Manufacturing using waste from space resources for a circular space economy

Timon Schild[1,4], Gwenaelle Aridon[2], Anthony Lecossais[2], Melchiorre Conti[3], Dennis Harries[1], Kathryn Hadler[1]

[1]European Space Resources Innovation Centre
[2]Airbus Defence & Space
[3]European Space Agency
[4]University of Luxembourg

Context

Space resources and lunar exploration

Image credit: Luc Viatour, CC BY-SA

Long term exploration target is the establishment of a **permanent lunar research outpost**

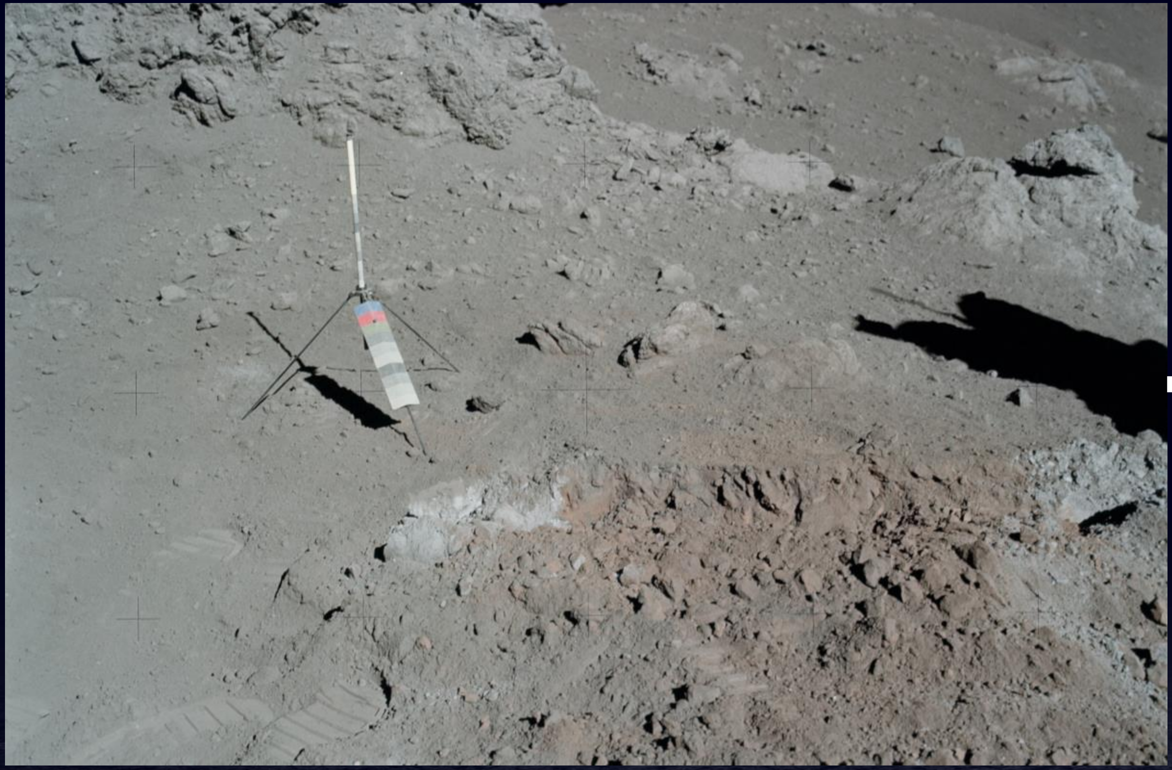
Requires:

- Large amount of construction material and consumables
- High degree of autonomy and resilience
- Efficient use of resources available
- Local and in-orbit refuelling capabilities

