LUWEX

Validation of Lunar Water Extraction and Purification Technologies for In-Situ Propellant and Consumables Production

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
Technische Universität Braunschweig
LIQUIFER SYSTEMS GROUP
ThalesAlenia Space
Wrocław University of Science and Technology
Scanway imaging space
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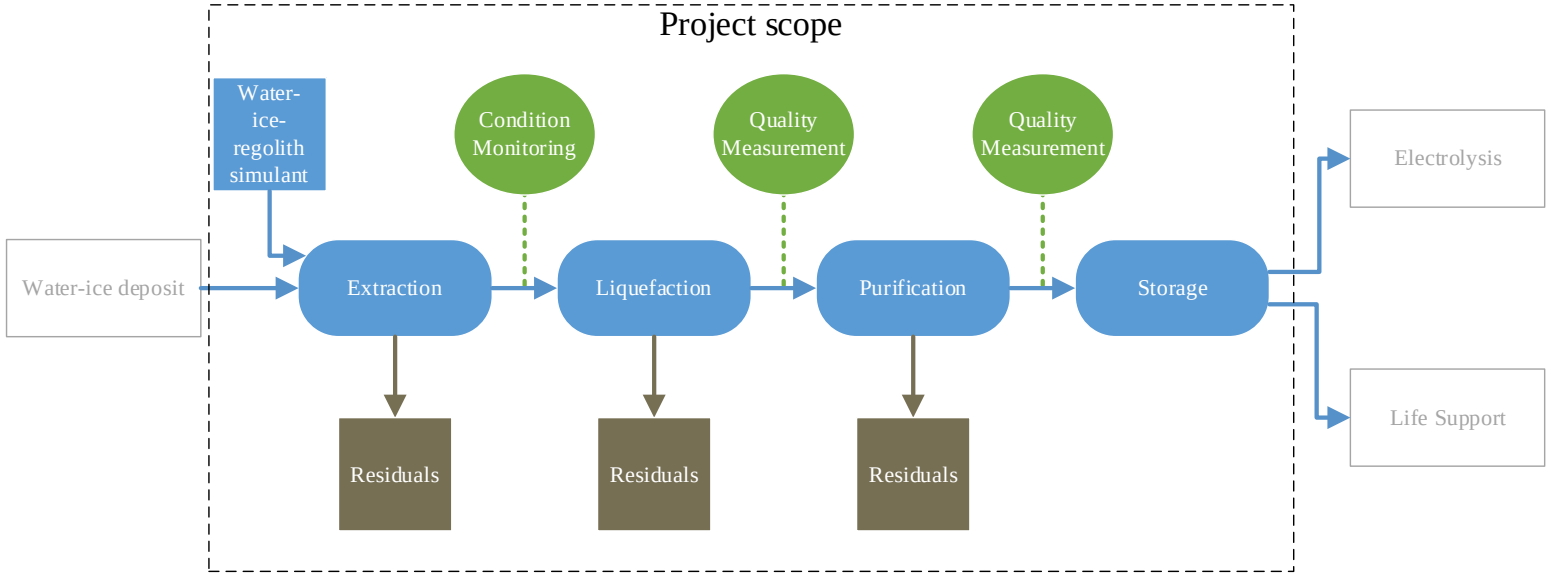
Validation of Lunar Water Extraction and Purification Technologies for In-Situ Propellant and Consumables Production

Duration: Nov. 2022 – Oct. 2024.

EU-funded with 1.5 million €

Objective

The development, integration and validation of lunar water extraction and purification technologies for in-situ propellant and consumables production for future space exploration missions



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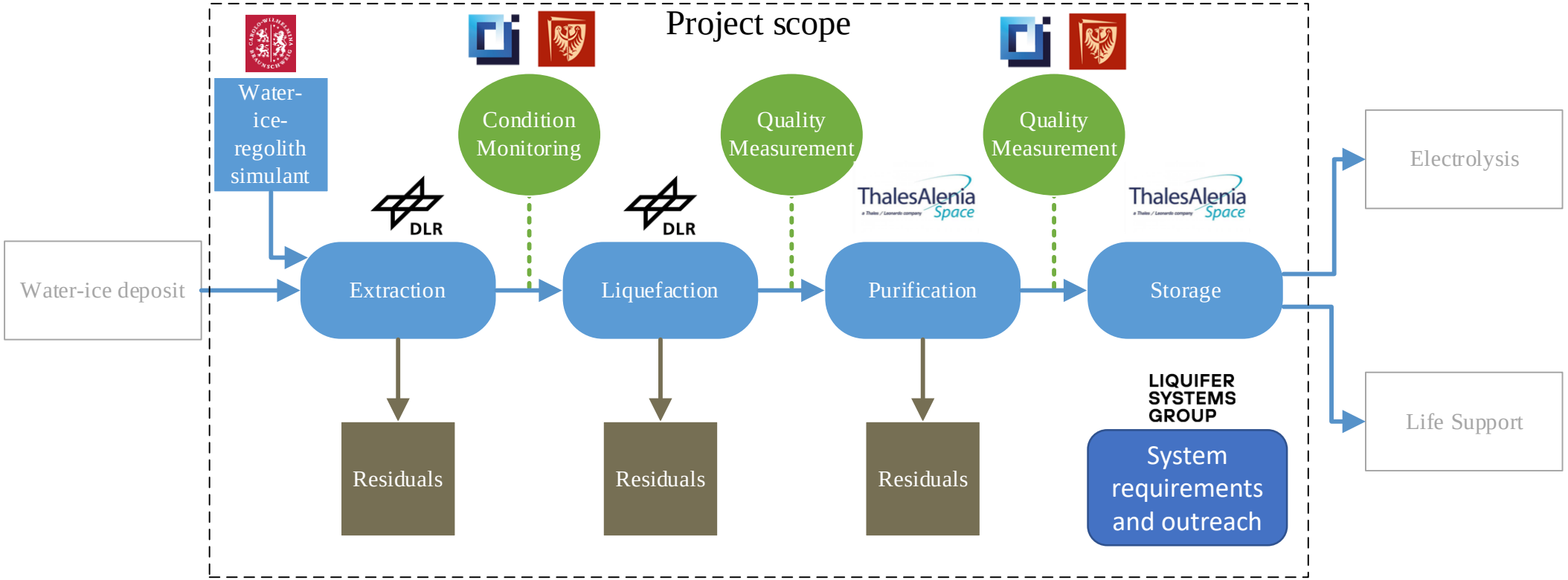


