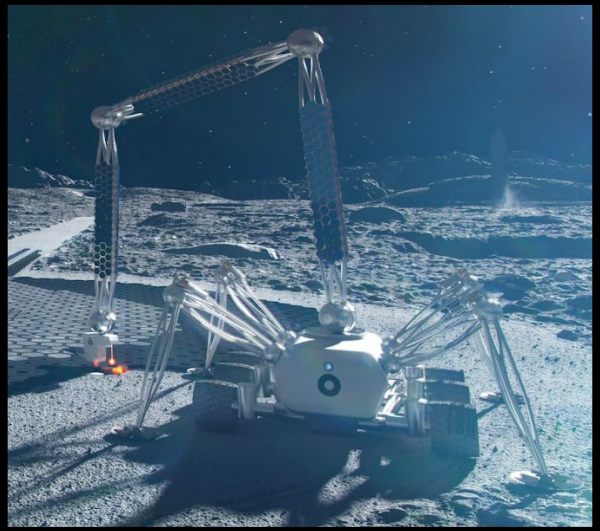
Our goal is to build infrastructure off-planet…
…starting with the moon.



Lunar demonstration to close lab testing



Going “off lander” for extended build volumes



Commercially scalable hab-capable system

2025 2026 2027 2028 2029 2030 2031 2032 2033

PROJECT OLYMPUS

ICON Off-Planet Construction Q1-Q3 2024

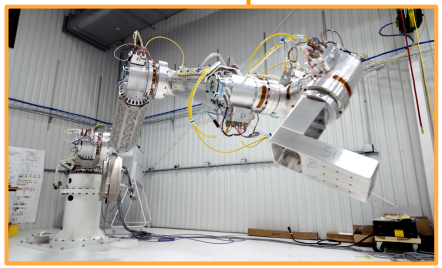
LSIC Monthly
(We are here)

Terrestrial Robotic Arm Subsystem
TVAC Test
@ Marshall V20 Chamber

Laser VMX
End Effector Subsystem
TVAC Test

Construction System
Demonstration
TVAC Test
@ Marshall V20 Chamber

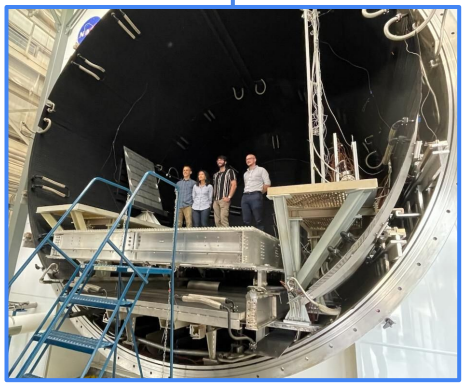
Jan | Feb | Mar | Apr | May | June | July | Aug | Sep



