Taking SOM to the Moon: A Lunar Demonstrator for Oxygen and Metals Extraction from Regolith based on the ROXY Process

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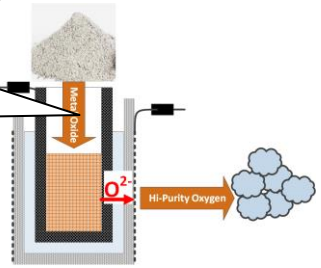
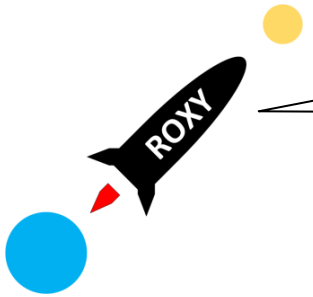
Overview

Introducing Mini-ROXY for lunar ISRU



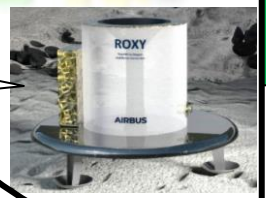


Preparing a Mini-ROXY lunar demonstration mission

Requests for Interest

Now Open for Application

RFI´s for scientific collaboration

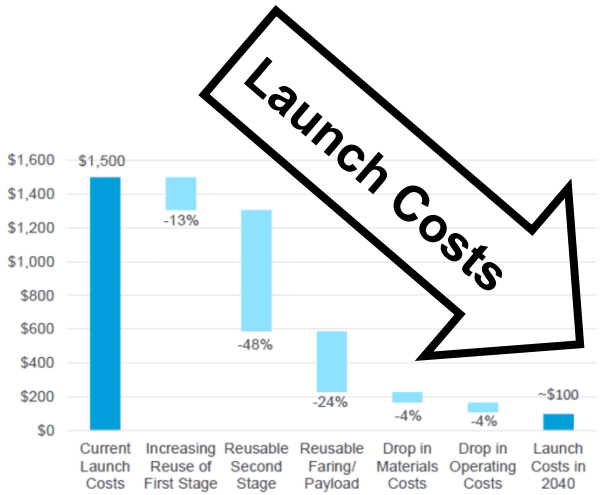


Searching for collaborators for lunar demo mission

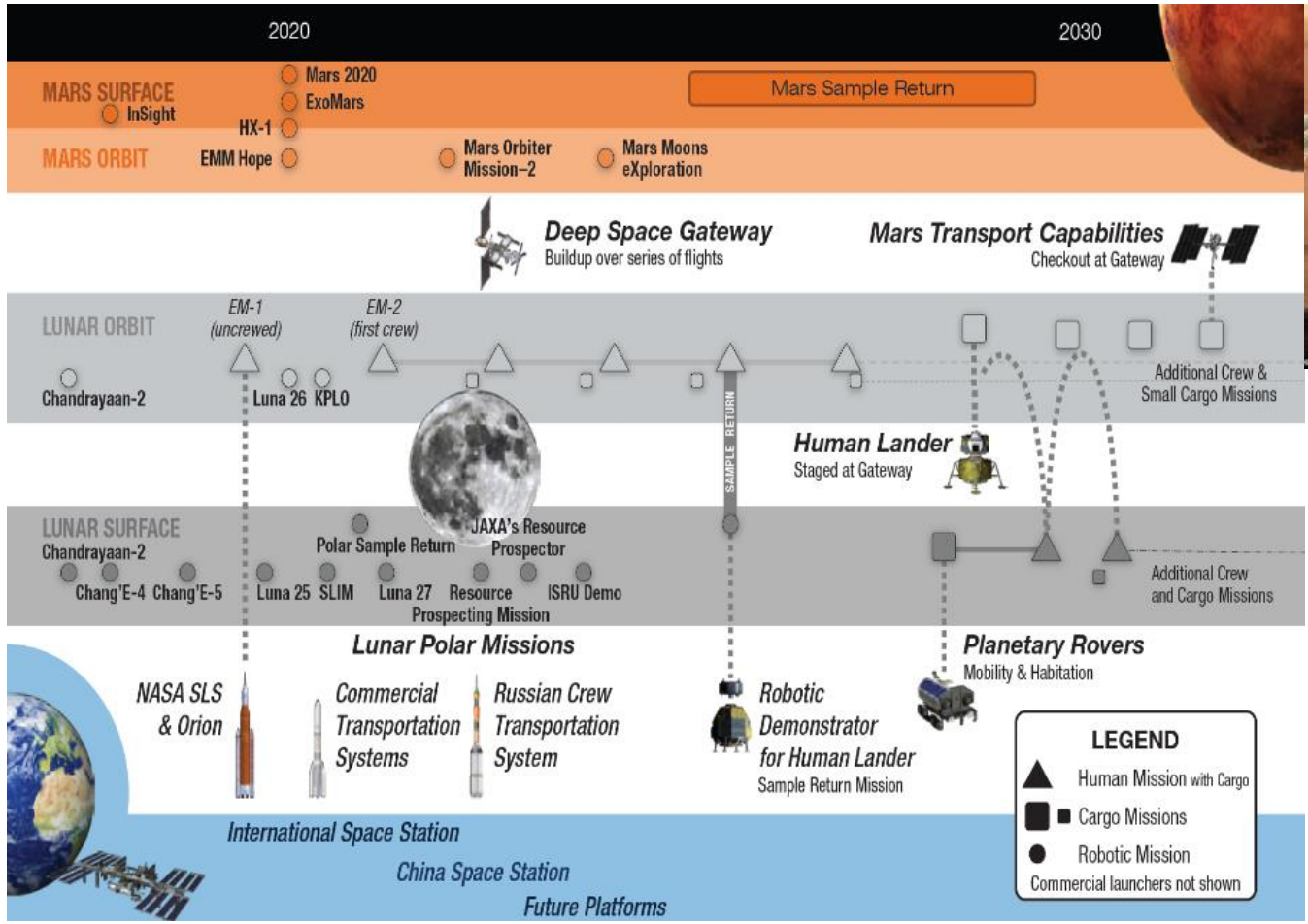
Further Reading

Link to RFI

Space Exploration: Evolving Mega-Trend



https://www.cnbc.com/2022/05/21/space-industry-is-on-its-way-to-1-trillion-in-revenue-by-2040-citi.html, 21.05.2022



