HELIOS

Space Resource RoundTable 2024

De-Oxygenated Regolith as a Potential Advanced Material for Lunar Construction Exploration

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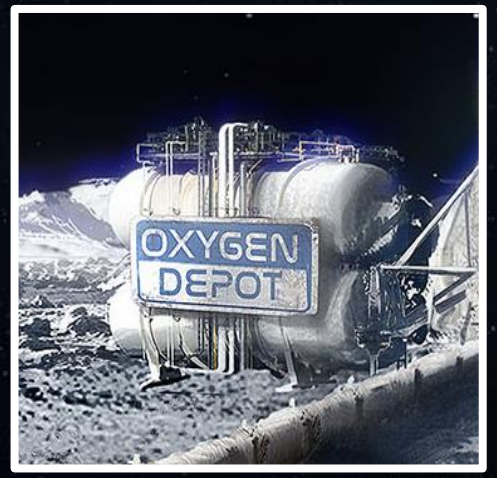
THE HELIOS STORY

- Established in 2018, as a space-tech company, developing technologies to enable the **separation of oxygen from lunar minerals** in extreme environments, where zero emissions are not an option but a necessity.
- Highlighting ISRU production of oxygen in the low gravity lunar environment, for use in life support and propellant, is crucial for the future of space exploration and development.

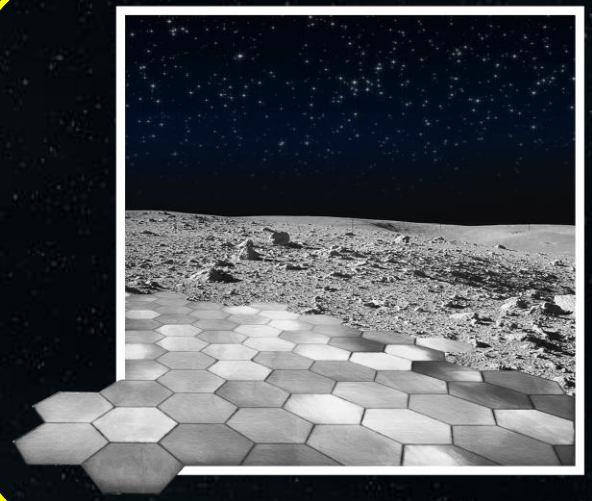
HELIOS CONTRIBUTION TO THE ISRU CONCEPT

- Helios is developing novel technology for the direct production of oxygen out of lunar regolith, where it is both ubiquitous and 42% of the total regolith weight.
- Helios's technology does not require consumables brought from Earth.
- Technology performs at a lower temperature than direct Molten Regolith Electrolysis (MRE).
- Produces high purity oxygen (above 99.6%) by physically separating the oxygen creation zone from the regolith melt zone.

What we contribute:



Oxygen gas for life support and LOX propellant

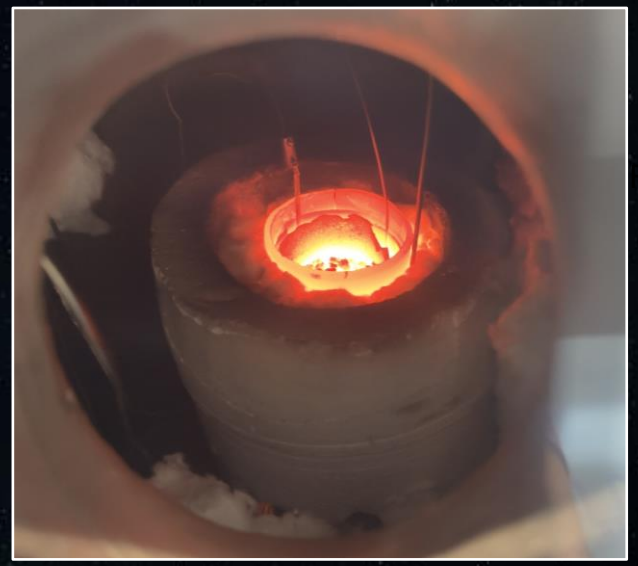


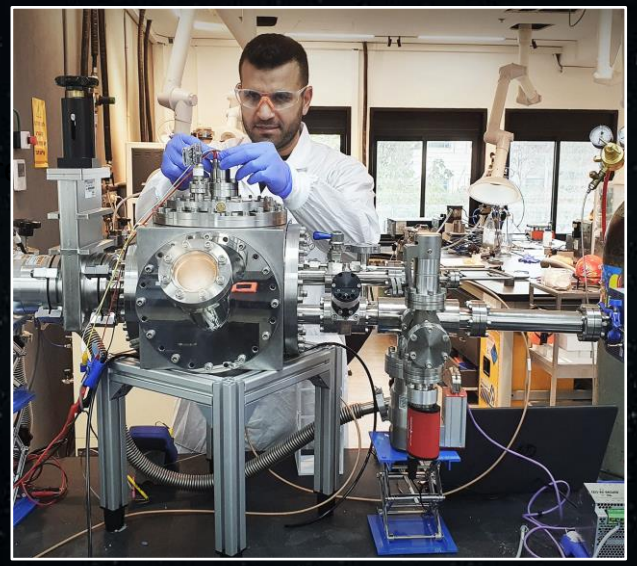
Construction raw Materials Heated Metal and de-oxygenated regolith (DOR)

HELIOS RESEARCH AND DEVELOPMENT TO DATE

- After years exploring MOE, Helios gravitated to developing cells based on solid-oxide electrolyzer cell (SOEC) technology.
- Currently, Helios is focusing on further developing “scaleup friendly” SOEC cells.

Monitoring abilities and upscaling





Initial oxygen production

Maturing technology

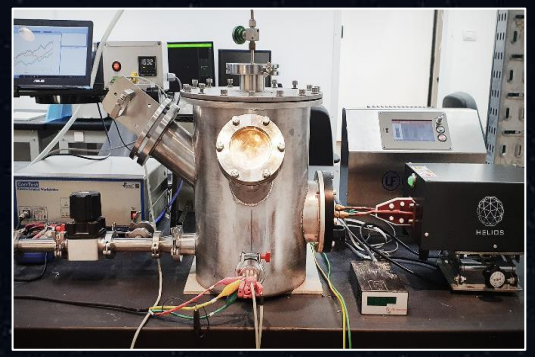
✓ CURRENT STAGE

OUR SCALE-UP APPROACH

Timeline

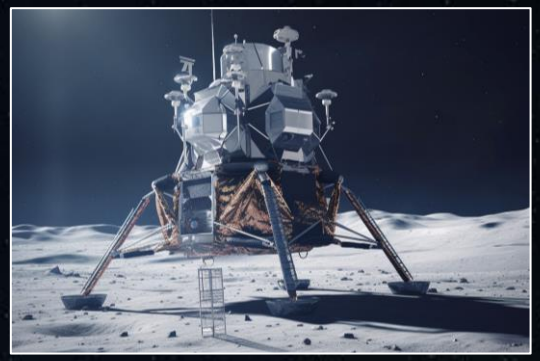
2022 | 2023 | 2028 | 2030 | 2035

MVP in Lab on Earth



Source: [Helios]

MVP on the Moon

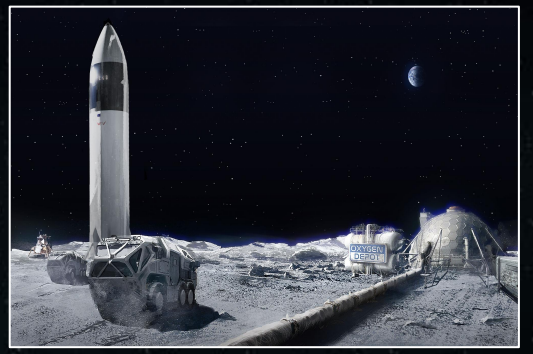


Source: [https://www.freepik.com]