Project schedule

- Requirements definition
- Preliminary design of subsystems and experiments

- Detailed design
- Manufacturing and procurement of hardware
- Development of ice-regolith and lunar raw water simulants

- Technology validation campaign
- Evaluation of experiment results
- Investigation of future terrestrial and space applications

Expected Outcomes and Impacts

Project Results

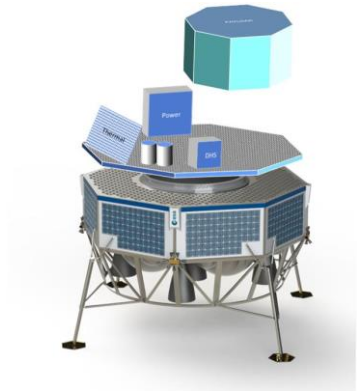
- Validated technologies
- Ice-Regolith simulant
- Lunar raw water simulant
- Experiment results

Medium-term outcomes

- Further development of technologies towards flight hardware
- Simulants and data for excellent science

Long-term impacts

- Innovative ISRU technologies
- Contribution to European lunar exploration mission



2022-2024 → 2024+ → 2030+

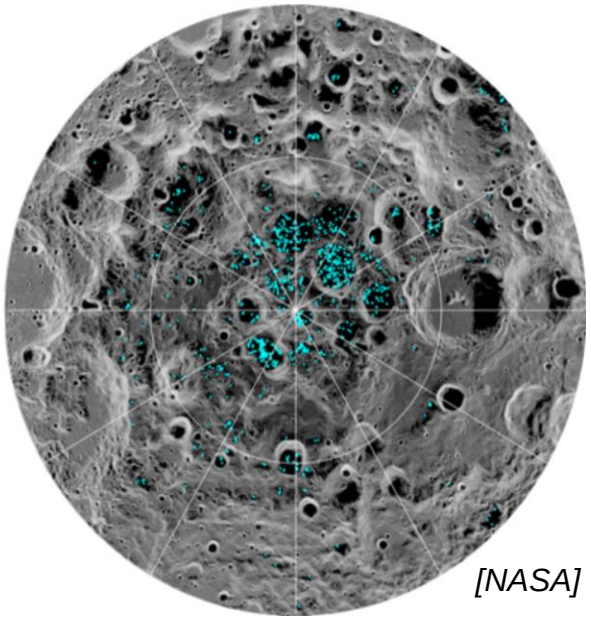
Background

- Water would be an excellent resource to gather on the Moon for space exploration, since it has many applications (fuel, drinking water, radiation shielding, oxygen etc.).

- Water on the lunar south pole:
  - Confirmed ±5wt.% in regolith in Cabeus crater (PSR).
  - Micro cold traps (which are more accessible) believed to have 0,1 – 1 wt.% water in the regolith.
  - Indications of local patches containing up to 20 wt.% water in the regolith.
  - NASA's VIPER Mission will look for other water sources near (but not in) Nubile crater.

- Current gaps[1]:
  - Form, concentration, and distribution of Water in PSRs is not known.
  - Technologies to locate and characterize resources.
  - Feasibility of mining techniques and operations in PSRs not verified by ground environmental chamber tests.