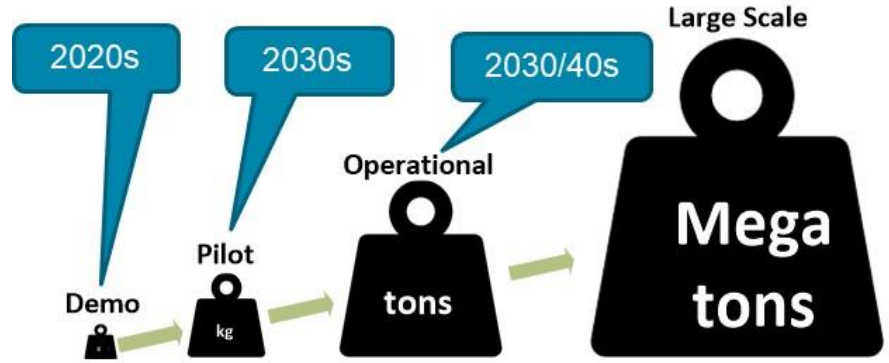
Mars City 2117

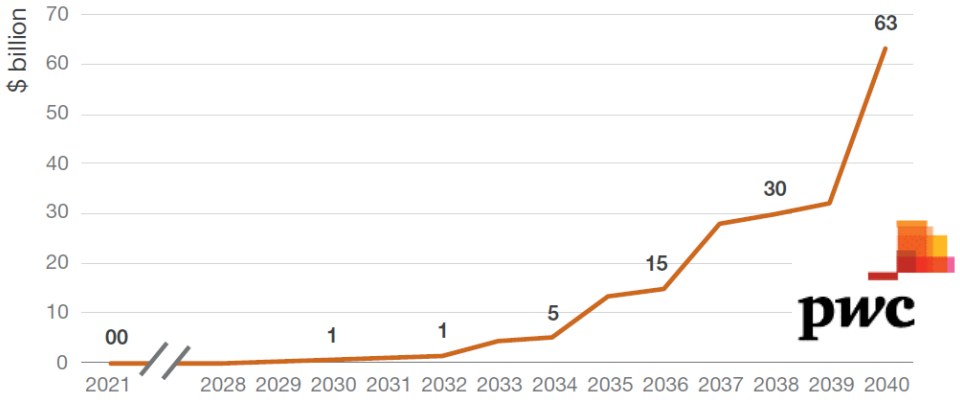
References: www.globalspaceexploration.org; hpshplaidline.org/2017/03/24/mars-2117-uaes-city-of-the-red-planet/

The next 100 years

ISRU: Enabler for Space Exploration

- The costs to transport resources from Earth to the Moon or even Mars are prohibitive
- Need to produce the major resources locally
- ISRU: In-Situ Resource Utilization
- ISRU is an enabler for space exploration
- ISRU will grow exponentially over the next decades
- Commercial demand ~ tens to hundreds of tons O_2 p.a. by 2030
- Demand for silicon and metals will soon follow





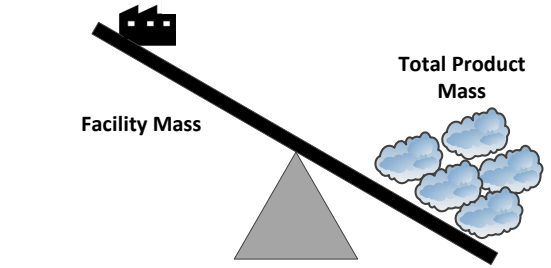
Evolution of the cumulative SRU market size "tremendous economic potential"

References: picture: A. Seidel et al, "MEFAM - The Metals Factory on the Moon", Space Resource Week 2022, Luxembourg; chart: Price Waterhouse

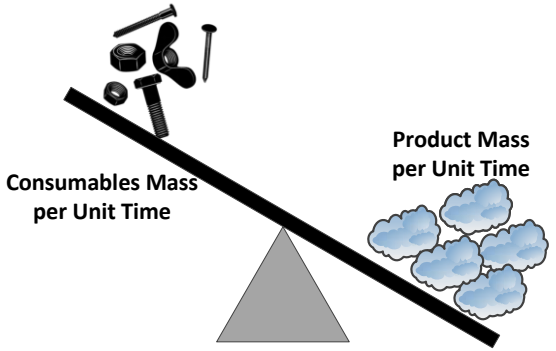
ISRU Viability & Scaling

The promise of ISRU

- Affordable exploration
- Minimized upload

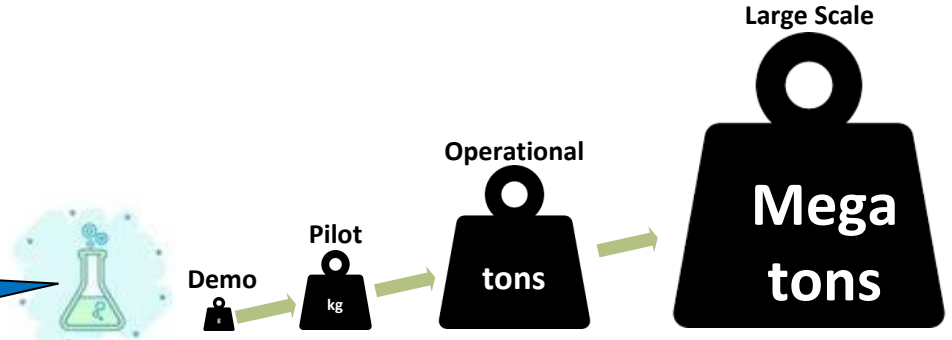


Need a low-mass facility with high efficiency



Need to minimize spares and consumables

Scaling: from ground demo to large scale



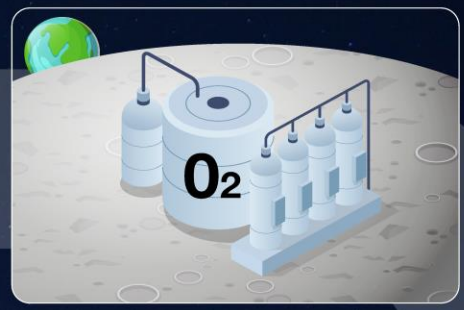
Need a process that is relevant for scale-up

Made on the moon

In the 2030s, Airbus tech being developed today could lead to the first oxygen and metal plant on the Moon producing the life-basics for human settlement. This is how it works.

