

Mini-ROXY: The next step towards an efficient method for oxygen extraction from regolith

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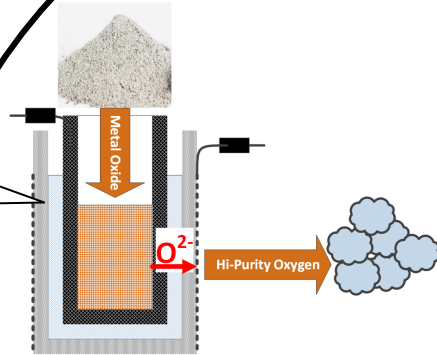
⁴TU Bergakademie Freiberg, Germany

⁵German Space Agency DLR, Germany

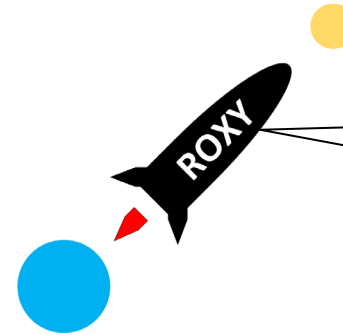
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Presentation Overview

Introducing Mini-ROXY for lunar ISRU – the next step towards resource efficiency



Preparing a Mini-ROXY lunar demonstration mission

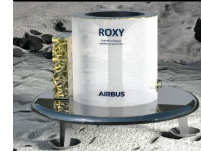


Searching for collaborators for lunar demo mission

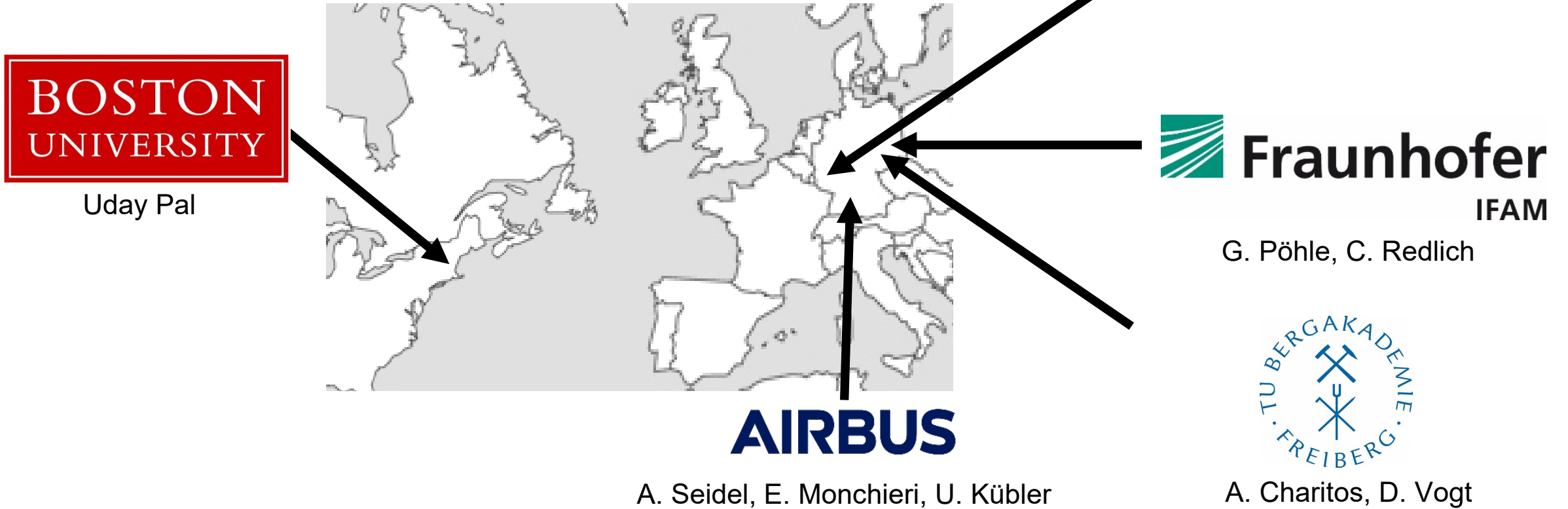


Requests for Interest
Now Open for Application

RFI's for scientific collaboration and hardware contributions for payload



Collaborators



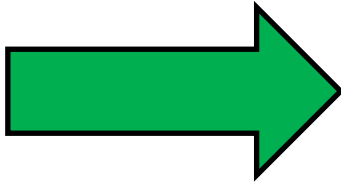
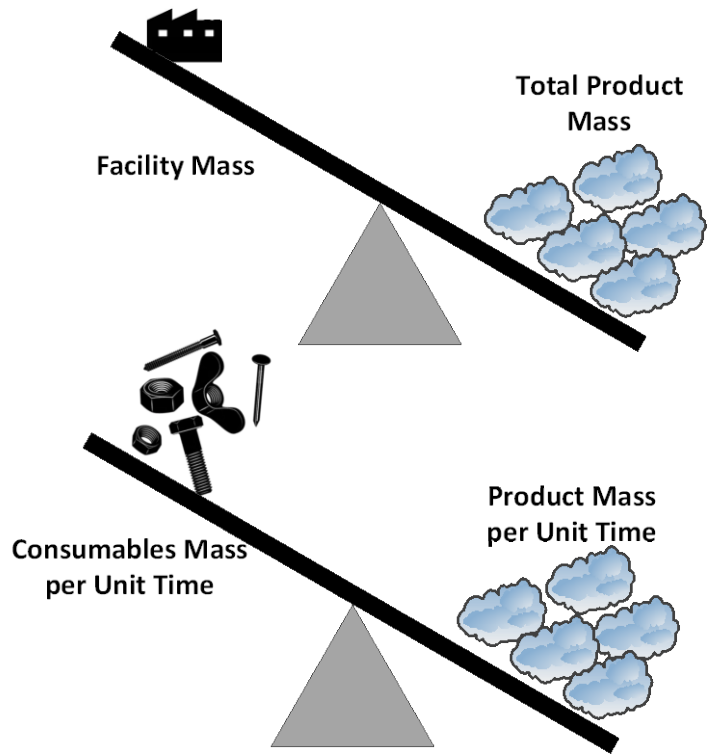
ISRU viability & scaling