Simulant Production Pilot Plant comes online

78” TVAC Chamber delivery

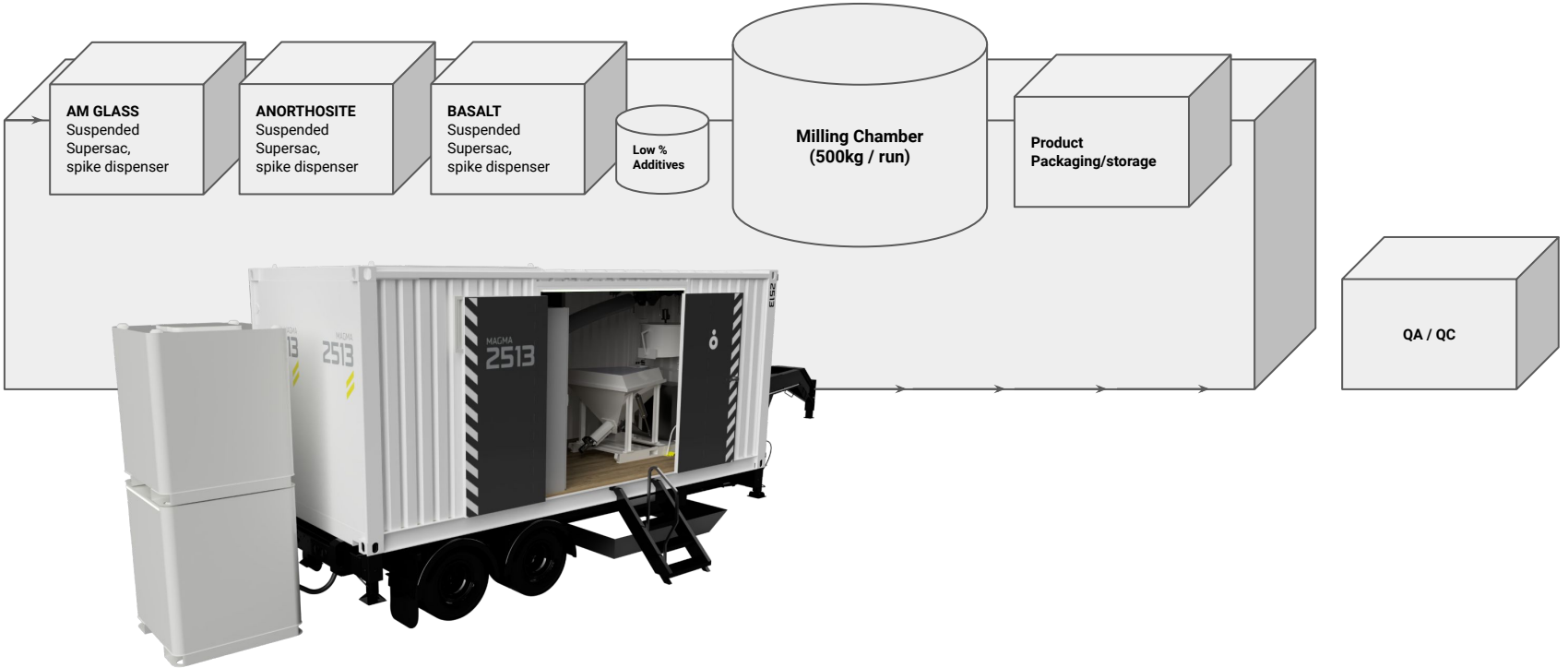
Large Regolith Room Robotic Testbed comes online



Simulant Production Pilot Plant

ICON Needs enough simulant to warrant our own production plant. Leveraging our expertise in transporting and mixing granular ceramic materials, and partnering with experts in industry and academia, we anticipate having high throughput, high fidelity simulant production online by the start of Q2 2024.

Simulant is available to the lunar community.



Testing services for ICON and partners

Lunar Surface Simulation Chamber

Open April 2024 in Austin, TX

Key Features:

21 feet x **28** feet area, HEPA filtered

3 foot deep bed (nominal)