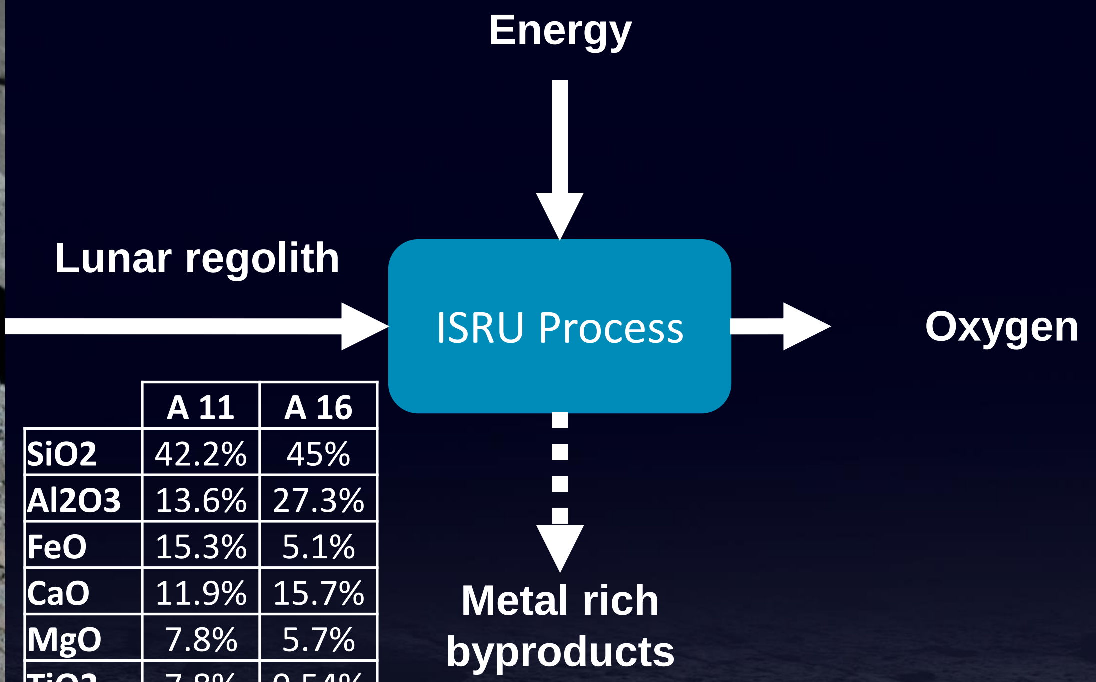
→ Circular economy and use of local resources are essential

Context

Oxygen production from lunar regolith



Apollo 17 orange soil at Shorty Crater, NASA



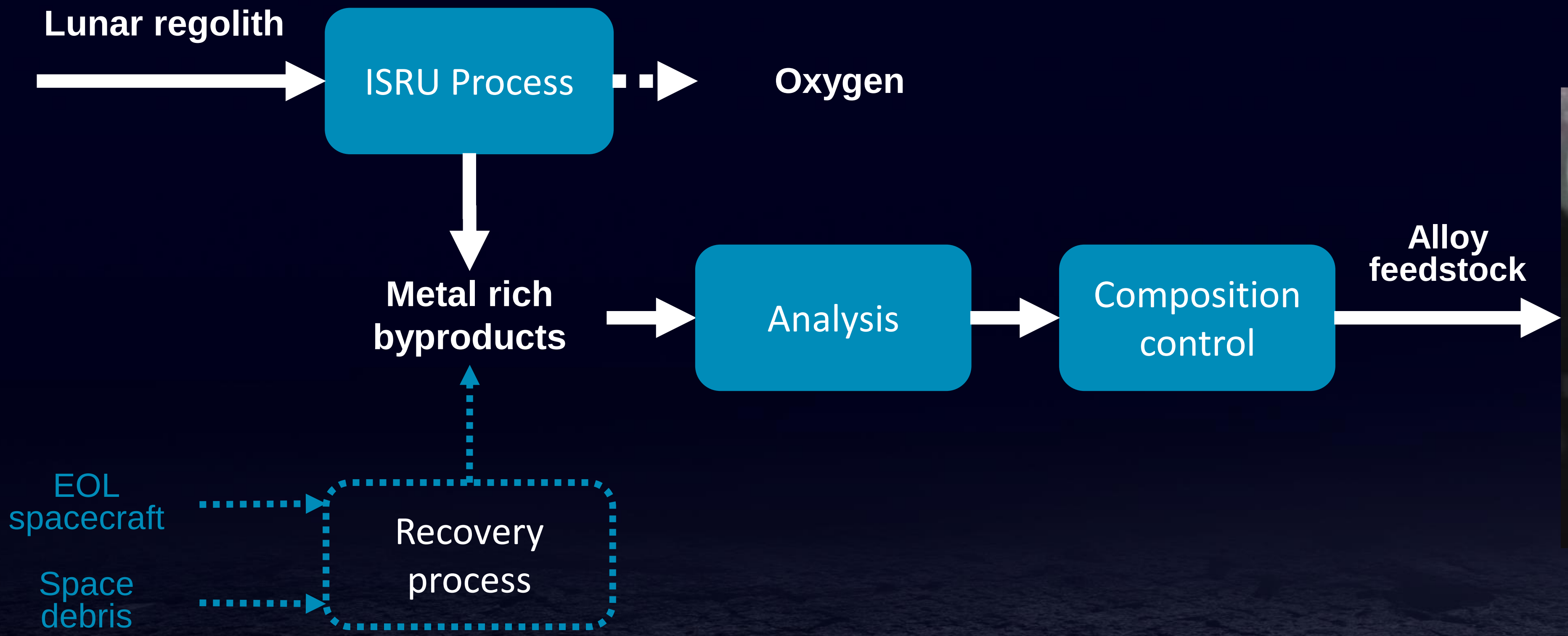
	A 11	A 16
SiO_2	42.2%	45%
Al_2O_3	13.6%	27.3%
FeO	15.3%	5.1%
CaO	11.9%	15.7%
MgO	7.8%	5.7%
TiO_2	7.8%	0.54%