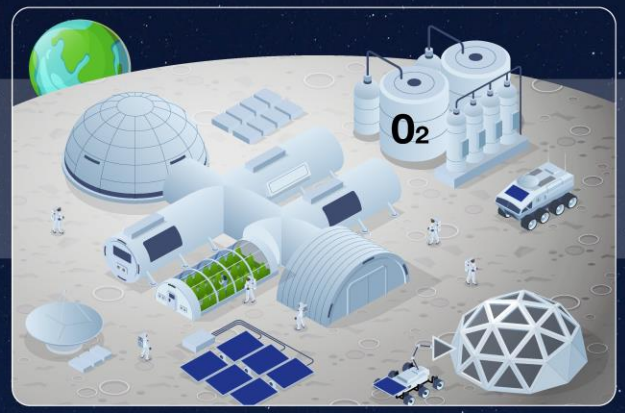
Lunar demonstrator will produce a few grams of oxygen from regolith by 2026/2027.

The oxygen produced here will be used for demo purposes.

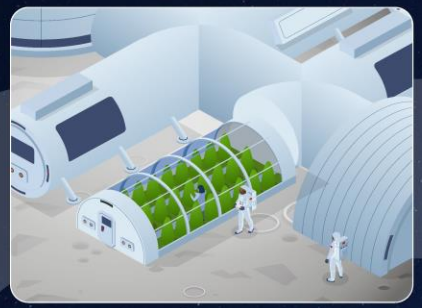


Pilot plant will produce 500 kg of oxygen per year by 2030.

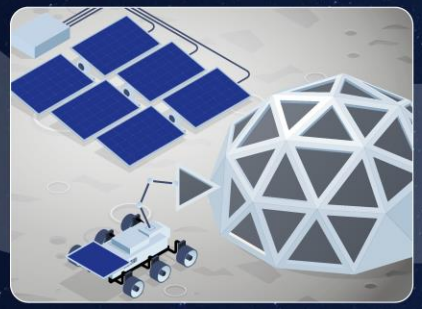
500 kg of oxygen can support a 28-day 4-crew mission needing about 112 kg of oxygen and about 300 kg of oxygen for water.



In the mid 2030s the plant will produce about **50 tons of oxygen per year.**



Oxygen and water will be provided to living quarters.Oxygen will also be provided to space suits.



Metal powder produced by the plant will be used to 3D print construction materials for habitats and raw materials for in-space manufacturing.

Oxygen is combined with hydrogen extracted from lunar ice **to produce rocket fuel** for spacecraft and satellites.

AIRBUS

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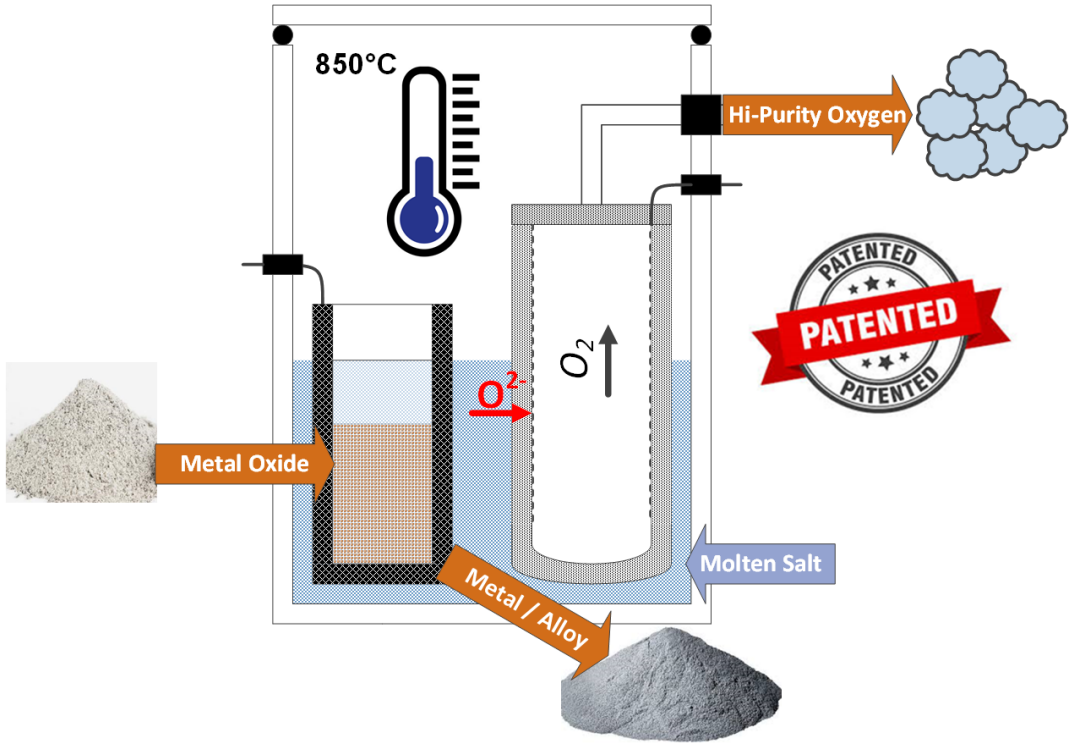
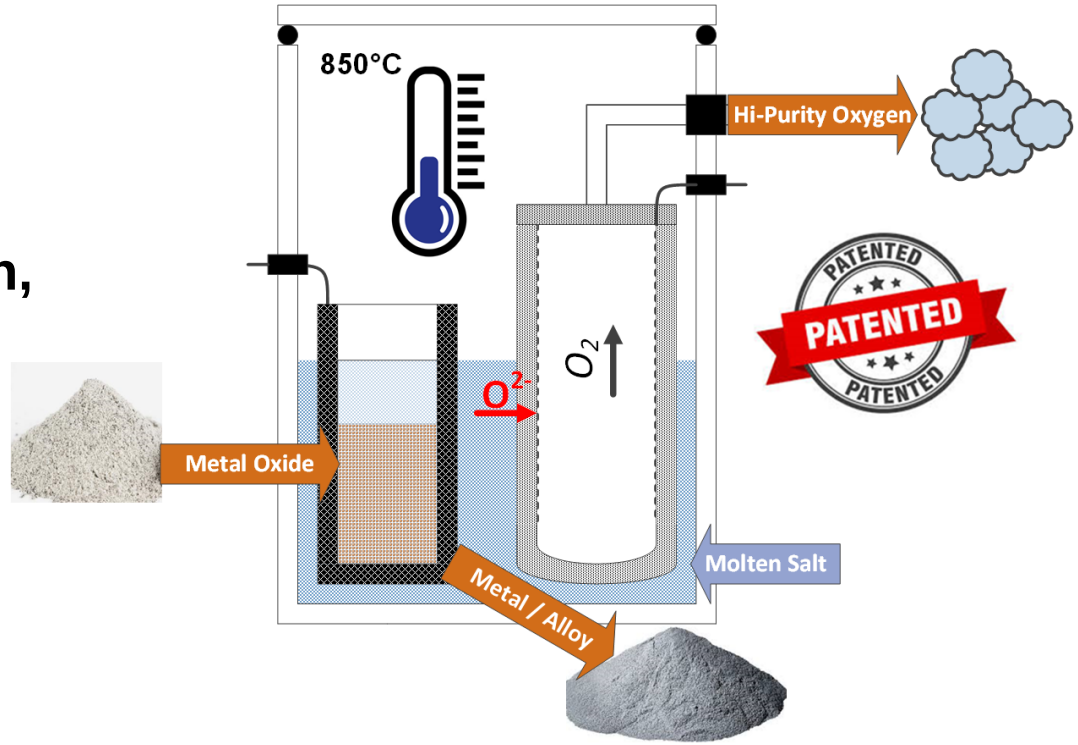
Introducing ROXY
(Regolith to Oxygen and Metals Conversion)

