IN-SITU RESOURCE UTILIZATION (ISRU): OXYGEN EXTRACTION FROM LUNAR REGOLITH

Switch to Space 4

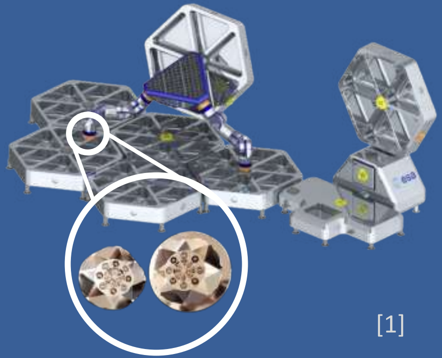
Arthur Vangeffelen – Space Applications Services

CONTENT

SPACE APPLICATIONS SERVICES

Space applications Services

- Technologies, Applications and Research
- Flight Systems
- Ground Systems and Software
- Operations Services
- …



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Mating/Demating Device HOTDOCK

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Lunar Rover LUVMI-X

ICE Cubes on the ISS

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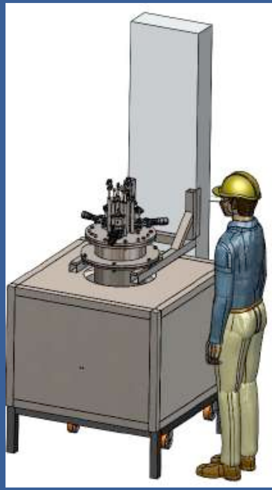
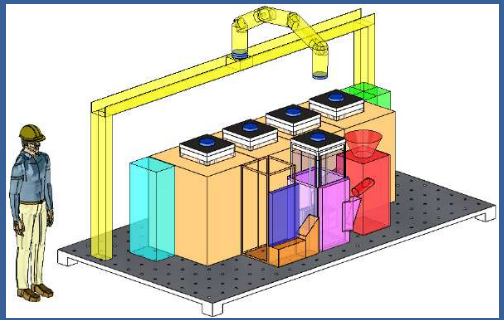
ISRU Activities



[2]

ISRULAB



[3]

GBPP

[4]

Alchemist

IN-SITU RESOURCE UTILIZATION (ISRU)

In-Situ Resource Utilization (ISRU)

At present, spacecraft must carry all the recourses they need, for propulsion or life support, from Earth for the entire mission
- Oxygen
- Water
- Fuel
- …

→ High cost and time

- Future exploration of solar system over the next decades : key enablers are locally sourced resources, such as oxygen
- Primary focus on the closest celestial body: the Moon
  - Lunar regolith (formed over time by meteorite impacts)
    - Minerals
    - Volatiles
    - …

[5]

IN-SITU RESOURCE UTILIZATION (ISRU)

In-Situ Resource Utilization (ISRU)

- Lunar regolith (formed over time by meteorite impacts)
  - Minerals
  - Volatiles
  - …

→ Metals/Construction material
- Habitats, Roads, Landing/Launch Pads, …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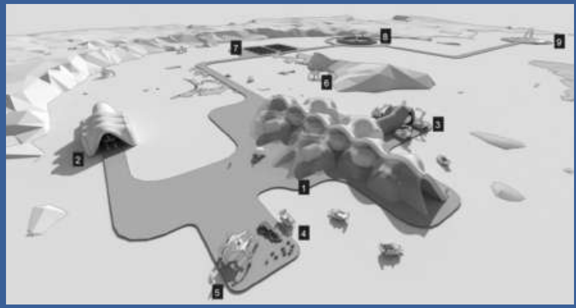
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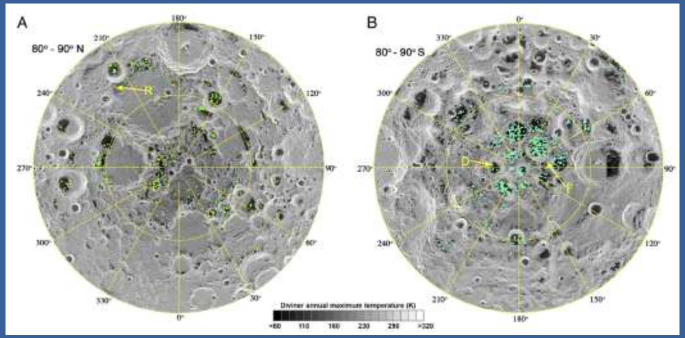
→Water (Lunar pole regions, lava tubes, …)
- Life support



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→ Oxygen (more than 45% of regolith is oxygen)
- Life support

What kind of processes and facilities to extract are required?