~72 tons of Highlands Simulant

2 x 6 DOF Robots

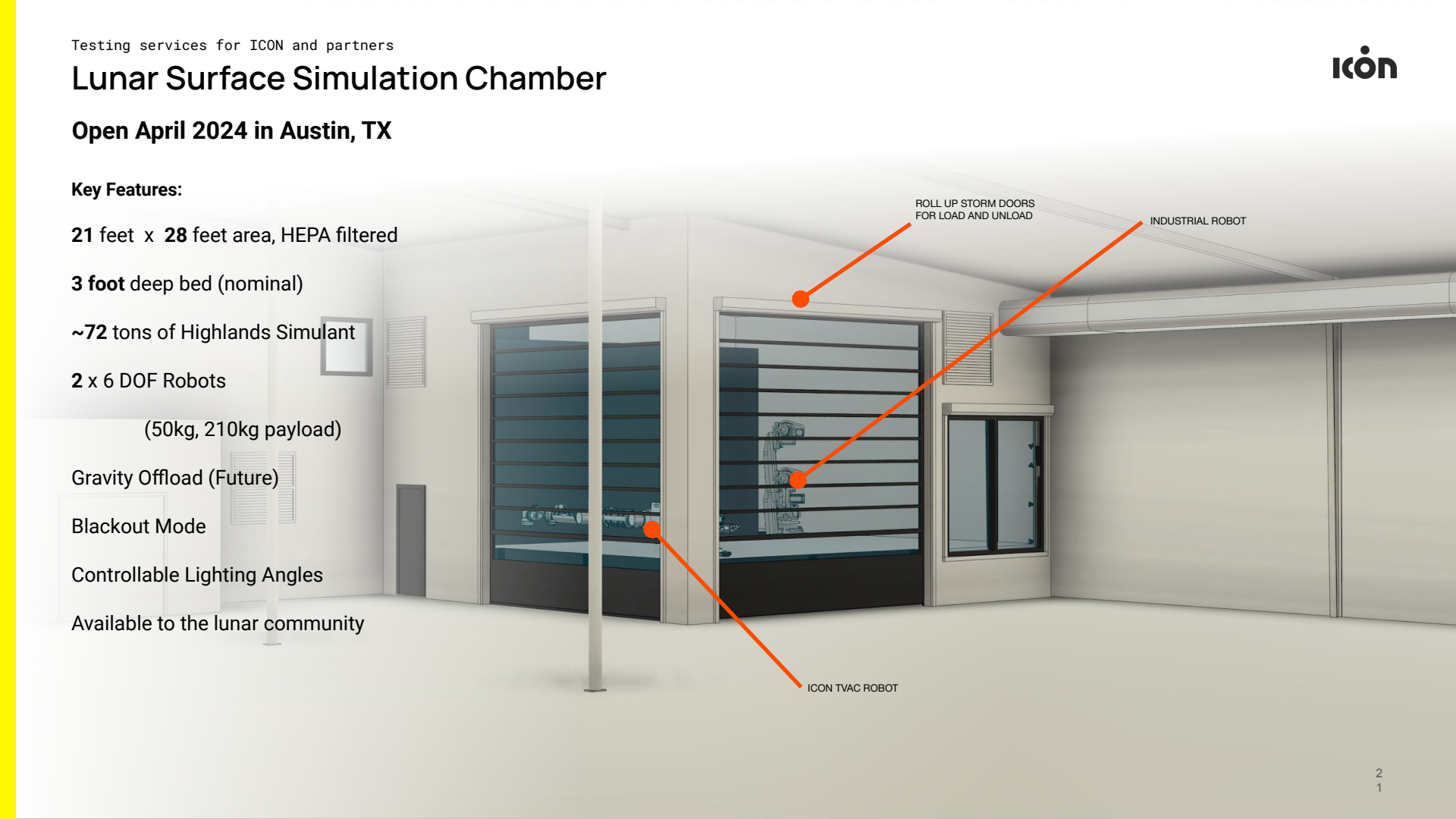
(50kg, 210kg payload)

Gravity Offload (Future)