- ROXY has been specifically conceived for oxygen and metal extraction from lunar regolith
- Invented by Airbus, based on a long heritage of the SOM process developed by Boston University
- ROXY meets all of the ISRU viability criteria
- ROXY is a molten salt electrolysis process
- Operation in vacuum, no process gas, direct production of hi-purity oxygen, production of metal powder



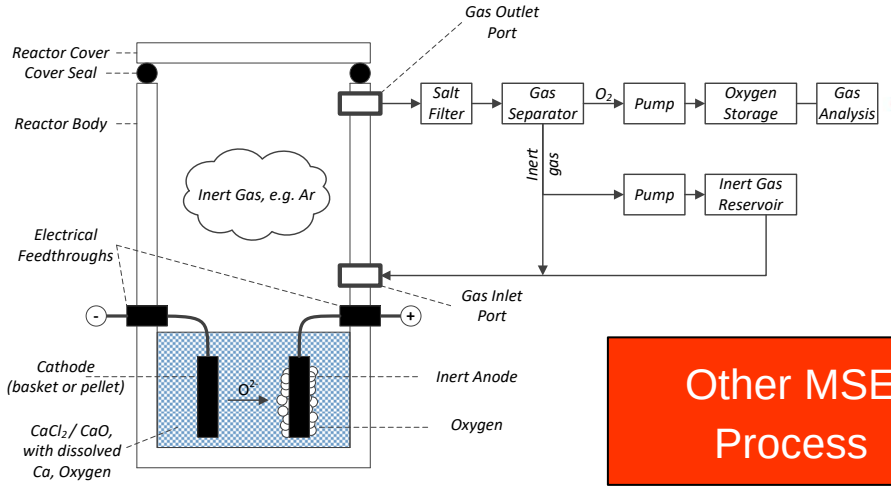
The ROXY Process Explained

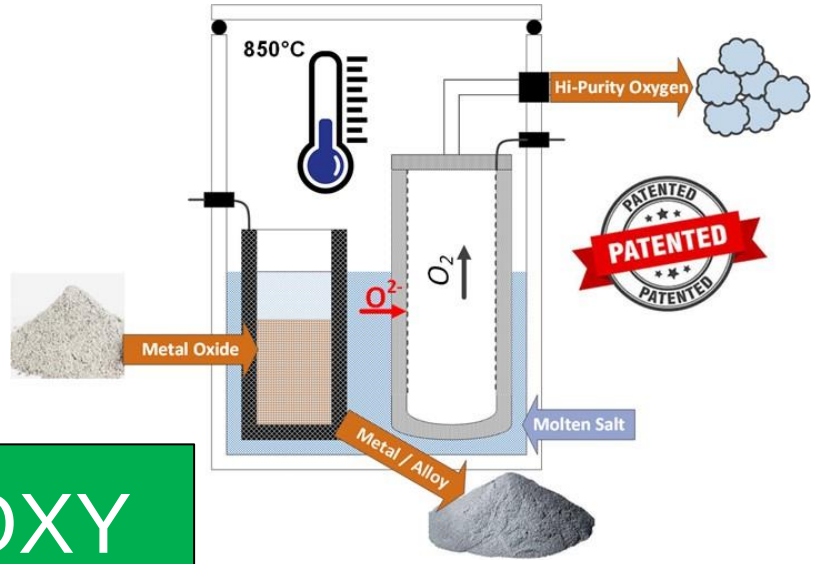
- Molten salt electrolysis of metal oxides
- Fluoride salts & solid oxide membrane "SOM" anodes
- Low reaction temperature (850°C)
- Reduces all regolith constituents
- Regolith containment by porous metal cathodes
- Built-in state of the art O_2 separation, purification, and measurement
- No molecular oxygen in the reactor
- Does not need a process gas
- Has no issues with gas bubbling in low gravity
- High energy efficiency that increases with increasing reactor size



ROXY Benefits

- Direct one-step production of oxygen
- Largely consumable-free process
- No corrosion issues with reactor, cathode and reduced regolith due to molecular oxygen in the reactor
- Near 100% current efficiency
- Much simpler, smaller reactor
- Lower complexity and mass
- Higher energy efficiency