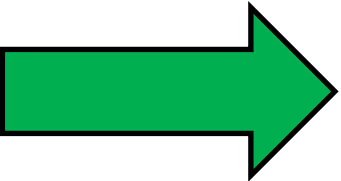
The promise of
ISRU

Affordable
exploration

Minimized
upload

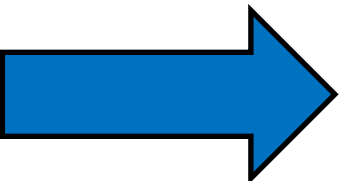
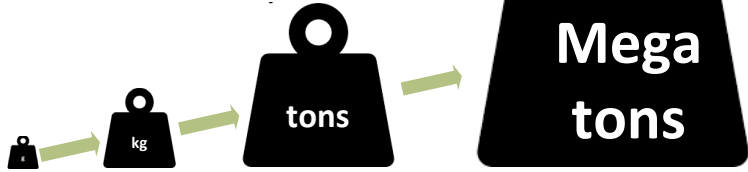


Need a low-mass
facility with high
efficiency



Need to minimize
spares and
consumables

Scaling: from ground
demo to large scale



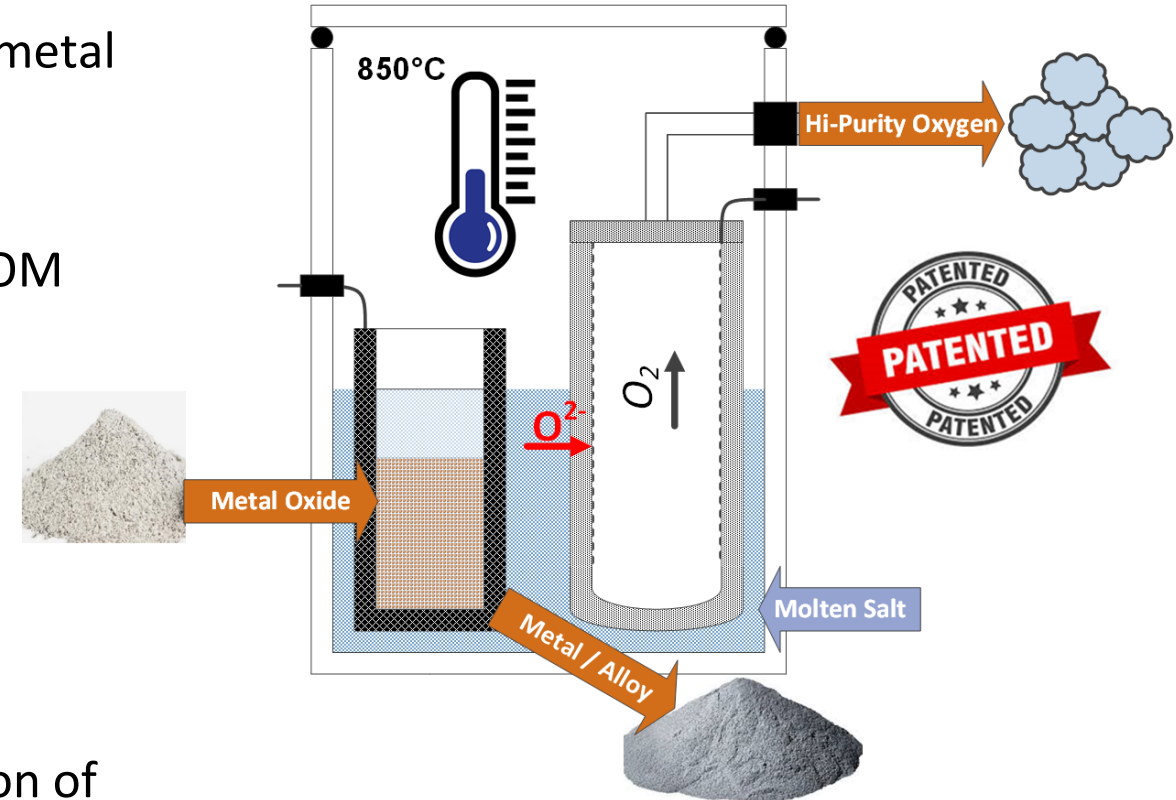
Need a process that
is relevant for
scale-up

A. Seidel, E. Monchieri, U. Kübler, U. Pal, G. Pöhle, C. Redlich, A. Charitos, D. Vogt, T. Driebe, R. Grellmann, „Mini-ROXY: The next step towards an efficient method for oxygen extraction from regolith“, Annual Meeting of the American Society for Gravitational and Space Research, November 14-18, 2023, Washington, D.C.