Maximum Performance Unit (MPU) on the Moon

Source: [https://www.freepik.com]

Oxygen Production Plant (MPUs) on the Moon



Source: [Helios]

10^{-2} | 1 | 10^{3} | 10^{4} | 10^{5}

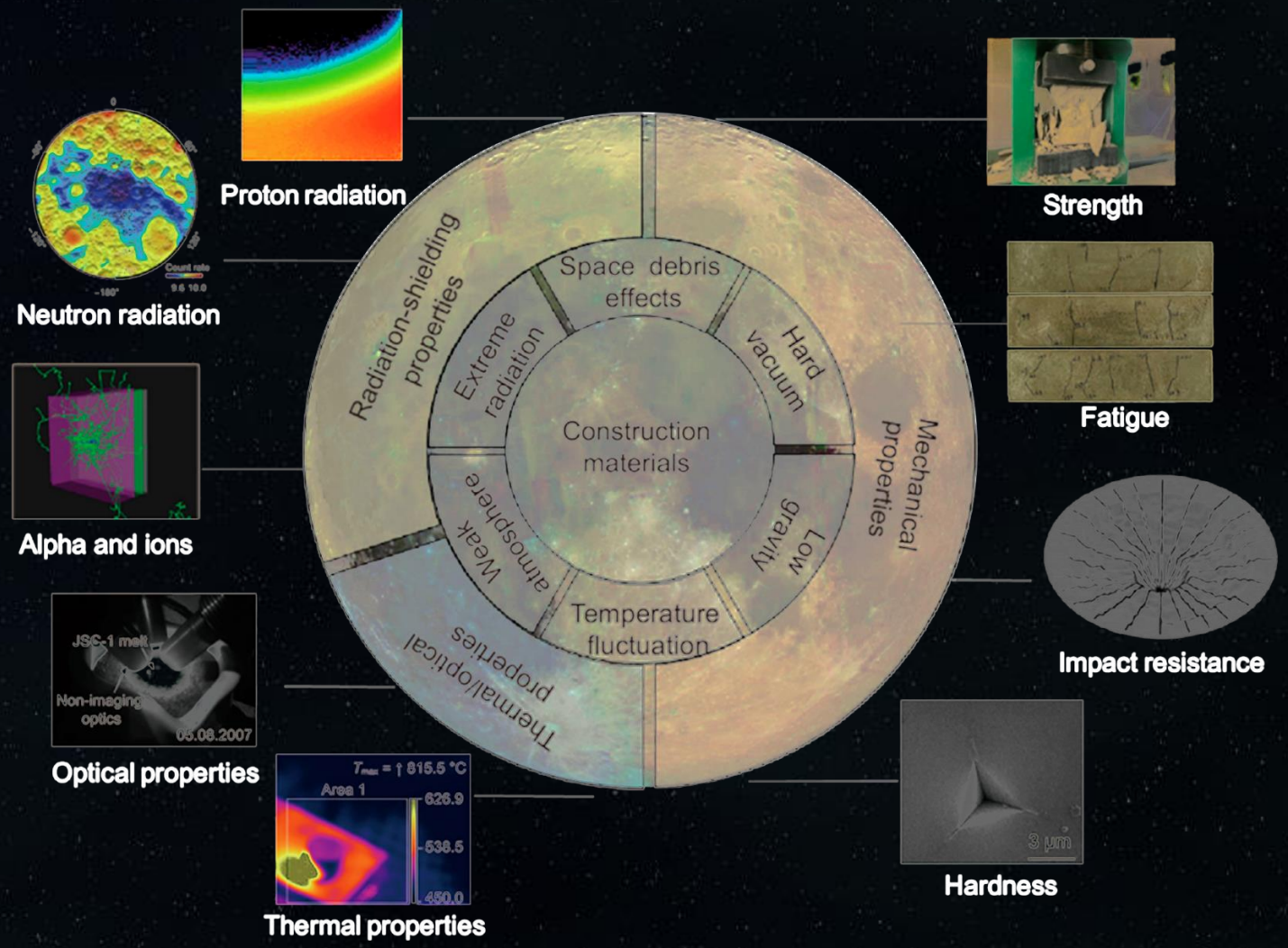
Kg DOR per Month

DOR can turn a burden into an asset!

REGOLITH-BASED MATERIALS FOR CONSTRUCTION

- Recent Studies extraterrestrial regolith-based materials have mainly focused on the forming principle or preparation and construction process.

- A comprehensive review that analyzes and compares the construction-related properties of these materials is lacking.



C. Zhou, Y. Gao, Y. Zhou et al. Engineering, 2024

CONSTRUCTION PROCESSES

Common extraterrestrial construction processes can be divided into two major types: **prefabricated assembly and 3D printing.**

3D PRINTING

By 3D printing, concrete or binders can be jetted to form the structures. Classical processes include D-shaping and contour crafting. Regolith can also be directly sintered by some 3D printing technologies, such as selective laser sintering and solar sintering.