Other MSE Process

ROXY

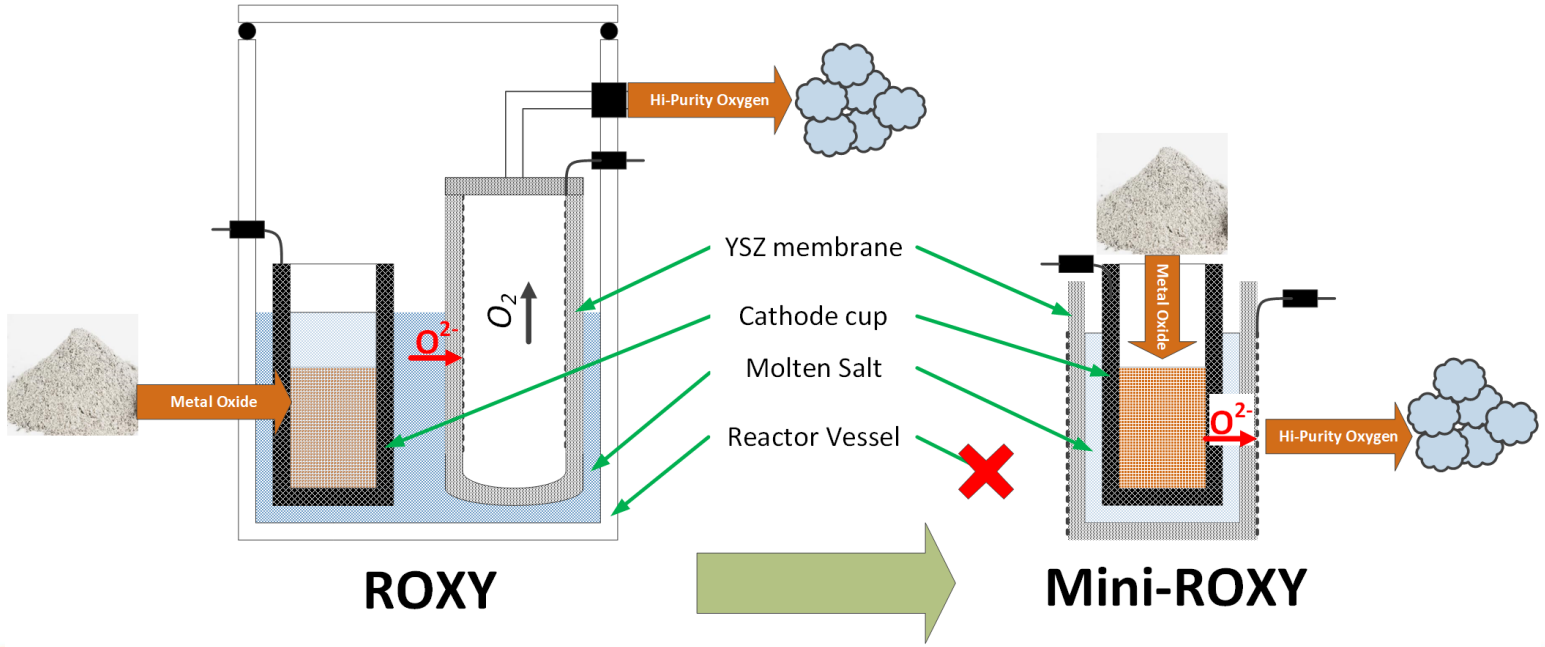
Mini-ROXY:
The Next Step Towards Resource Efficiency

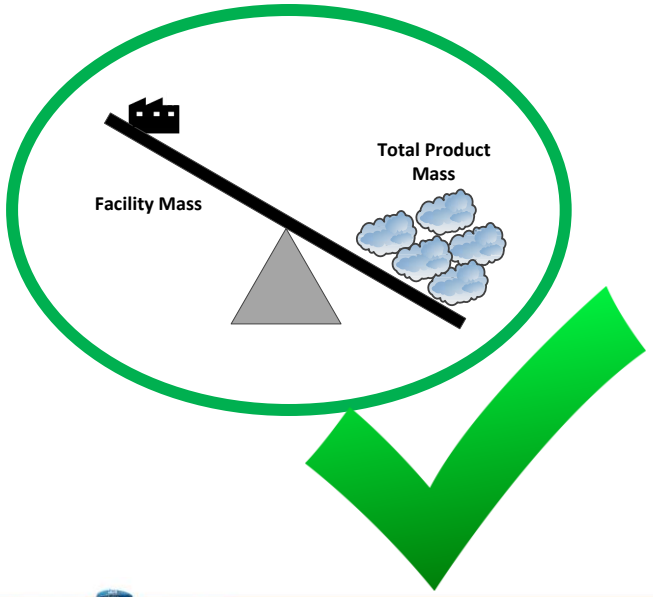
Principle

- **Elimination of the reactor vessel**
- **Use of the YSZ tube as crucible**

Features

- **Much smaller form factor**
- **Further mass reduction**
- **Flexible power needs via thermal insulation**





The Making of ROXY

AIRBUS — Airbus R&D — BOSTON UNIVERSITY — Fraunhofer IFAM

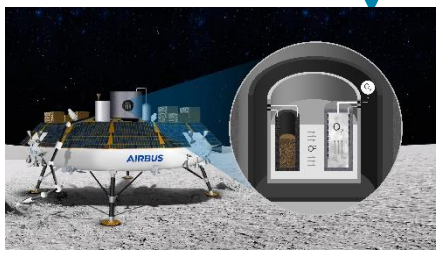
Fraunhofer IFAM — DLR Project — AIRBUS — BOSTON UNIVERSITY — TU BERGAKADEMIE FREIBERG

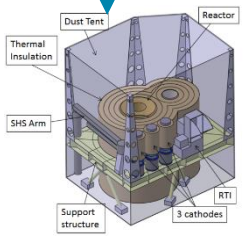
ROXY

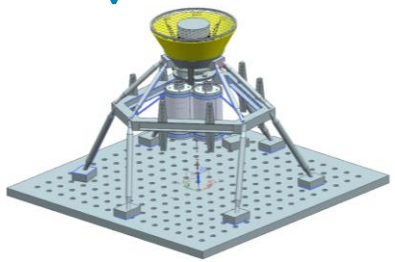
BOSTON UNIVERSITY | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 …

- 20 years of heritage
- ISRU studies
- ROXY invented
- Proof of Concept
- Mini-ROXY invented
- Proof of Concept
- Start lunar demo preps
- Performance demo
- Start Lunar Mission Development