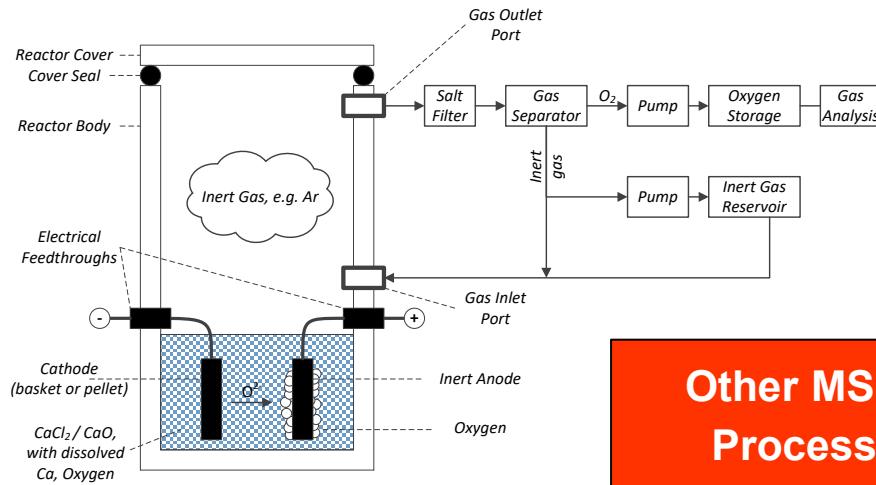
Introducing ROXY (Regolith to Oxygen and Metals Conversion)

- 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



ROXY Benefits

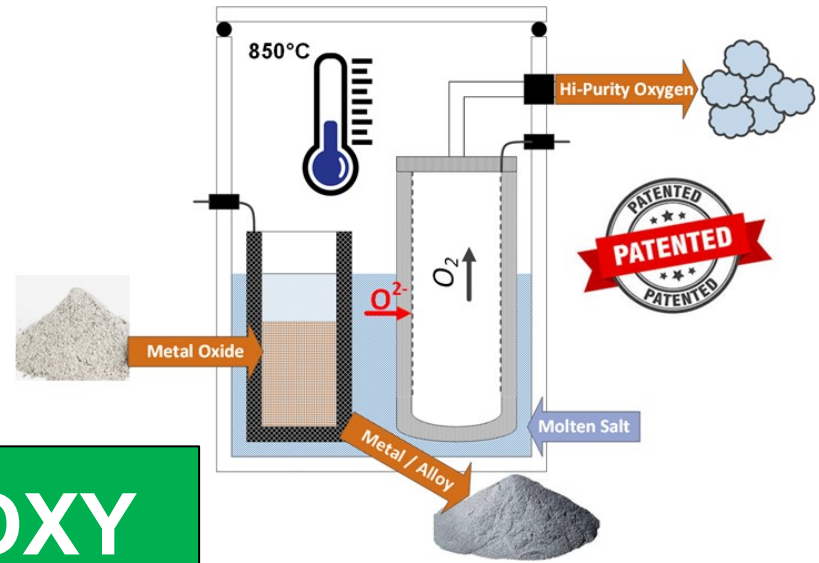
- Direct one-step production of oxygen
- Largely consumable-free process
- No corrosion issues with reactor, cathode, and reduced regolith due to molecular oxygen in the reactor
- Near 100% current efficiency
- Much simpler, smaller reactor
- Lower complexity and mass
- Higher energy efficiency



Other MSE Process



ROXY



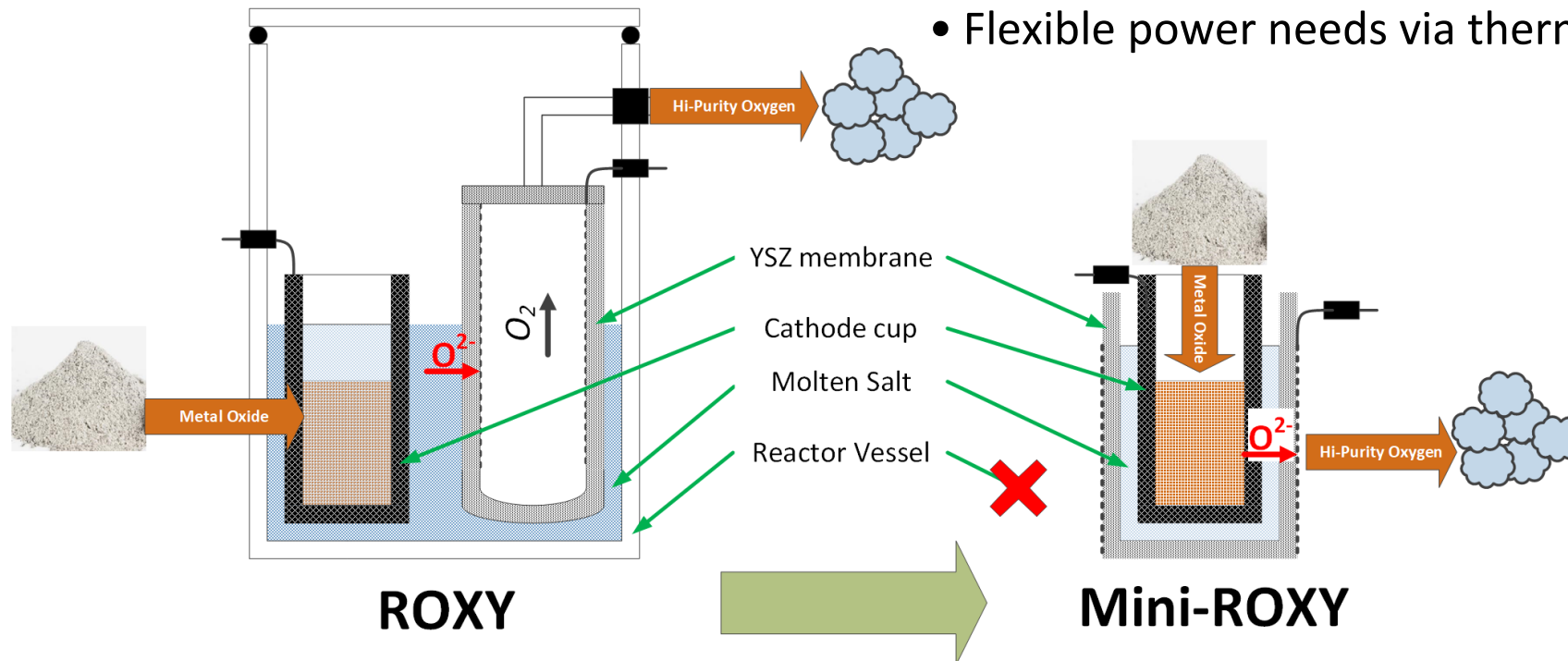
Mini-ROXY: The next step towards resource efficiency