(adapted from McKay, 1991)

esric

Objectives

End-to-end process from regolith to alloy parts

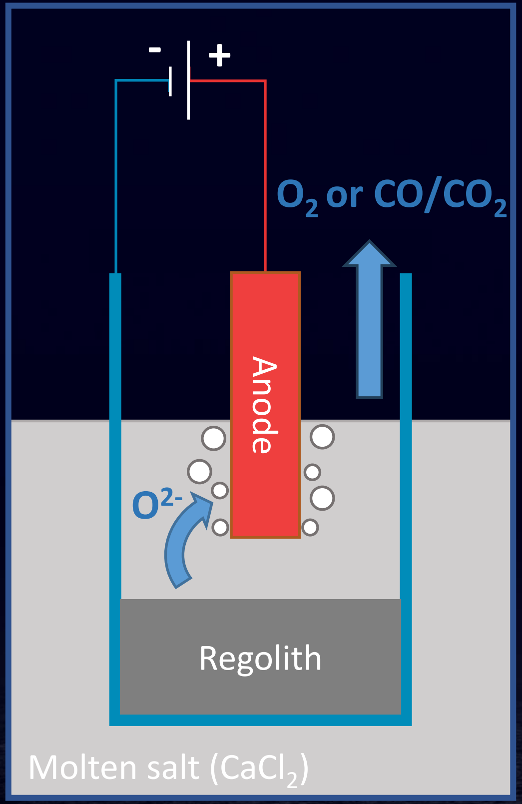


Airbus' Metal3D in-space additive manufacturing system

Image credit: Airbus

Powered by: esa, LUXEMBOURG SPACE AGENCY, LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY LIST

FFC molten salt electrolysis



Description:

Electrochemical process to remove oxygen from metal oxides, yielding pure metals

Current status:

- Has been demonstrated to **extract up to 96% of oxygen** present in lunar regolith simulants (Lomax et al., 2019)
- Operational **prototype reactor at ESA-ESTEC**, processing 25g of simulant in 24h

Upcoming developments:

- Investigation of **metal products** recovery and refinement
- Demonstration of **end-to-end process** with Metal3D
- Next generation prototype **at ESRIC by early 2024**

Powered by: esa LUXEMBOURG SPACE AGENCY LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY LIST