Concept for a lunar base built by construction robots and a form of 3D printing known as contour-crafting. Credit: NASA

PREFABRICATED ASSEMBLY

In a prefabricated assembly, sintered regolith bricks and cured concrete are welded or bonded to form a structure. The interlocking process is made optional by applying interlocking bricks.

KLS-1 Lunar regolith simulant microwave sintered.
Y.-J. Kim et al. Ceramics International, 2021

SINTERED AND MELTED REGOLITH

- Typically, Basalt rock can exhibit 4-7X higher compression strength in compression than normal Portland cement concrete typically used on Earth.
- Sintered basalt regolith has achieved 206 MPa in compression tests.

(5X higher than Portland Cement concrete)- KSC Swamp Works with PISCES, Hawaii collaboration

	Portland Cement	Basalt
Density (Kg/m3)	2500-2900	2500-2800
Compressive Strength (MPa)	20-40	144-292

- Fully melting of lunar regolith simulant could be used for construction materials and support materials, associated with infrastructures of future lunar outposts.

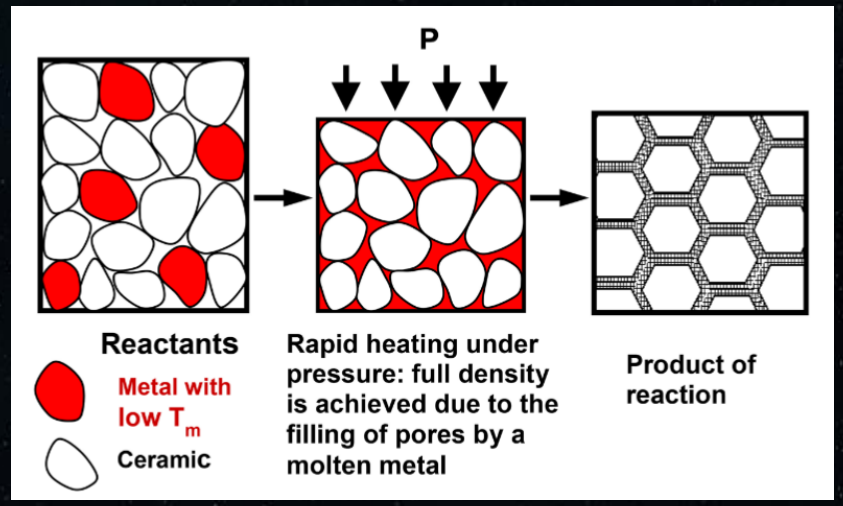
	Compressive Strength (MPa)	Vickers hardness (GPa)
HIT-L-1	98.1	6.09