Principle

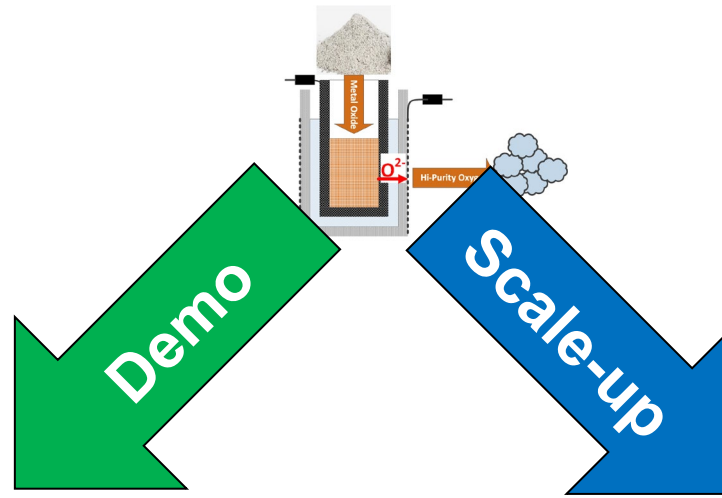
- Elimination of the reactor vessel
- Use of the YSZ tube as crucible

Features

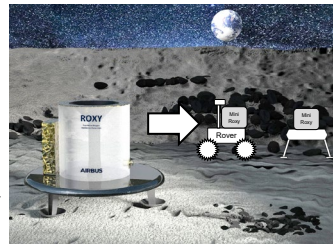
- Much smaller form factor
- Further mass reduction
- Flexible power needs via thermal insulation



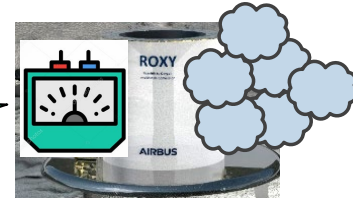
Mini-ROXY: Benefits



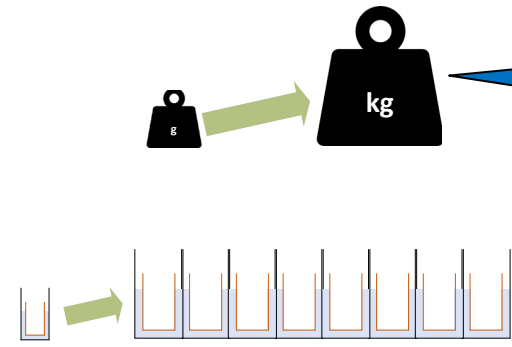
Small demonstrator – flexible accommodation



Demo and characterization of O₂ production on the Moon



Low complexity → rapid development cycle



Basis for Scale-up

**Many cells
Moderate size increase
Improved failure tolerance**

Mini-ROXY demo size cell design is relevant for upscaling

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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

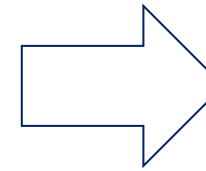
Ongoing Work – DLR Project

Today

Ground test campaign



Lab Model

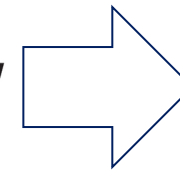


Process characterization

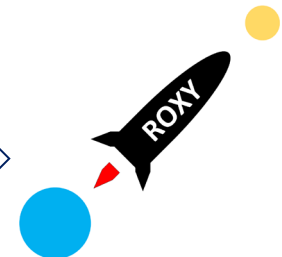
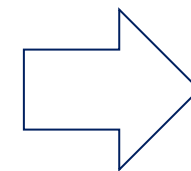
Lunar demonstration preparations



System design



Development planning



Mission assessment

Mini-ROXY: Collaboration Opportunities

- We focus on the regolith reduction system and process characterization
- More elements will be needed for a lunar demonstration mission
- Collaborators are welcome - Contact us if you are interested