Moon´s South Pole
Blue dots represent indications of water



[NASA]

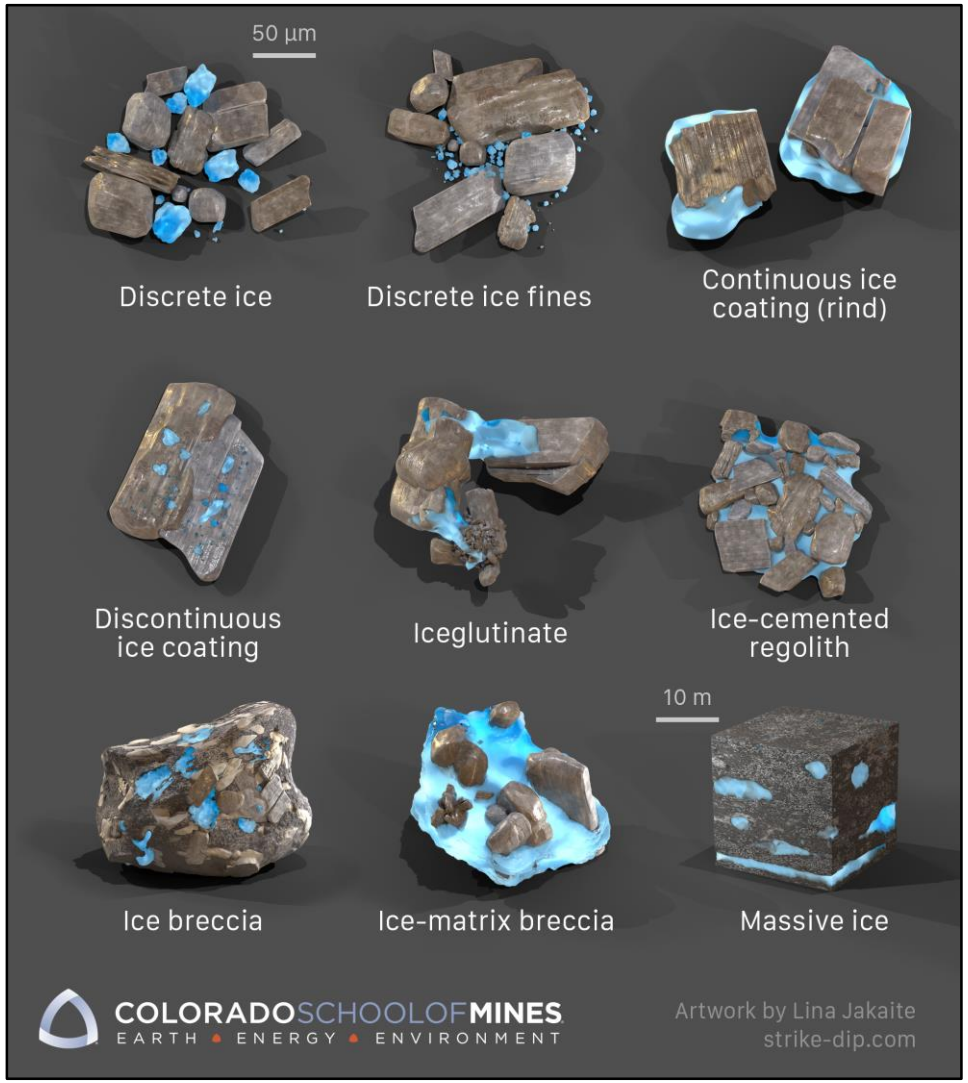
1: NASA - SRR/Planetary & Terrestrial Mining Sciences Symposium (PTMSS) June 2021

State of Water on the Moon

- Water-ice
  - Particle size? Blocks of pure ice?
  - Found in deep craters at the poles and micro cold traps.
  - 5wt%, potentially as high as 20wt%.

- Water trapped in glasses and minerals
  - Only release at temperatures where minerals decompose.
  - 100 - 400 µg/g.

- Metal-hydroxyls
  - Recombinative Desorption.
  - Amounts depend on the time of the lunar day.