Blackout Mode

Controllable Lighting Angles

Available to the lunar community



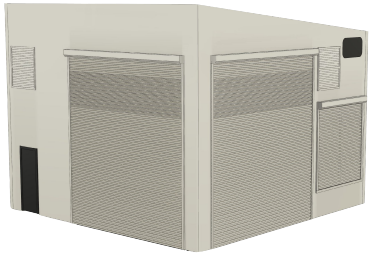
Testing services for ICON and partners

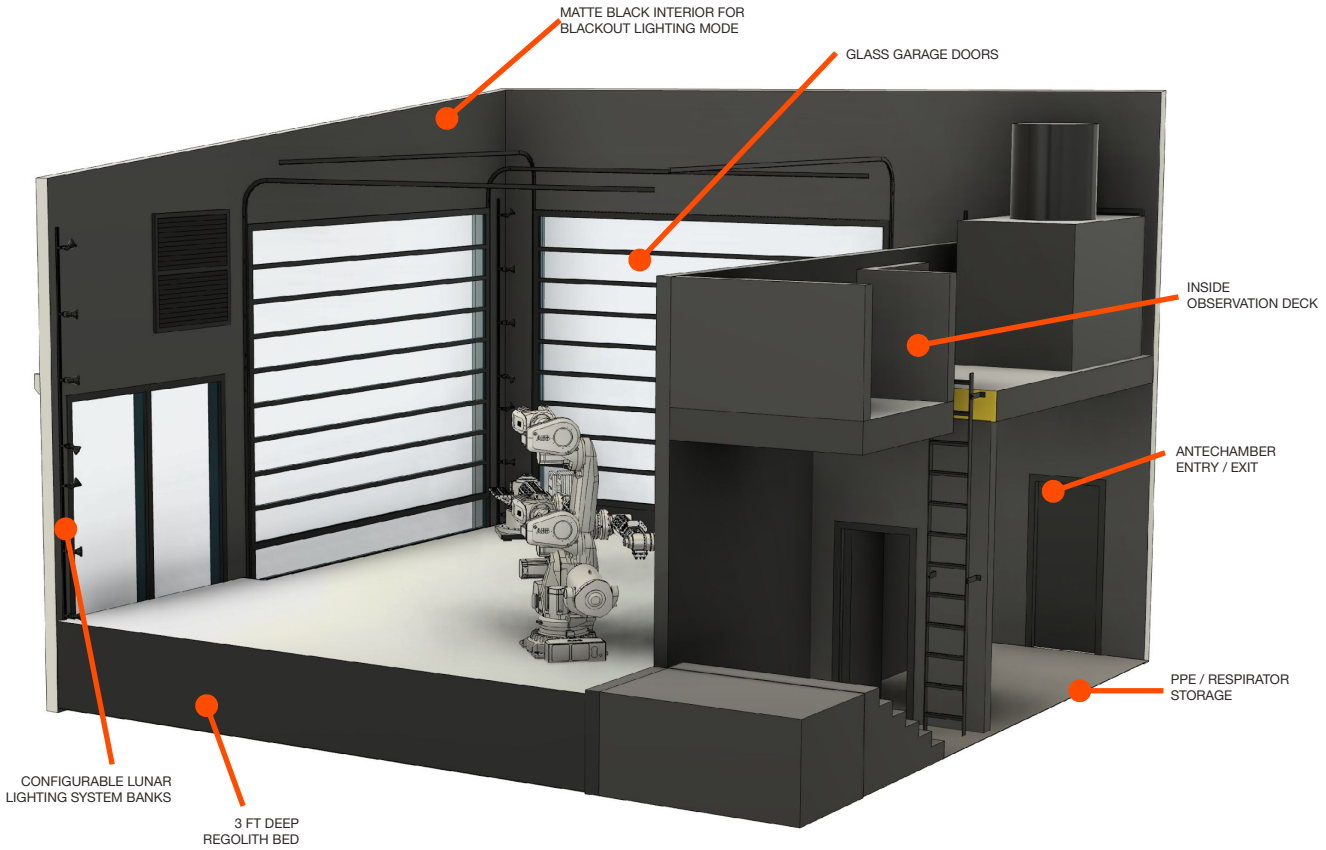
Lunar Surface Simulation Chamber

CHAMBER OPEN

CHAMBER SEALED

CHAMBER SAFE + BLACKOUT





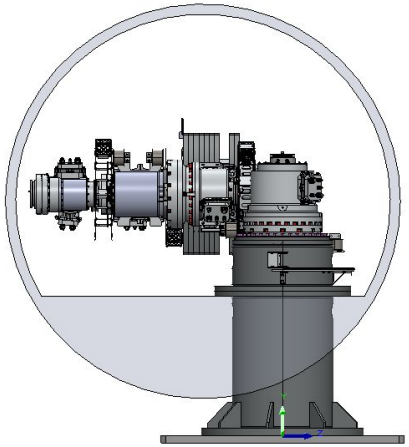
Testing services for ICON and partners

High Fidelity Space & Lunar Surface Simulation Chamber (Online Q2 2024)

78” ID // 90” Length Dirty TVAC Chamber
ICON Lab // Austin, TX

Capabilities:

- ➔ $10E^{-7}$ torr (~45 minutes to achieve $10E^{-6}$)
- ➔ -180°C to 100°C
- ➔ Highly modular vacuum ports (ISO 250, ISO 150, NW25, CF2.75, 4x CF10)
- ➔ Control system (automated pump down, temperature control, and vent)
- ➔ Available to the lunar community.



WWW.ICONBUILD.COM

Evan Jensen
Vice President of Strategic R&D
ICON Technology, Inc.
evanjensen@iconbuild.com