Preliminary results

Material production

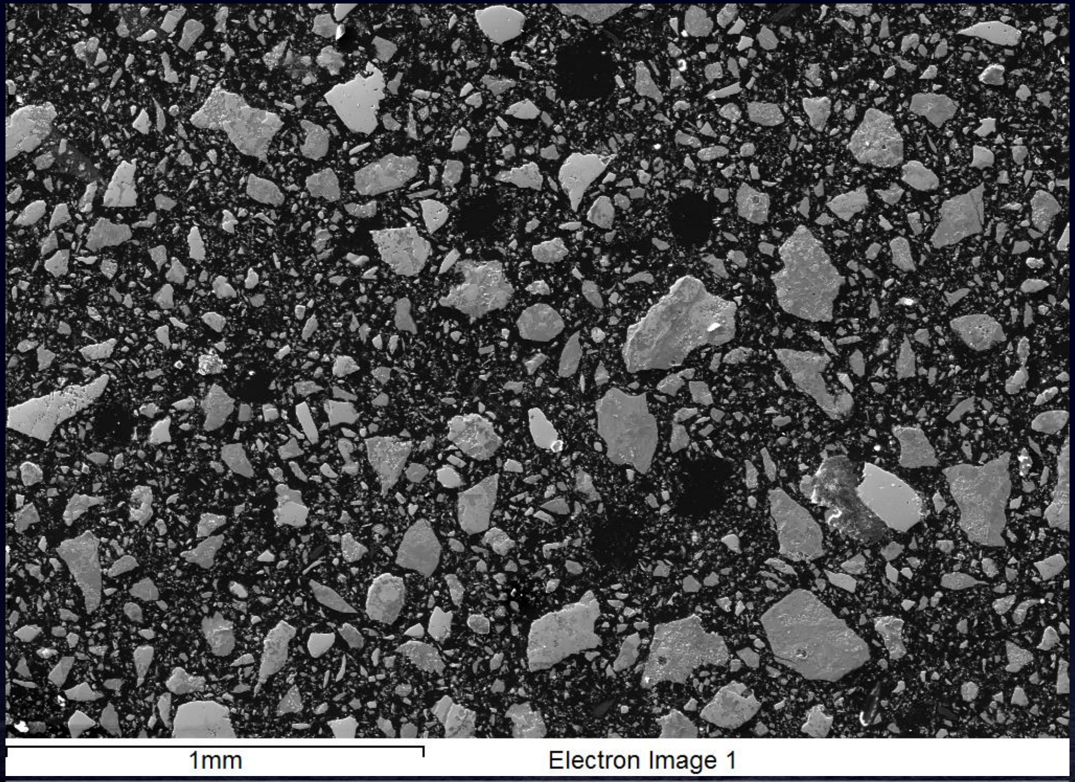
LHS-1 highland regolith simulant feedstock