Lunar Demonstrator Development







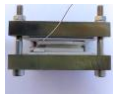
Mini-ROXY Lunar Demo: Where We Are

Previous Work

Performance ✓

Key technical issues ✓

Bench test campaign ✓



Lunar design concept ✓

Resource estimates ✓

Lunar environment assessment ✓

Vacuum: vacuum-compatible process, no process gas, Dust: no process gas – no sealing issues, Gravity: no gas bubbling, no liquid transport

Today

Ongoing Work – DLR Project

Ground test campaign

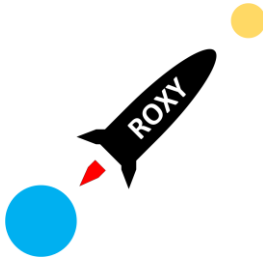
Lab Model

Process characterization

Lunar demonstration preparations

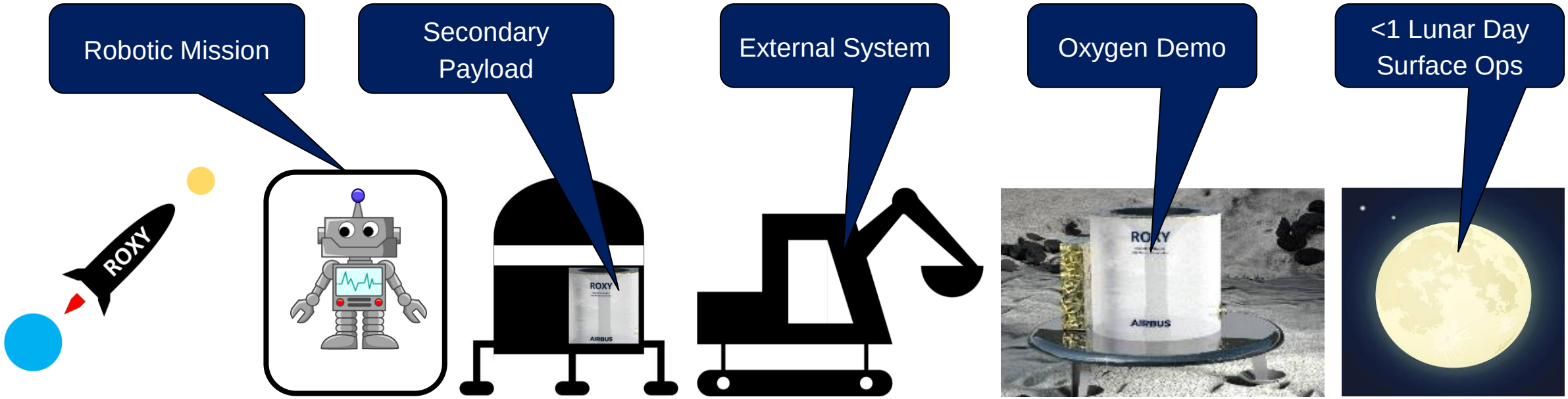
System design

Development planning



Mission assessment

Mini-ROXY Lunar Demo Mission Concept



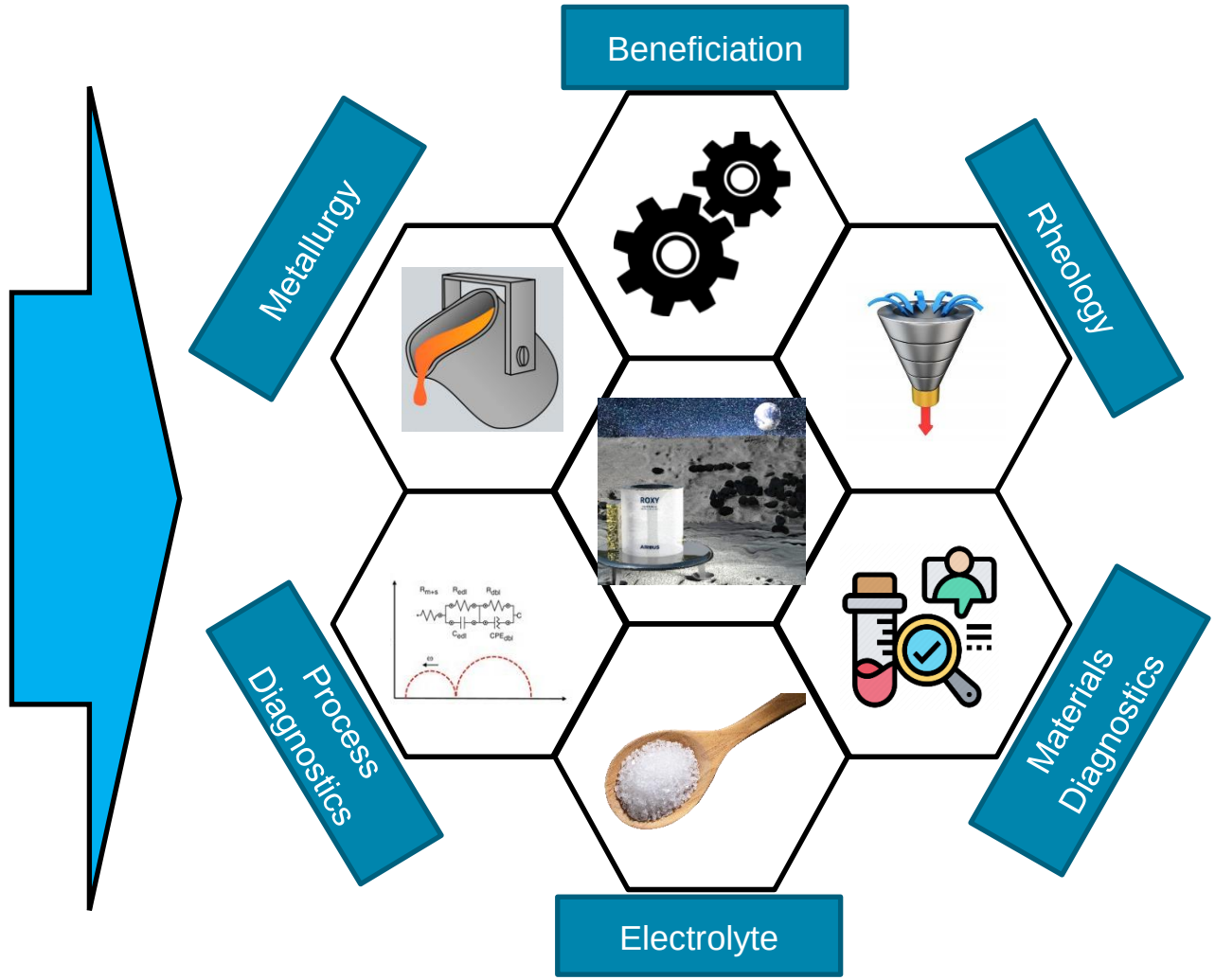
Mini-ROXY Mission Objectives & Science Disciplines