Water Extraction and Capturing subsystem

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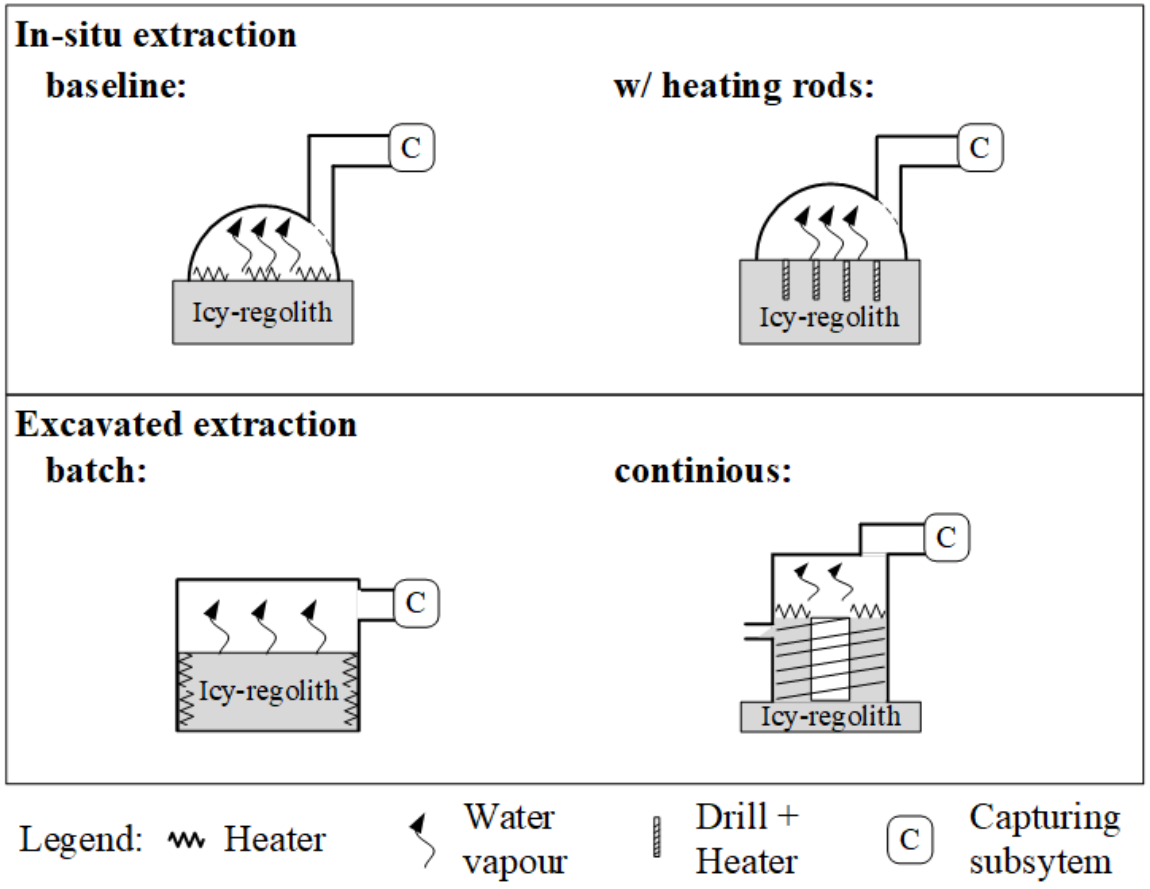
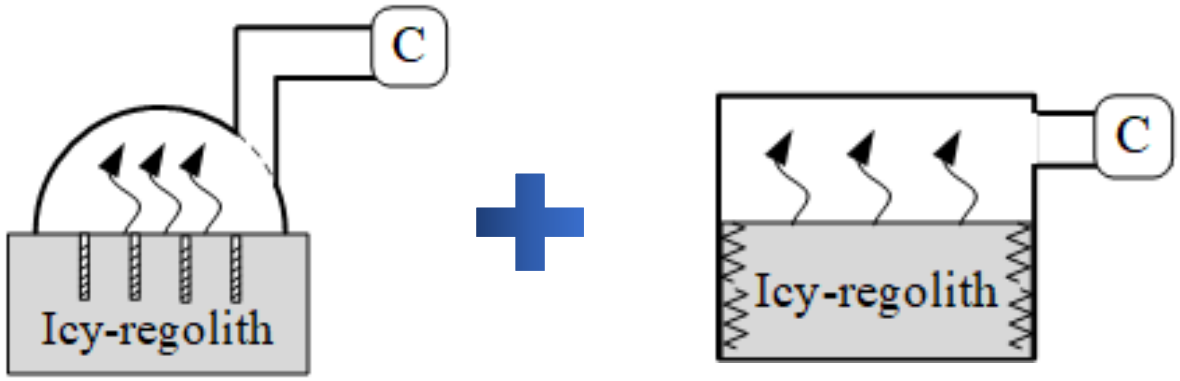
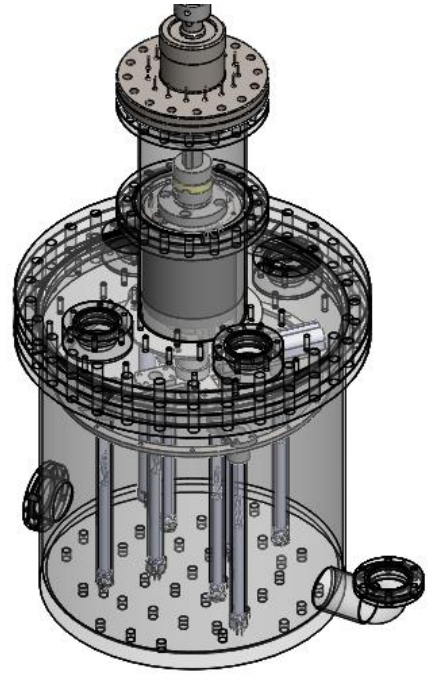
Initial design ideas for Extraction