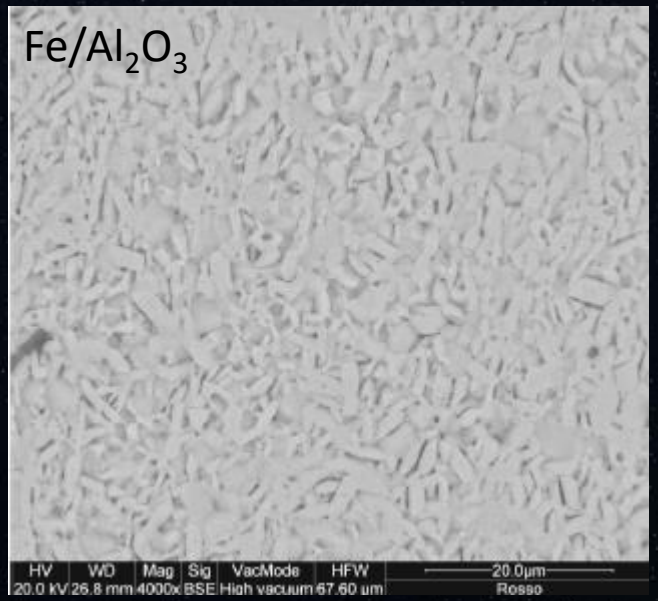
W. Zheng, G. Qiao, Advances in Space Research 69 (2022) 3130–3139

CERAMIC METAL COMPOUND (CERMET)

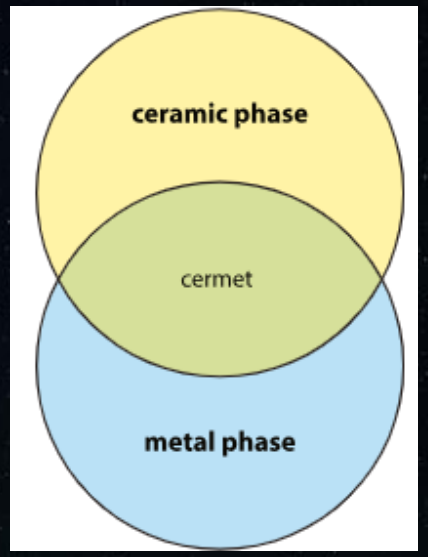
- A cermet can combine attractive properties of both a ceramic, such as high temperature resistance and hardness, and those of a metal, such as the ability to undergo plastic deformation.
- The metal is used as a binder for an oxide, boride, or carbide.
- Cermets are usually less than 20% metal by volume.

SDI (short distance infiltration) method





JMEPEG (2023) 32:4391–4403



Application	Composition
Cutting tools, dies, drills, jet blades, Wankel seals	WC–Co, (TiC, $MoSi_2$)–Ni
	TiC–Mo (W, Co), TiC–Fe
Nuclear fuels	UO_2–(U, Mo, W, Fe), PuO_2–Fe,
Control rods	U_3O_8–Al, UAl_2–Al, B_4C–Al
Bearing	BN–W, Fe–Fe_2O_3
	Fe–SiO_2, Fe–SiO_2–Graphite, Fe–Al_2O_3–Graphite
Thermocouple protection	ZrO_2–Mo, Al_2O_3–Mo, Cr_2O_3–Cr, Al_2O_3–W
Crucibles	Al_2O_3–Fe
Contacts	Graphite–Cu (Sn, Pb), CdO–Ag, BeO–Cu
Emitter cathodes	UO_2–Mo, Ba_2CaWO_6–W
Ignition pellets	Fe_2O_3–Al, BaO_2–(Al, Mg), ThO_2–Ca
Armour	B_4C–Al