Understand…

- **the properties of the feedstock by analyzing the feedstock and determining its rheological, physical, mineralogical, and chemical properties.**

- **the regolith reduction process, its performance and limitations, under lunar environmental conditions, in particular related to reduced gravity, vacuum, build-up of electrostatic charge, and true regolith.**

- **the characteristics of the product, particularly the amount and purity of oxygen produced.**



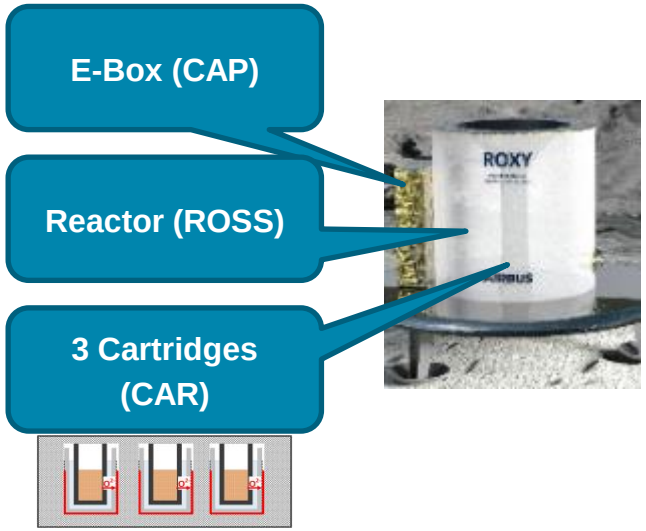
Mini-ROXY Lunar Demonstrator

Mission Objective

- Produce 1 liter of O_2 and characterize processes

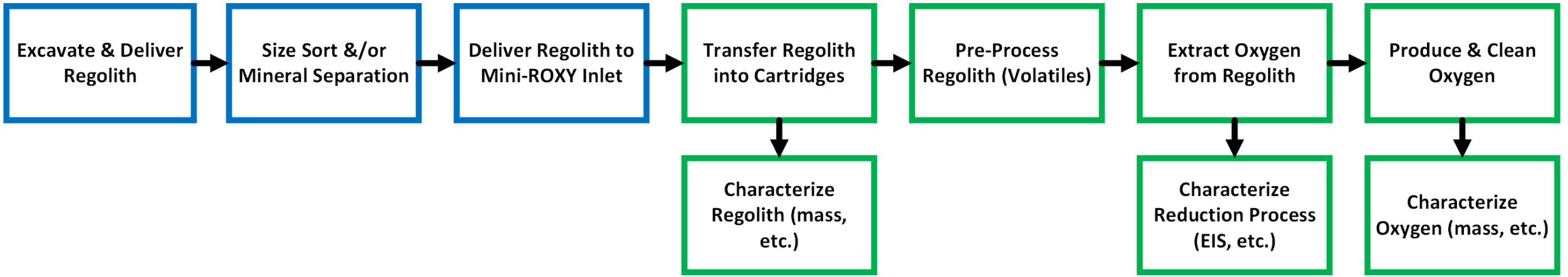
Design Concept

- Mini-ROXY is the result of a radical simplification exercise
- Features are reduced to the bare minimum needed to achieve mission objectives
- “Minimum Viable Product”
- External elements from other partners (e.g. NASA) are needed to perform mission

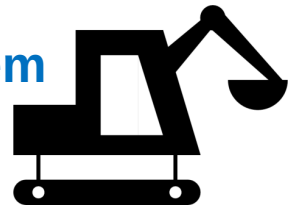


Mini-ROXY Lunar Demonstrator

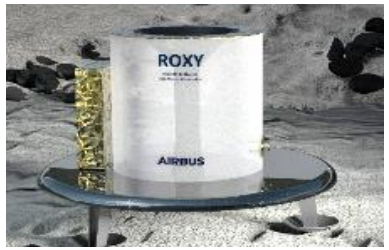
Main Functions



External System

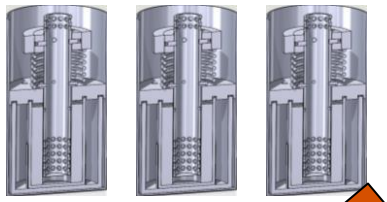


Mini-ROXY



Mini-ROXY Lunar Demonstrator

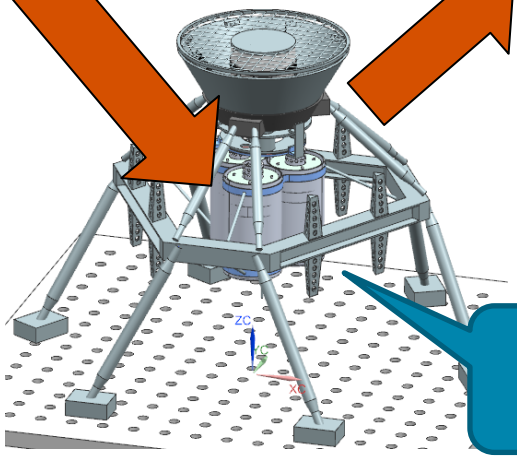
3 Cartridges



Mini-ROXY Lunar Demonstrator

~30cm

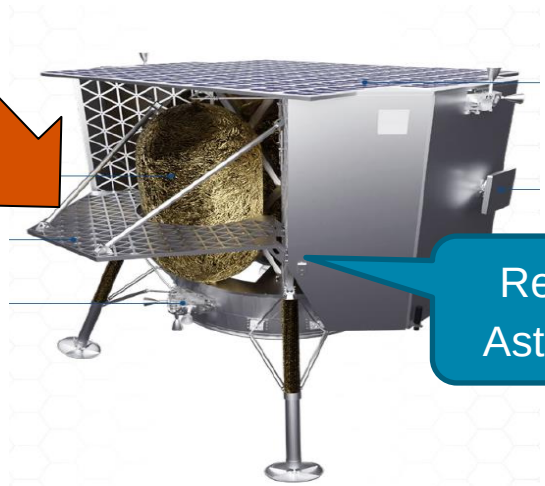
~50cm



Thermal insulation removed

Main features:

- 3 cartridges
- 1 liter of O_2 per cartridge
- < 1 lunar day ground ops
- Process diagnostics via EIS
- Mass ~ 30kg

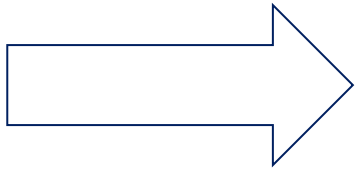


Reference Lander: Astrobotic Peregrine

Lunar Mission Preparation Roadmap

Ground test campaign

Lab Model



Process characterization

DLR Project

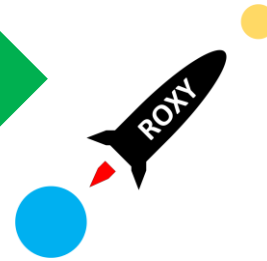
Lunar demonstration preparations

System design

Development planning

Phase B
Development Model

Phase C/D
Flight Model



Scientific Mission Preparation

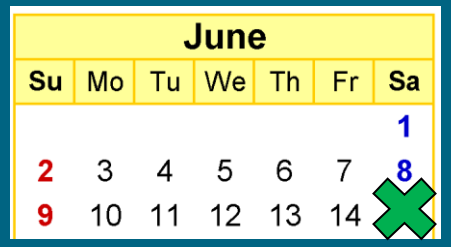
Request for Interest - Now Open for Application

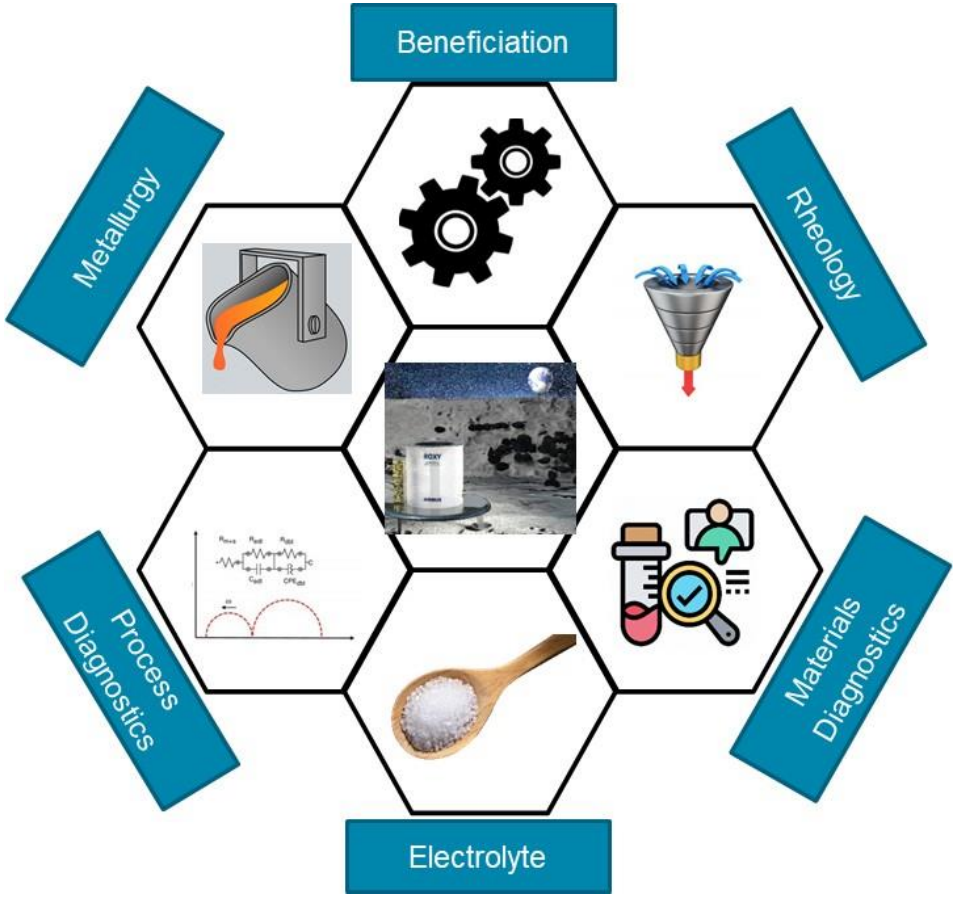
Searching for parties interested in scientific collaboration for a Mini-ROXY lunar demo

Target Groups

- Universities
- Research Institutions
- In the US and Germany

Application Deadline





More Information

Fraunhofer IFAM

https://www.ifam.fraunhofer.de/en/Aboutus/Locations/Dresden/Cellular_metallic_materials/aerospace.html

Interested? Please contact us here at TMS or send a message

Conclusions

- ROXY is an innovative process to extract oxygen and metals from lunar regolith that meets the viability criteria for ISRU
- Lunar ROXY facilities will be very attractive due to their compactness, low mass, low power consumption, and high efficiency
- The advanced Mini-ROXY concept is the next step towards resource efficiency and basis for upscaling towards larger lunar facilities
- Mini-ROXY will allow a low-cost lunar demonstration of the ROXY process, with short development time, and flexible accommodation options on a variety of landers or rovers
- Work in preparation of a Mini-ROXY lunar demonstration mission has started
- We are looking for collaborators for the scientific preparation of the mission

Acknowledgements

- The ROXY and Mini-ROXY development work was funded by Airbus

- The current Mini-ROXY lunar demonstration project is funded by the German Space Agency DLR

- The SOM heritage work was conducted at Boston University over many years and funded by different industries, the National Science Foundation, and the Department of Energy

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Further Reading & RFI

White Paper NASA NTRS

Request for Interest Fraunhofer IFAM

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