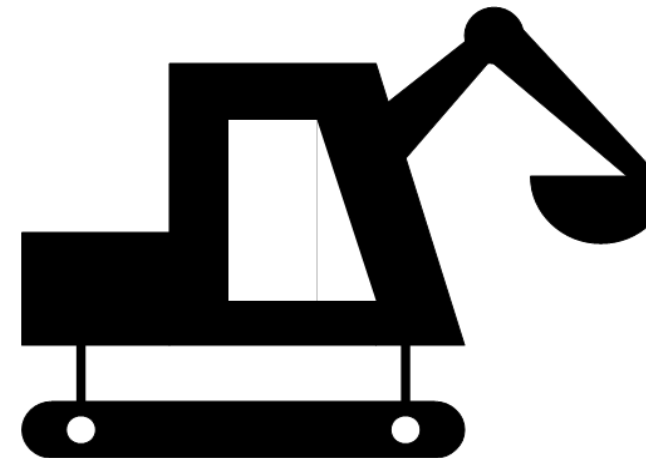
Mini-ROXY lunar demonstration collaboration options



Lander

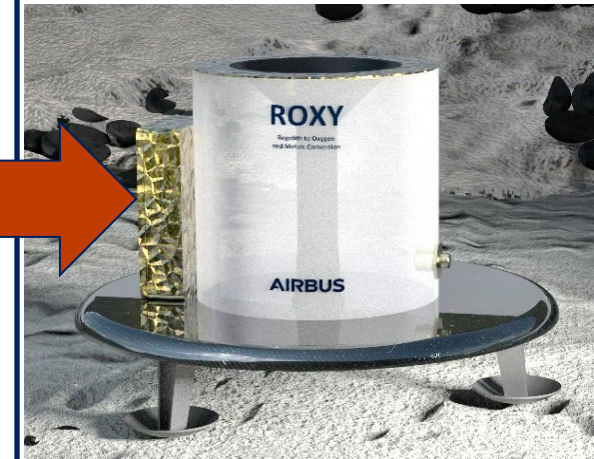


Rover



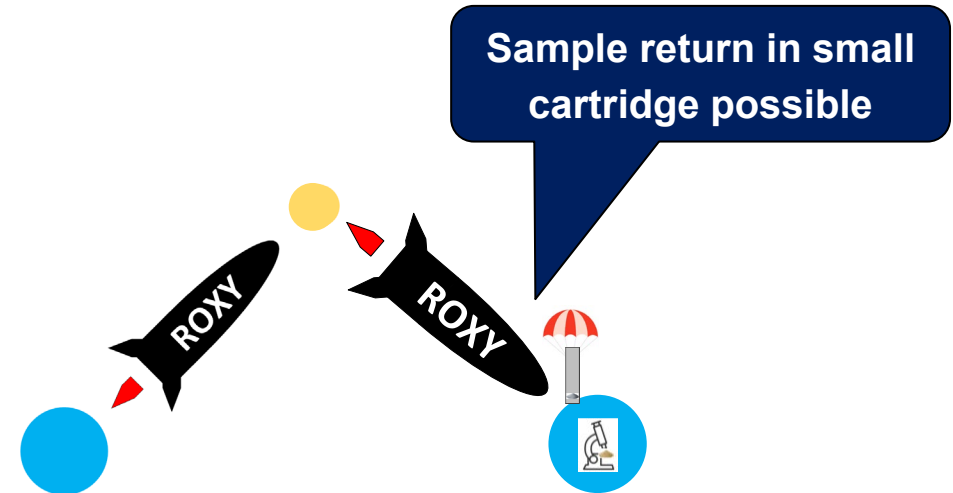
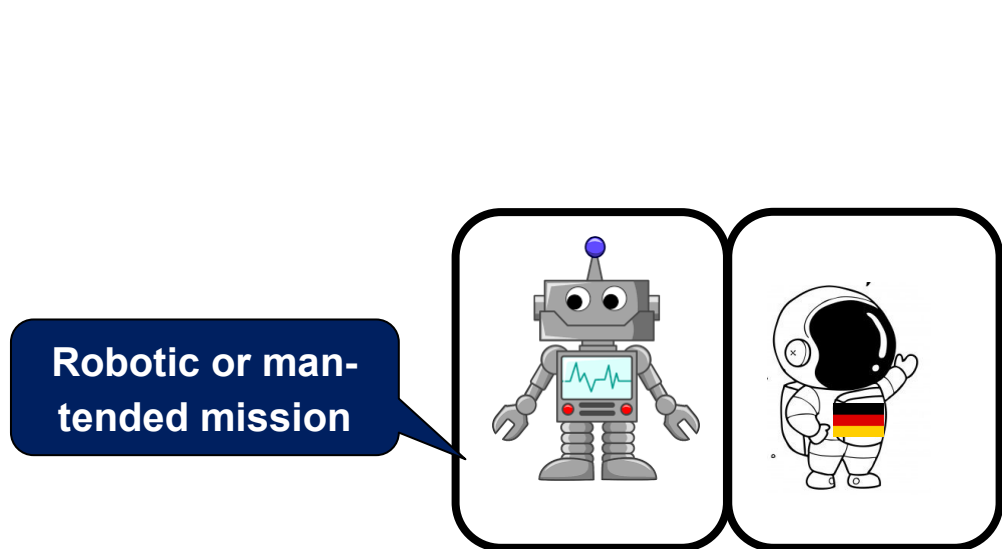
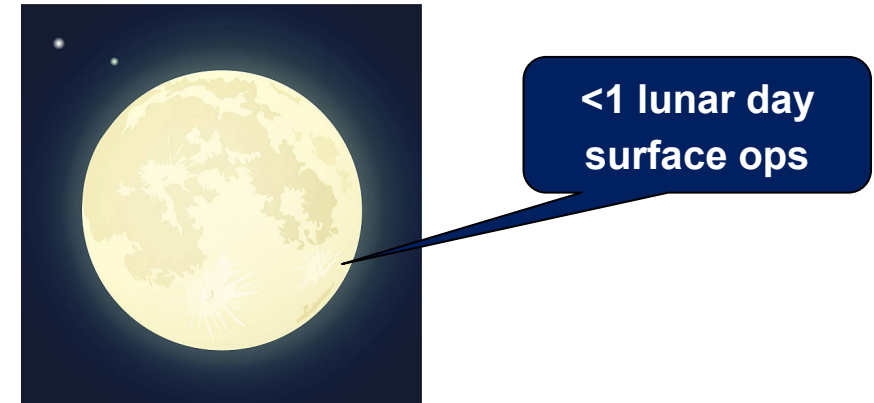
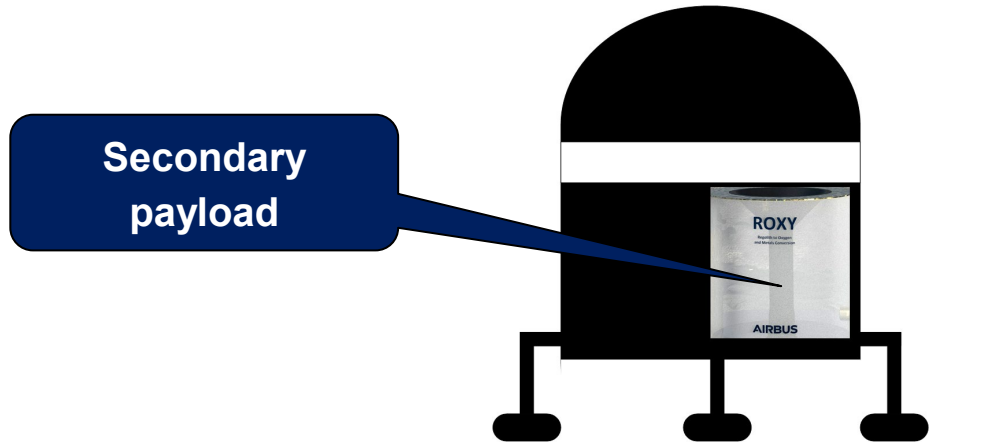
Excavator