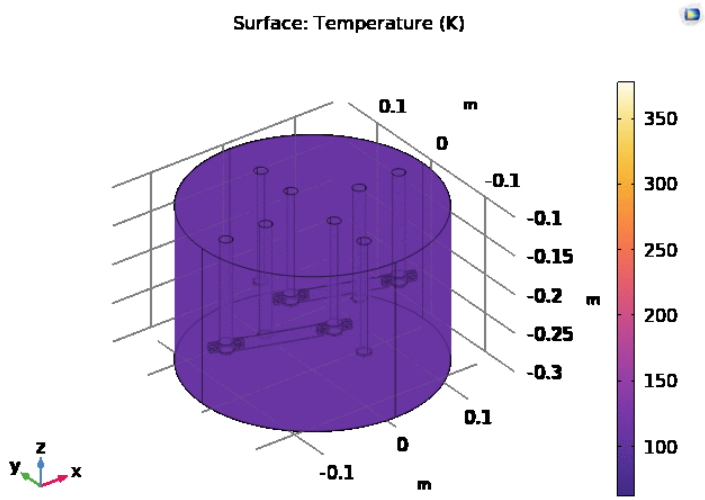


Initial design ideas for Extraction



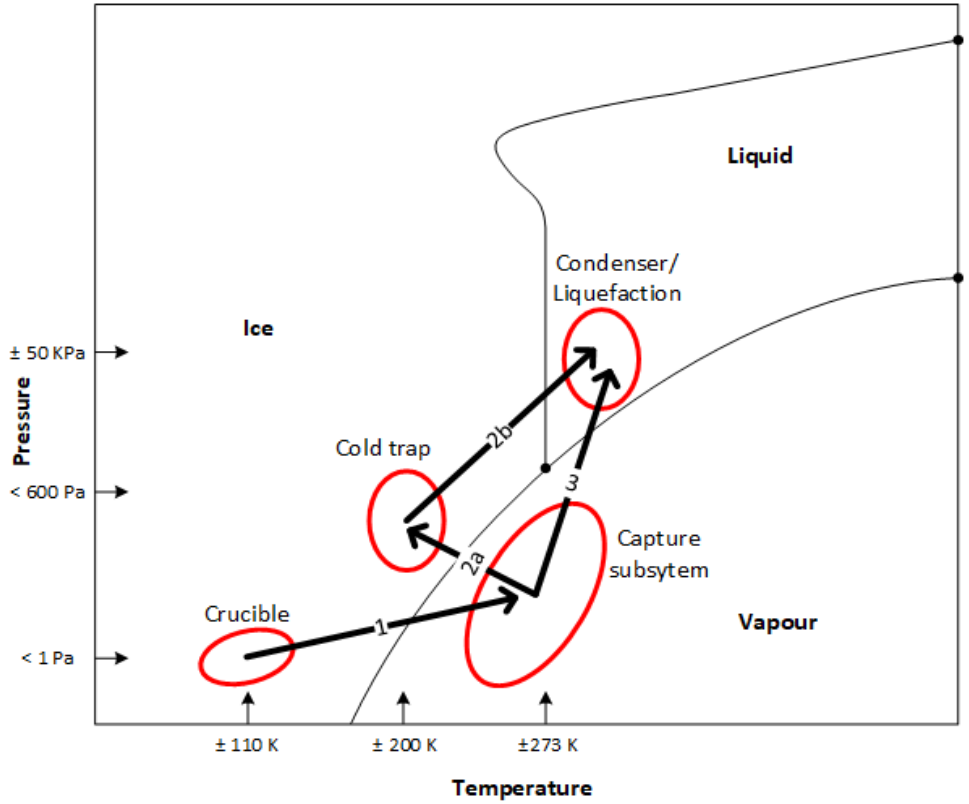


[Purrington et al. 2022]



Options for Water Vapour Capturing Subsystem

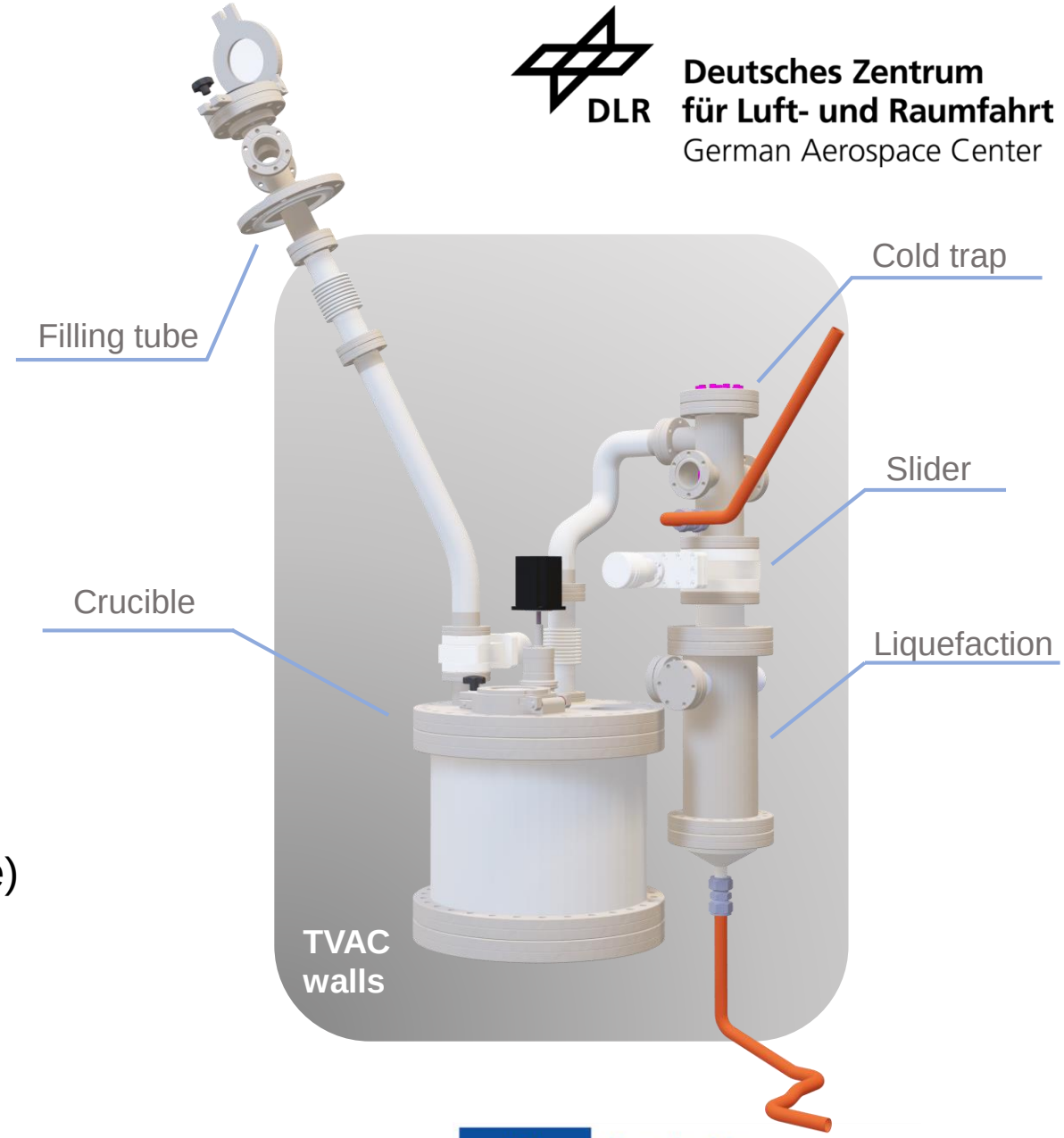
- Objective: capture and collect the water vapour
- Potentially first step of purification
- Two methods are considered:
  - Cold trap, the water vapour is deposited on a cold surface (2a) and then liquefied (2b)
  - Condenser, the water vapour is condensed on a cold surface (3)
  - Difference between the two is the phase and the temperature as well as pressure at which it occurs