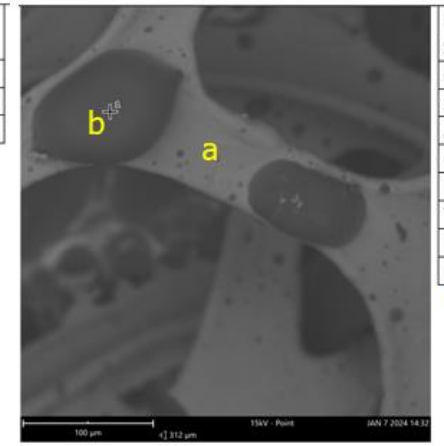
N. Travitzky, Advances in Applied Ceramics, 2012

HELIOS SYSTEM OUTPUT- DEOXYGENATED REGOLITH

- Along with oxygen production, the new class of de-oxygenated regolith (DOR) materials are two essential components of lunar infrastructure.
- One possibility is separating the iron and the silicon from the rest of the DOR and using them as feedstock for specialized types of infrastructure construction.
- Another possibility is the direct use of this ceramic-metal compound (cermet), which has the potential to represent unique mechanical properties.
- Vickers microhardness, measured with a LECO LM 247AT tester, was 6.19 GPa.

a

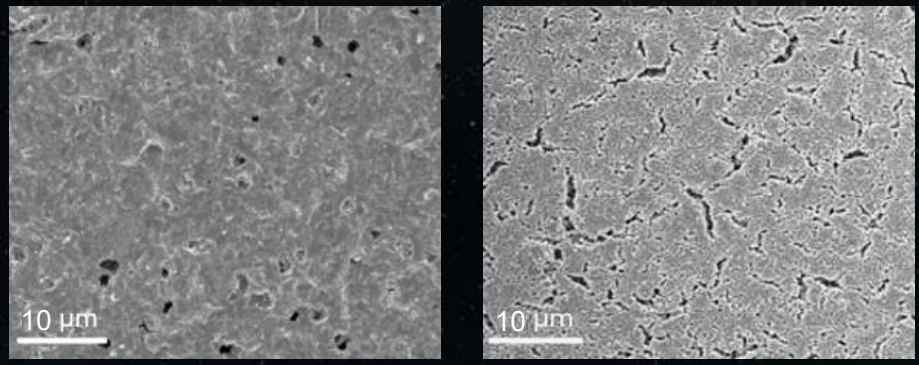
Element Symbol	Atomic Conc.	Weight Conc.
Ni	84.93	93.21
O	12.01	3.59
Fe	3.06	3.20



b

Element Symbol	Atomic Conc.	Weight Conc.
O	65.37	50.61
Si	17.92	24.35
Al	6.34	8.28
Ca	2.37	4.60
Mg	3.72	4.37
Ti	1.28	2.96
Ni	0.86	2.43
Na	2.16	2.40