IN-SITU RESOURCE UTILIZATION (ISRU)

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In-Situ Resource Utilization (ISRU): Oxygen Extraction from Lunar Regolith

What kind of processes and facilities are required?

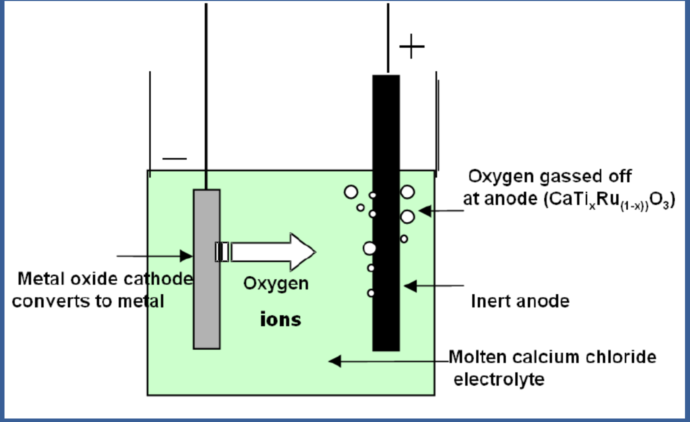
- Electrochemical process: Fray-Farthing-Chen Cambridge (FFC)
    - Electrolyte: $CaCl_2$ (molten)
    - Cathode: Metal oxide powder MeO_x (regolith)
    - Anode: Carbon or other inert anode

    - Cathode reaction

      $$MeO_x + 2xe^- = Me + xO^{2-}$$

    - Anode reaction

      $$C + O^{2-} = CO + 2e^- ; C + 2O^{2-} = CO_2 + 4e^-$$



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Process temperature are ~750°C

IN-SITU RESOURCE UTILIZATION (ISRU)

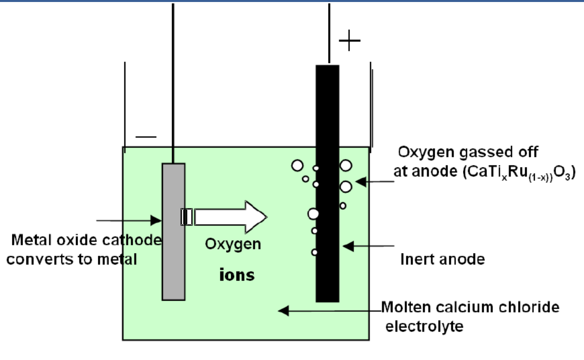
In-Situ Resource Utilization (ISRU): Oxygen Extraction from Lunar Regolith

What kind of processes and facilities are required?

- Electrochemical process: Fray-Farthing-Chen Cambridge (FFC)

  Advantages:

  - Simple one-step reaction
  - Unconstrained by regolith type
  - Useful byproducts: Regolith becomes a natural alloy after O2 removal
  - Power: Low power consumption and electrical power is readily available
  - Relatively mild temperature requirements (though still one of the main challenges)



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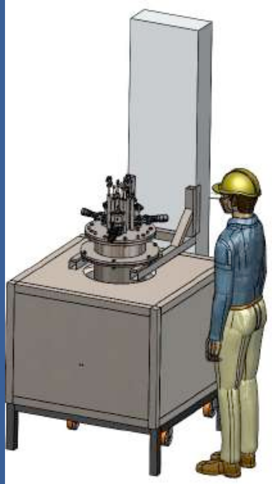
IN-SITU RESOURCE UTILIZATION (ISRU)

Related Space Applications Services Lunar payload scale, pushing the SoA

- ISRULAB
  → FFC cells earth based, experimental proof of reduction
- Ground-Based Pilot Plant (GBPP)
  → FFC cells earth based, Lunar payload scale
- Alchemist
  → Lunar payload