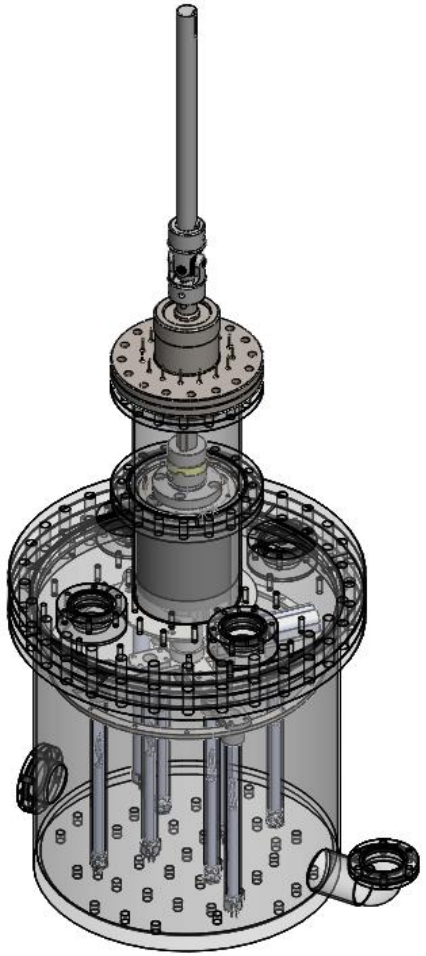
Extraction and capturing process

- Design for extraction and water capturing chosen using simulations and trade-offs.

- A water extraction crucible and a cold trap capturing device are placed in a “dusty” TVAC.
  - Temperature ≈ 80 – 100 K.
  - Pressure ≈ 10e-6 mbar.
  - Crucible size = ⌀30 cm x 30 cm.
  - Icy regolith simulant mass up to 15 kg.
  - Amount of water present 5 wt.%, 750 mL (baseline)
  - Presence of volatiles: CO_2 & Methanol