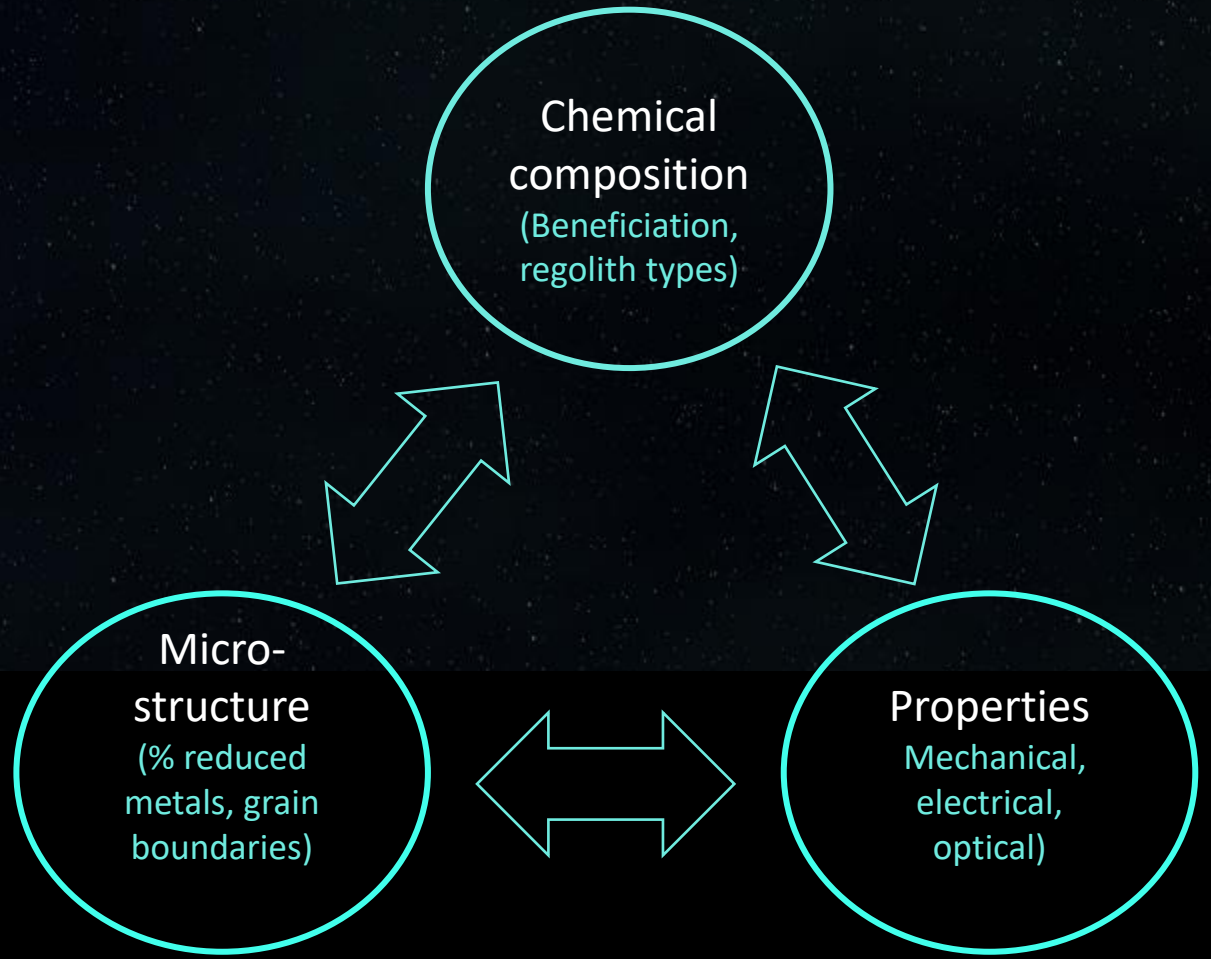
SEM-EDS chemical composition and x-ray spectra on the DOR on current collector.
(Phenom ProX Desktop SEM with energy-dispersive X-ray diffraction, 15 keV, 7.7 mm WD, 120 sec)



LMS-1 simulant post extraction at the region close to the current collector where extraction occur (right) and bulk (left)

FUTURE WORK

- How beneficiation affects the mechanical properties by mean of reduced metal content and oxide phases?
- Microstructure tuning exploration: needle like vs. curly flower or phases distribution.
- DOR Flow Dynamics for Efficient Continuous Reactor Flow.



BOTTOM LINE - DOR UTILIZATION

- Humanity's expansion to the Moon and beyond, will require the ultimate sustainable technologies when it comes to resource utilization.
- The environment in space is unforgiving, energy and mass brought from earth are exorbitantly expansive.
- Utilizing DOR for construction will save energy and costs, unlocking enhanced material properties that are more suitable to harsh space.
- Creating a marketable by product from LOX production, will improve the LOX unit economics, and the overall unit economics of cislunar space.

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Thank you!
SCAN ME
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OXYGEN
DEPOT