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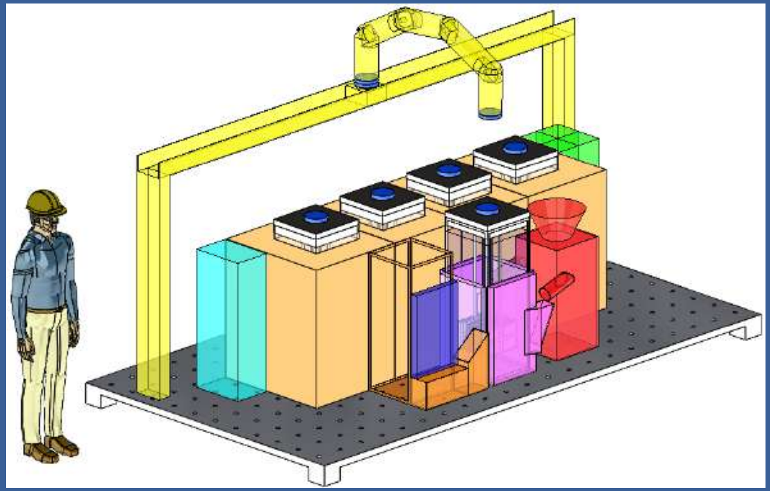

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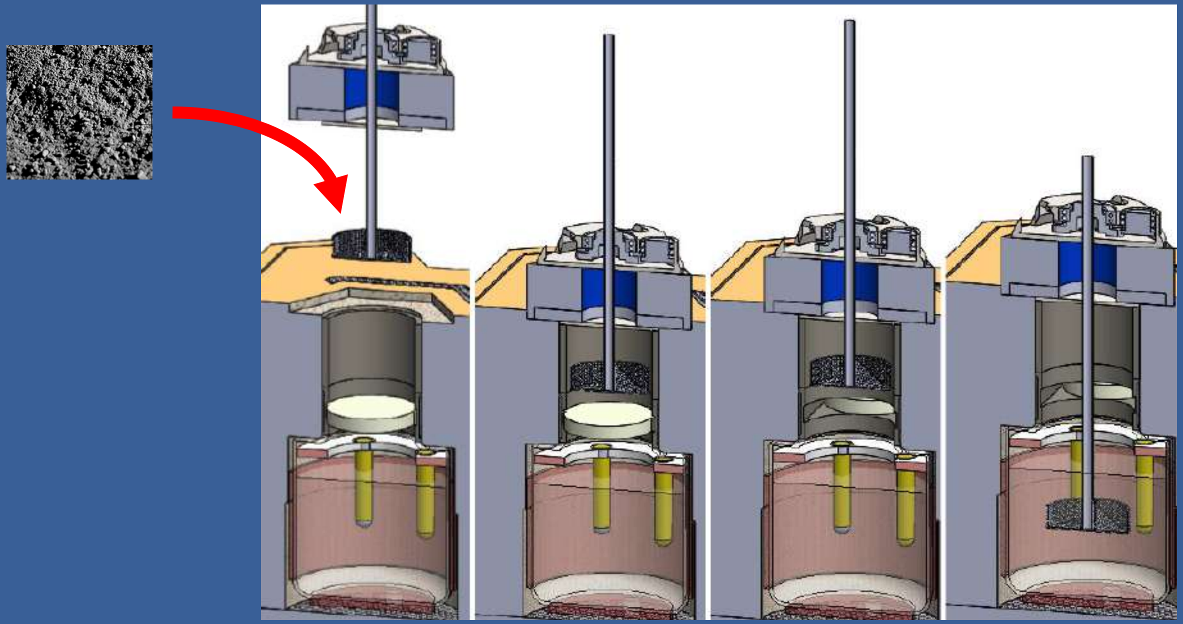
→ Overall process



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IN-SITU RESOURCE UTILIZATION (ISRU)