Our Work



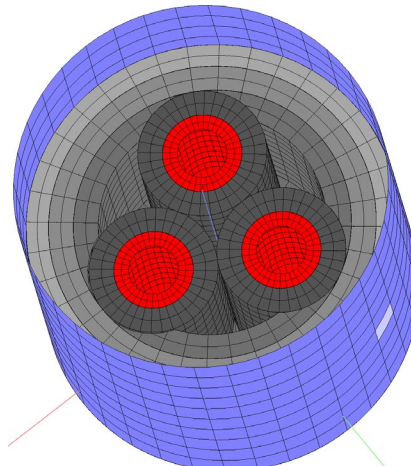
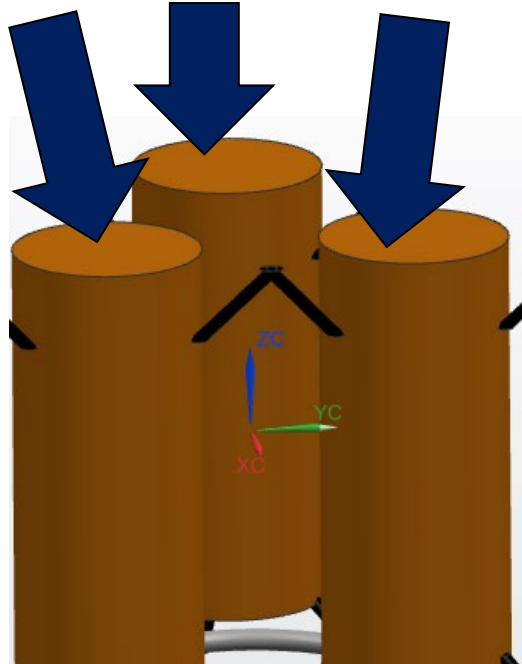
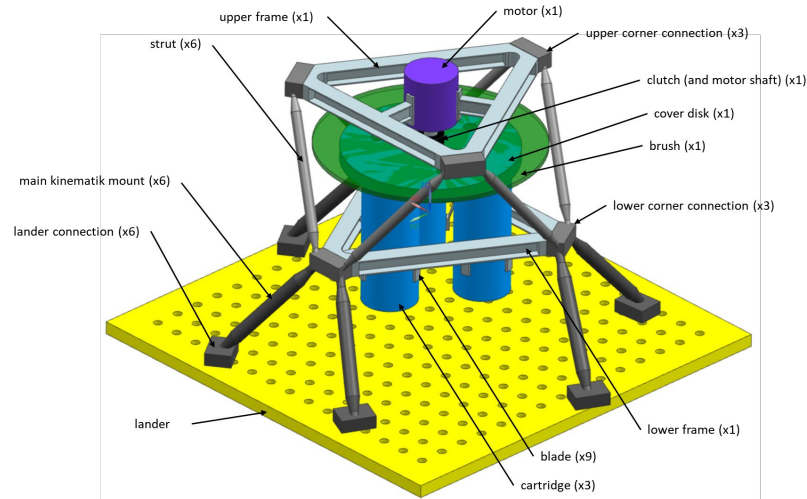
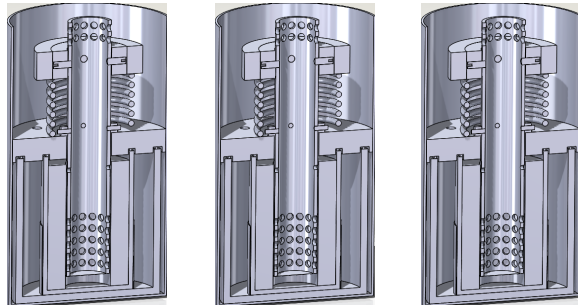
Mini-ROXY