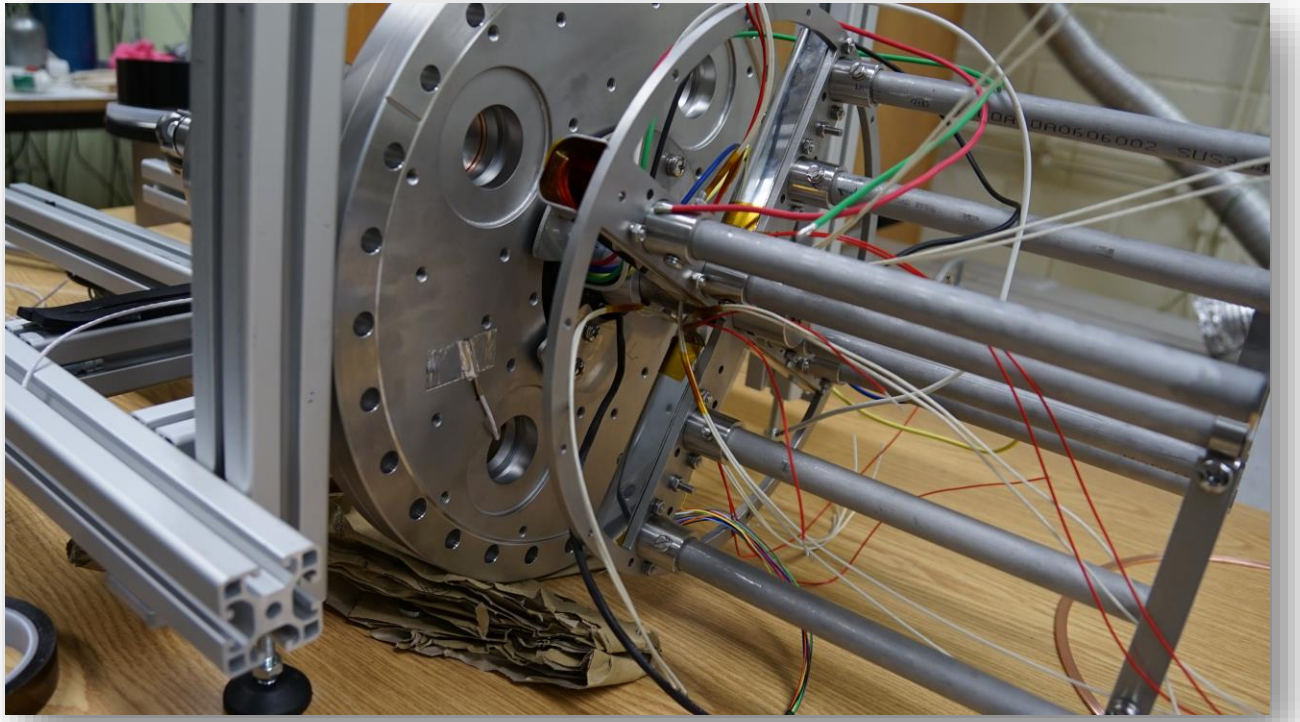


Extraction and capturing process



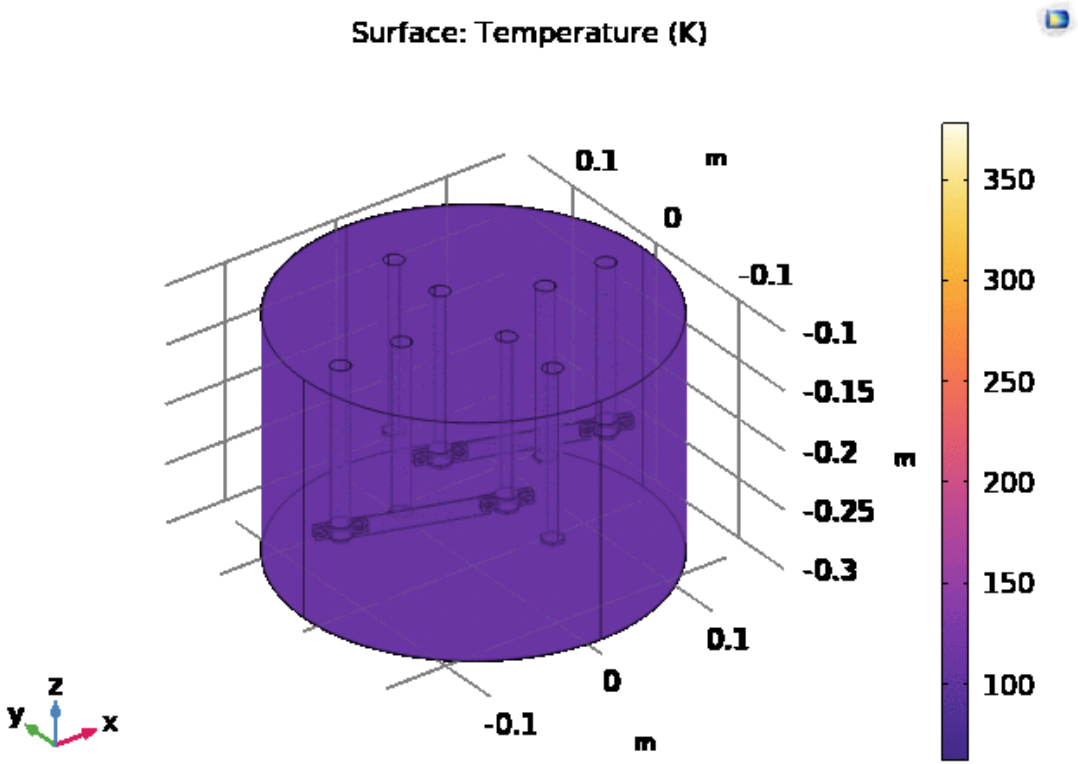
Crucible

Extraction and capturing process



Crucible

Extraction and capturing process



Crucible

Extraction and capturing process

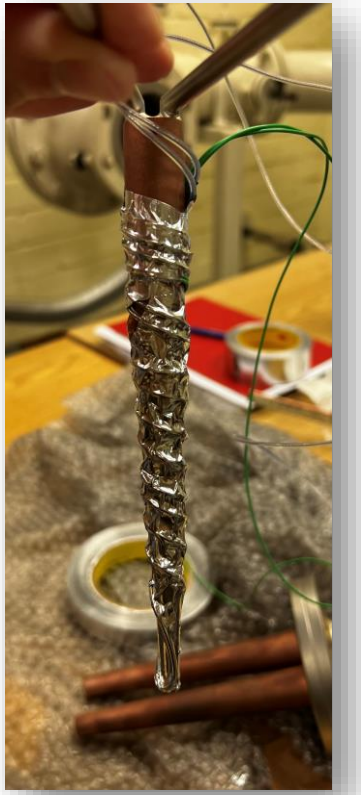
- Each part is covered in different layers to enhance thermal contact in vacuum:
  - Heating cable
  - Aluminium tape
  - Insulation material