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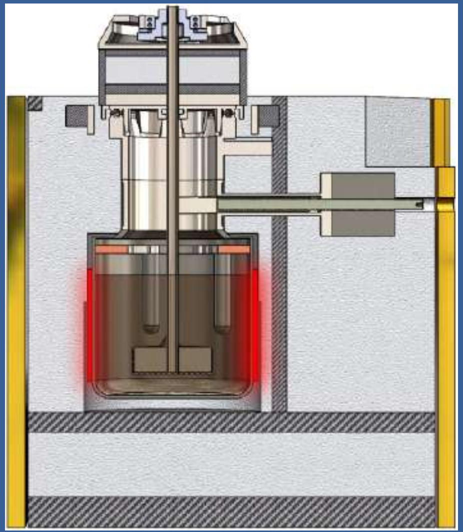

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→ Key project design trade-offs

- Materials (Anode, Electrolyte and Insulation)
- Reactor pressure and temperature: process efficiency ↔ structural requirements
  → Light pressurization with inert gas at a temperature of 750°C
- Cathode holder geometry: process efficiency ↔ batch size
  → Finned and perforated metal cup
- Anode geometry: process efficiency ↔ structural stability
  → Four cylindrical anodes

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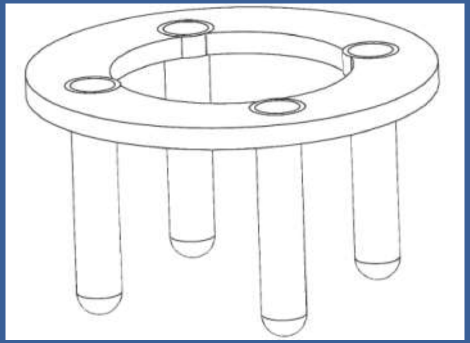

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PROSPECTS/VISION

Future challenges

- Oxygen production process
    - Sustainability of consumables (molten salt and anodes)
    - Batch process (limiting productivity)
    - Cost of anode (potentially inconsequential for ISRU when compared to mass to surface costs)
    - High temperature
        - Seal performance (temperature and dust resistant)
        - Removal of cathode with salt exposed to external environment while salt is expected to be still in molten state and reactor is open (possible freezing)
        - Cool down of salt when exposed to vacuum
        - Heat losses in the system

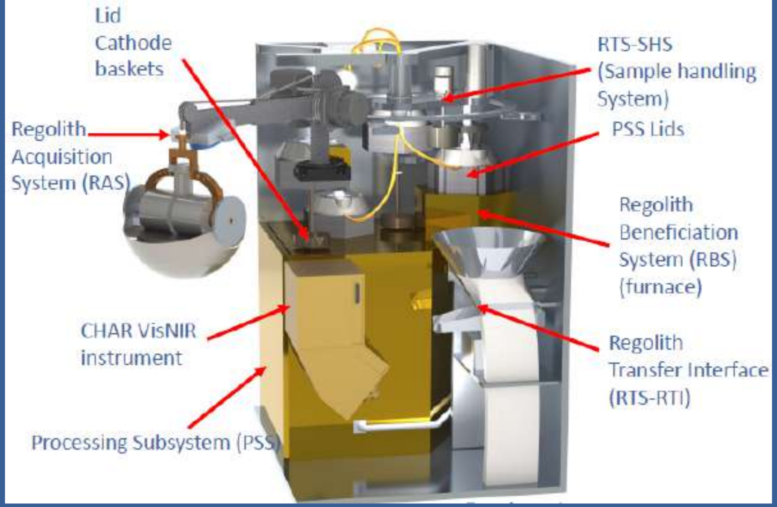
→ Cooling of critical chamber areas by inert gas loop with the positive side effect of pre-heating it

→ Modifications in the reactor (geometry) to reduce likelihood of freezing before extraction

PROSPECTS/VISION

Future challenges

- Other steps in production chain
  - Prospecting for locations with optimal regolith composition
    → Satellite/Rover observation missions
  - Extraction, handling and pre-processing of regolith
    → Mining
    → Transport
    → Filtering
    → Pre-sintering
  - Product post-processing
    → Oxygen storage
    → Metal byproduct processing