Mini-ROXY lunar demo mission concept



Mini-ROXY lunar demo payload: Early design concept

Example: 3-cartridge design for redundancy



Main features (indicative):

3 cartridges

1 liter of oxygen per cartridge

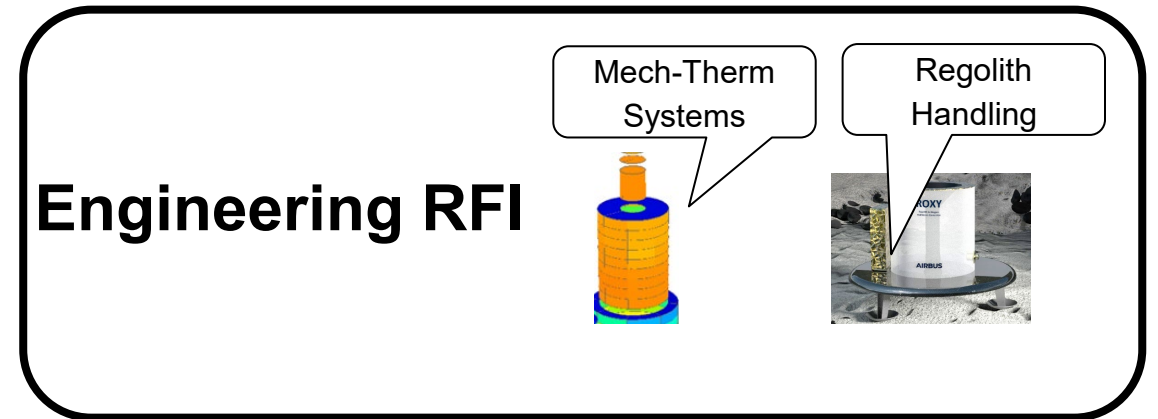
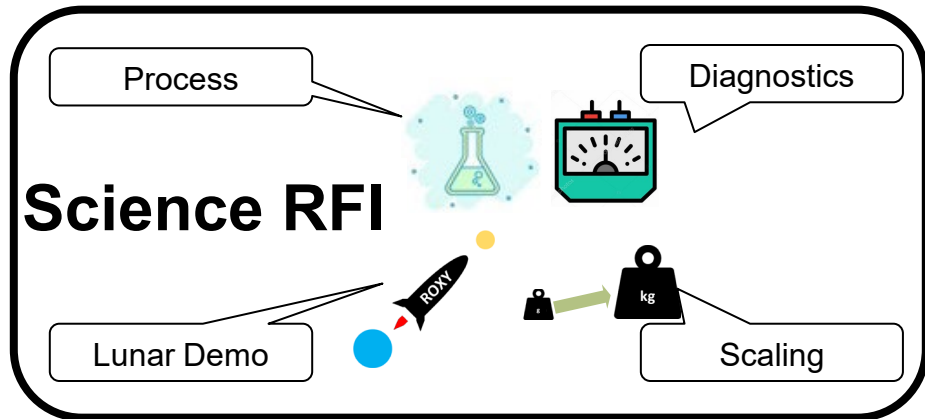
< 1 lunar day ground ops

Advanced process diagnostics via EIS

Mass ~ 30kg

Requests for Interest (RFI) – Now Open for Application

Searching for parties interested in scientific collaboration and/or contributing hardware to a Mini-ROXY lunar demo



Target Groups

Science RFI

- Universities
- Research Institutions
- Worldwide

Engineering RFI

- Companies (in particular SME's)
- Worldwide

Application Deadline

January 2024

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	2	3	4	5	X
7	8	9	10	11	12	13

More Information

Web:

→ **Projects**

→ **Mini-ROXY**

<https://www.aviation-space.fraunhofer.de/en/projects.html>

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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

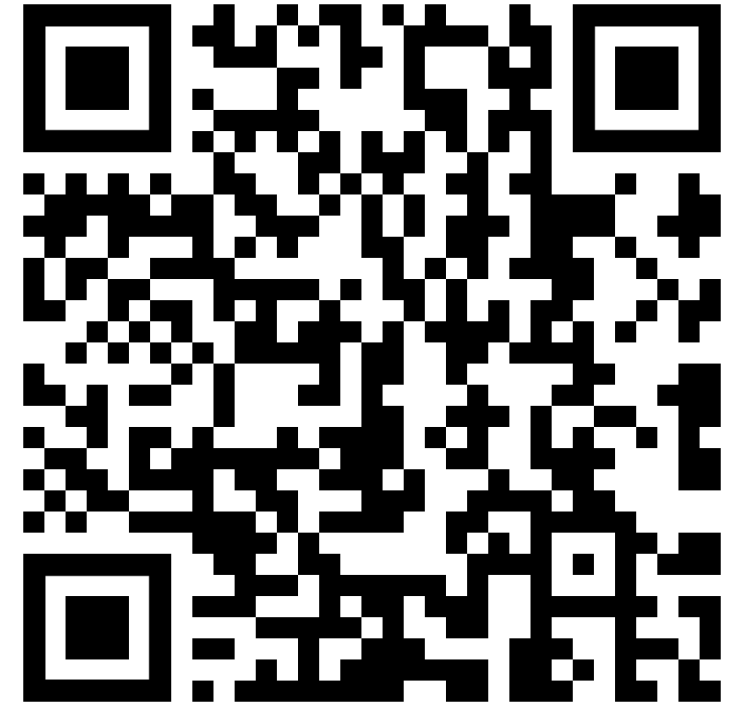
The advanced Mini-ROXY concept is the next step towards resource efficiency and basis for upscaling towards larger lunar facilities