Solid material recovered after FFC process

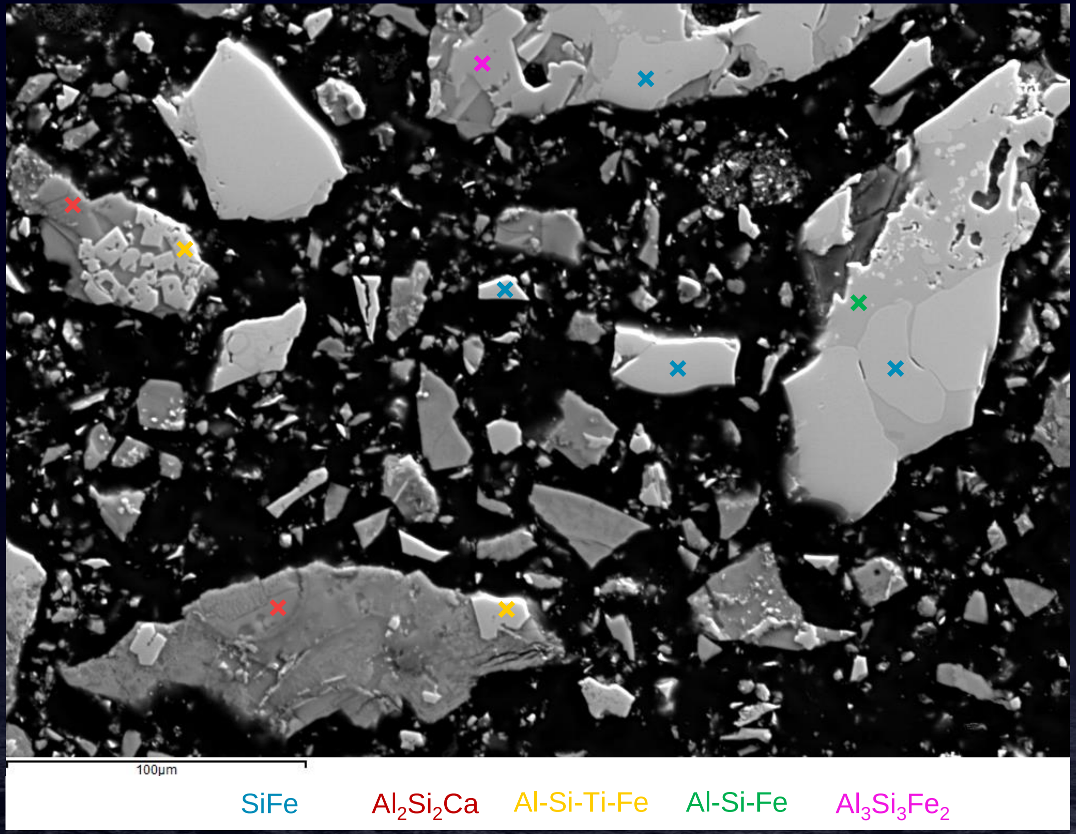
Preliminary results

Material characterization (SEM-EDX)

Low magnification SE image of solid product (coarse size fraction)



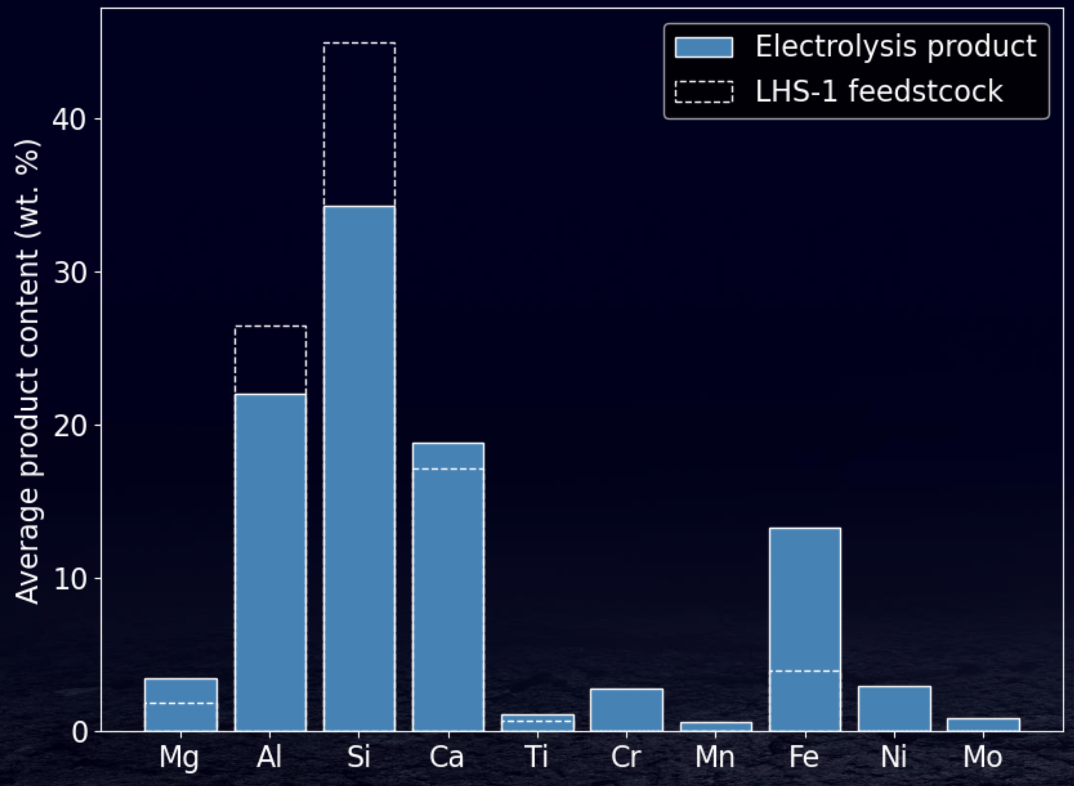
Higher magnification SE image of solid product (coarse size fraction)