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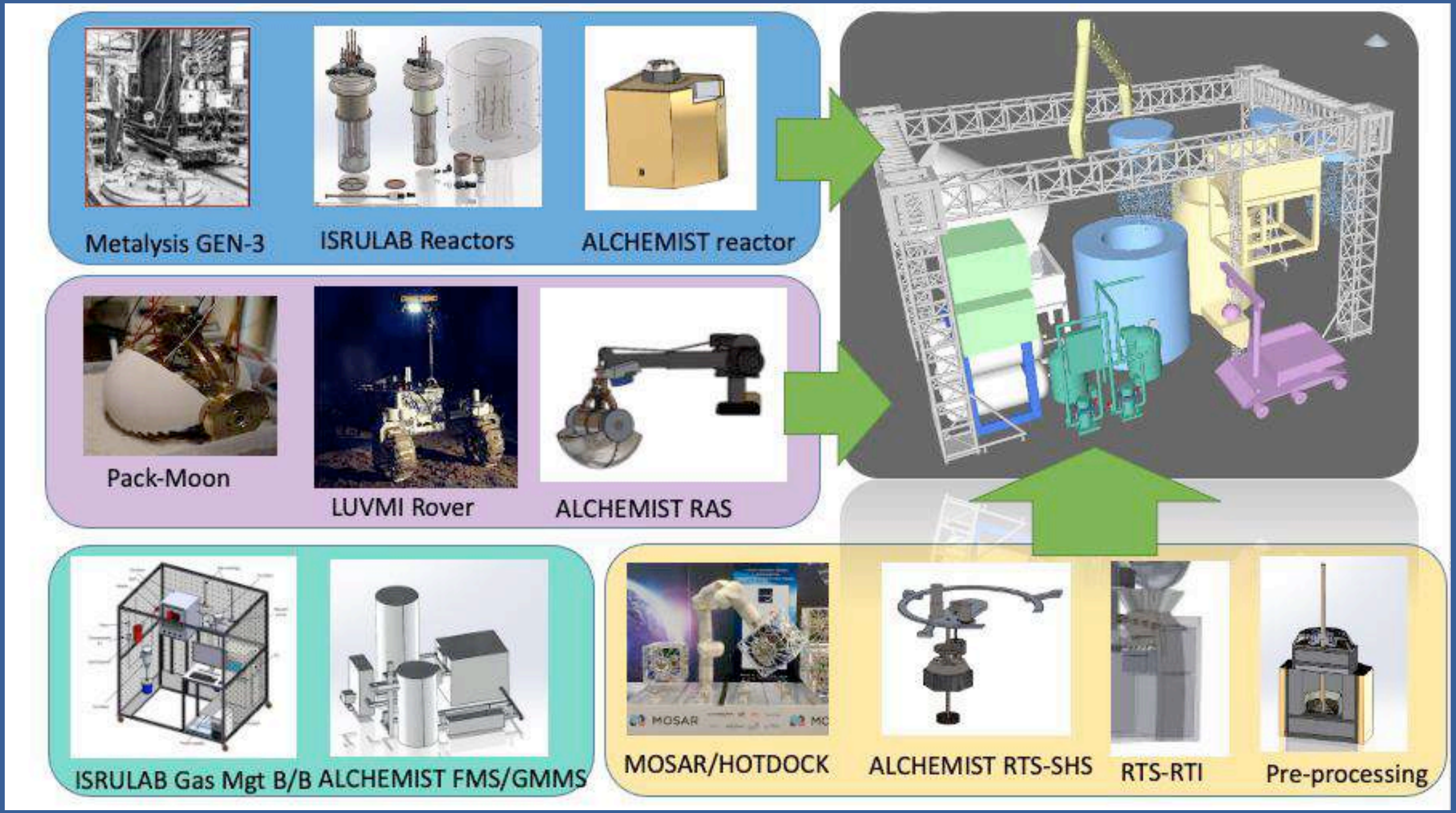
Multi-disciplinary problem with various technological challenges

PROSPECTS/VISION

Long term vision: Large scale plant scenario

Human Oxygen needs on a Lunar base 1200 kg/year O2 for 4 crew

→ Excavate ~22 kg regolith per Earth day



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Thank you

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