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 – on mission level (lander, regolith delivery), on the scientific exploitation of the mission, and on hardware contributions to a Mini-ROXY lunar demonstrator payload

Link to RFI's



→ <https://www.aviation-space.fraunhofer.de/en/projects.html>

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

Gefördert durch:



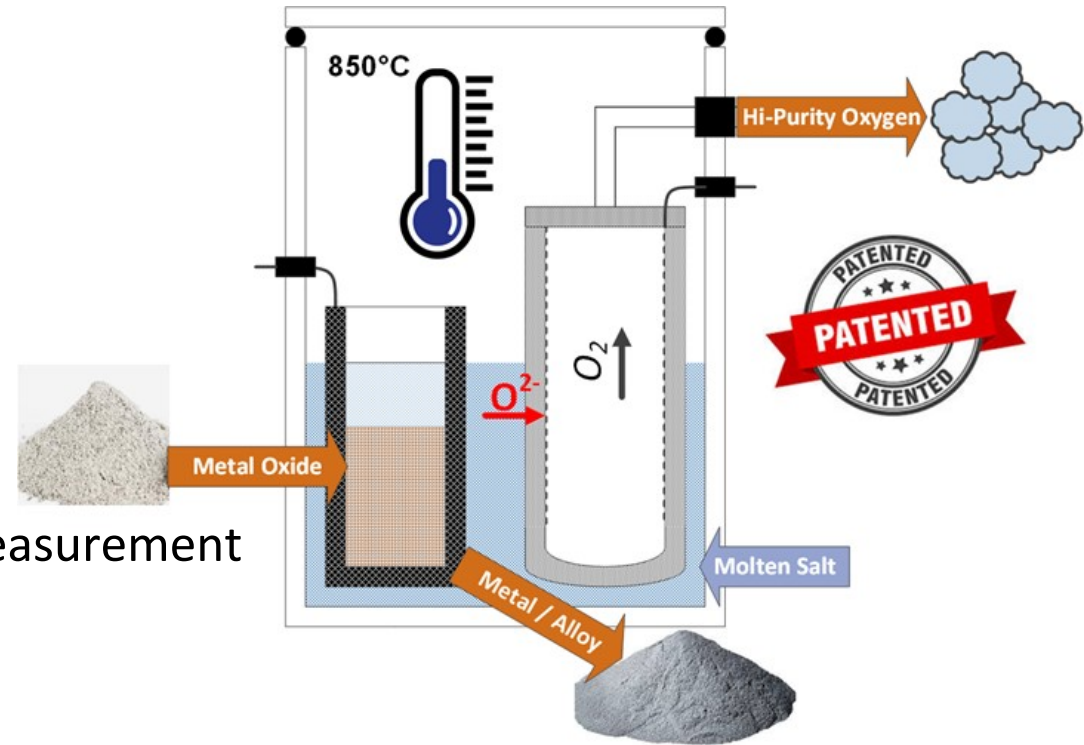
aufgrund eines Beschlusses
des Deutschen Bundestages

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

Thank you

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 O₂ 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

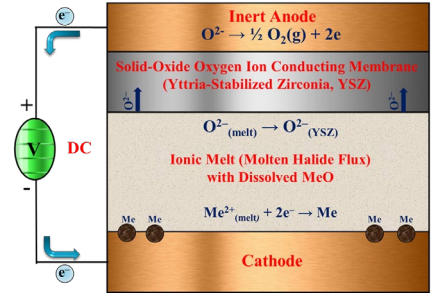


The SOM Process: Heritage

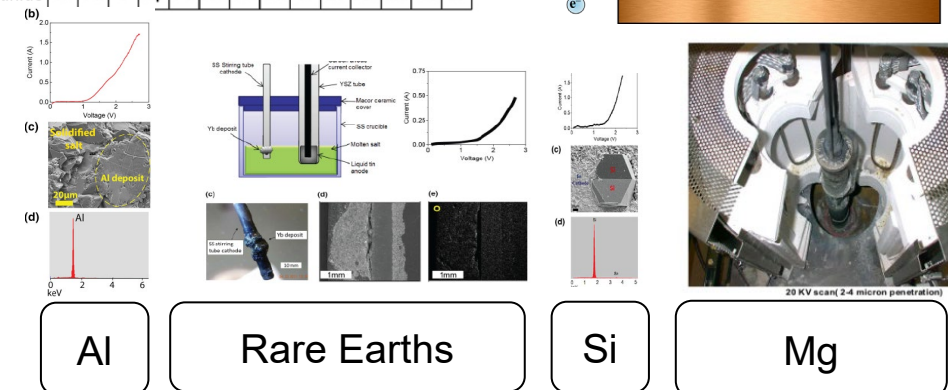


Periodic Table of the Elements

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Unq	Unp	Unh	Uns	Uno	Une	Unn								
Lanthanide		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
Actinide		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		



- A universal platform to extract metals and oxygen from oxides
- Long heritage in science and industry
- Demonstrated for many metals
- From lab scale to industrial scale
- Optimized fluoride salt electrolytes



Optimized fluoride salt electrolytes

800-1400°C

Current efficiency up to 100%

Cell voltages >4V

Built-in O2 extraction, purification & measurement

Currents up to 450 amps

Metals production

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