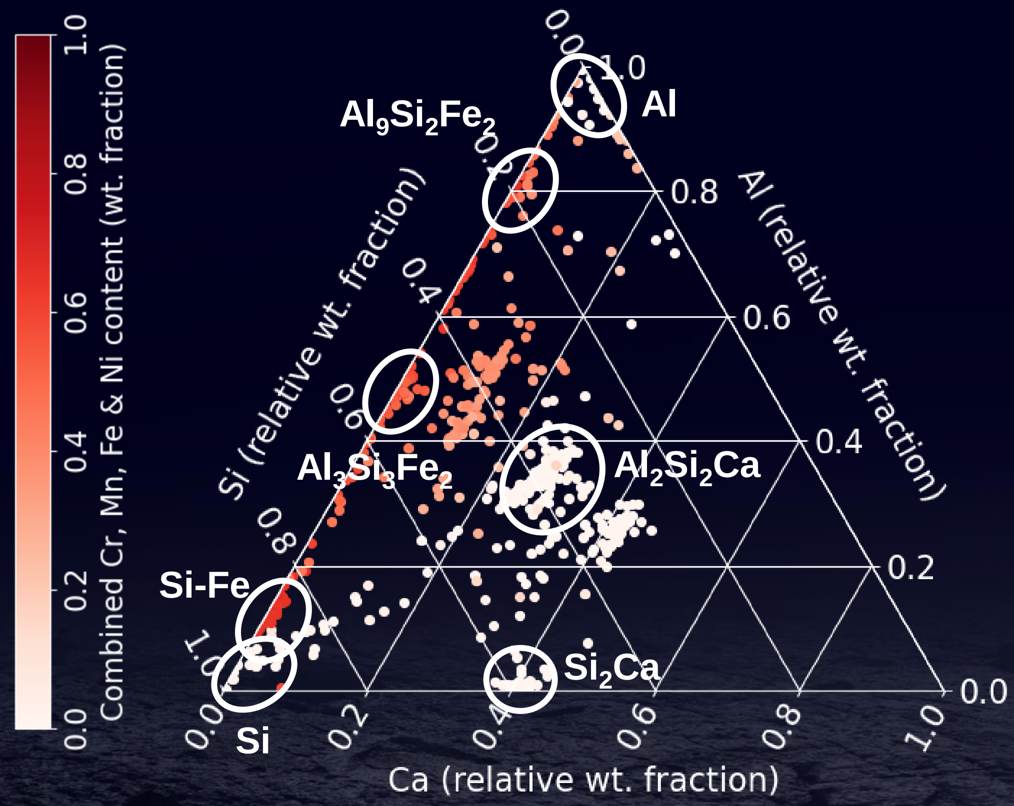
Preliminary results

Material characterization (SEM-EDX)

Average composition of product obtained from LHS-1 feedstock



Local compositions of phases mapped in Al-Si-Ca-Fe system



Conclusion

Current findings

- Product **mostly composed of Al, Si, Ca & Fe**, presence of Mg, Ti & stainless steel
- **Ca-rich and Fe-rich phases** tend to be separated
- Notable phases include **Al_2Si_2Ca, SiFe, $Al_3Si_3Fe_2$, Si_2Ca, Si, Al**
- As little as **3 wt.% residual oxygen** in recovered product

→ **Al-Si alloys can be a target end product**

Conclusion

Upcoming work

Conclusion

Links between ISRU and clean space

- **Materials:** Heterogenous mixture of metals, with prevalence of Al alloys
- **Environment:** Processes must be adapted for in-space operations
- **Circularity:** Need for closed loop, zero-waste approach

Thank you!

References

McKay, D.S., Heiken, G., Basu, A., Blandford, G., Simon, S., Reedy, R., French, B.M., Papike, J., 1991. *The Lunar regolith*, in: Heiken, G., Vaniman, D., French, B.M. (Eds.), *Lunar Sourcebook: A User's Guide to the Moon.* Cambridge University Press, pp. 285–356.

Lomax, B.A., Conti, M., Khan, N., Bennett, N.S., Ganin, A.Y., Symes, M.D., 2020. Proving the viability of an electrochemical process for the simultaneous extraction of oxygen and production of metal alloys from lunar regolith. Planetary and Space Science 180, 104748. https://doi.org/10.1016/j.pss.2019.104748