- PT1000 sensors are placed to track the temperature of each part individually

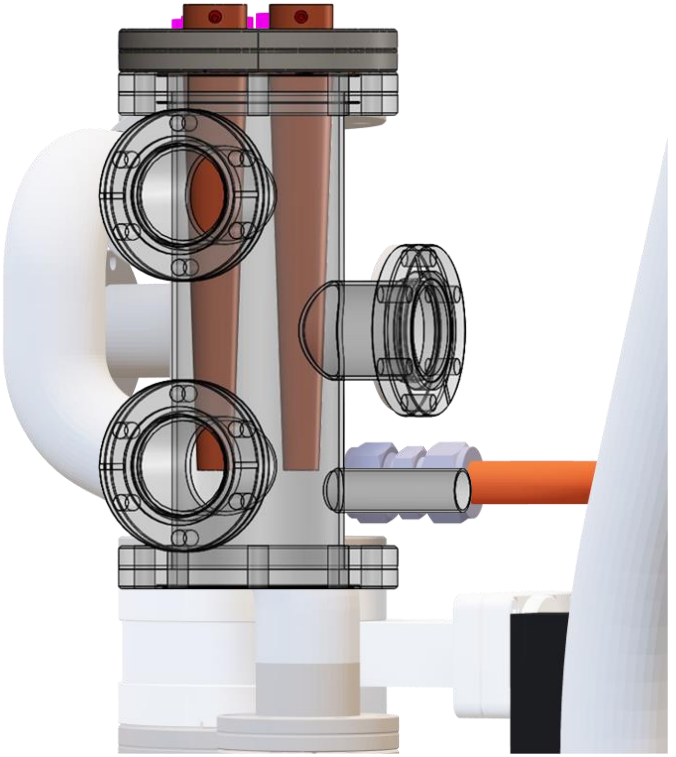
Crucible

Extraction and capturing overview

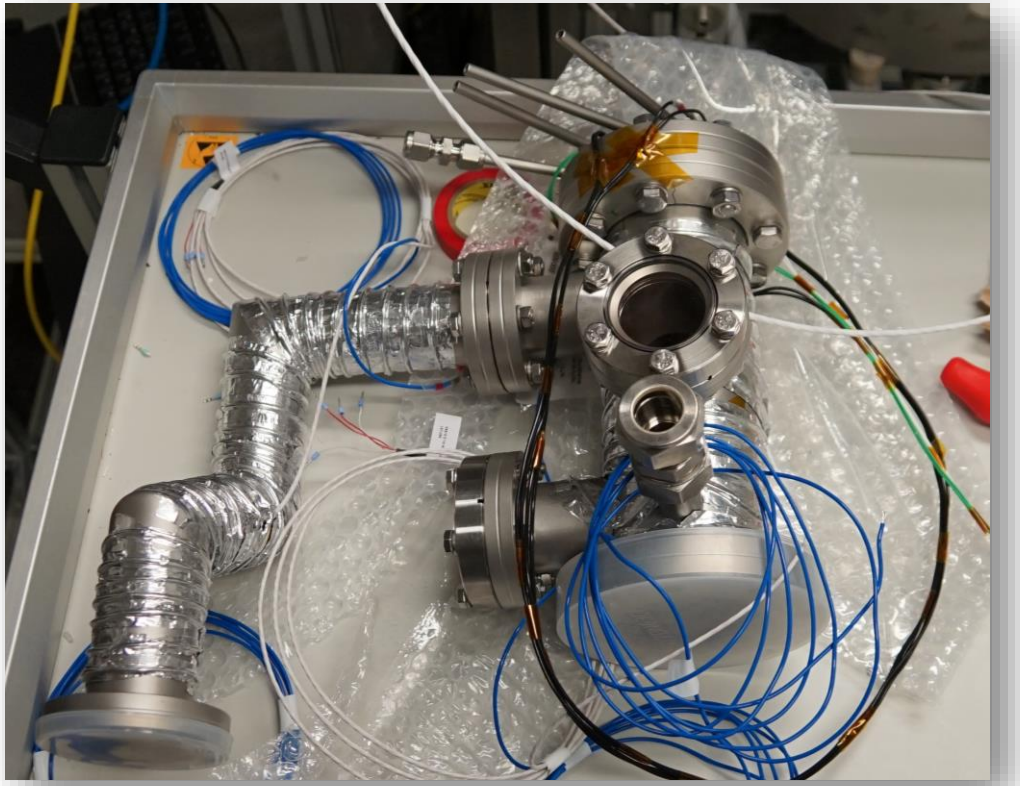
- Cold trap captures the sublimated water vapor, which is deposited in the cold fingers.
- Temperature control inside the cold fingers allows the delamination and fall of the ice
- Inside temperature set to 180 K



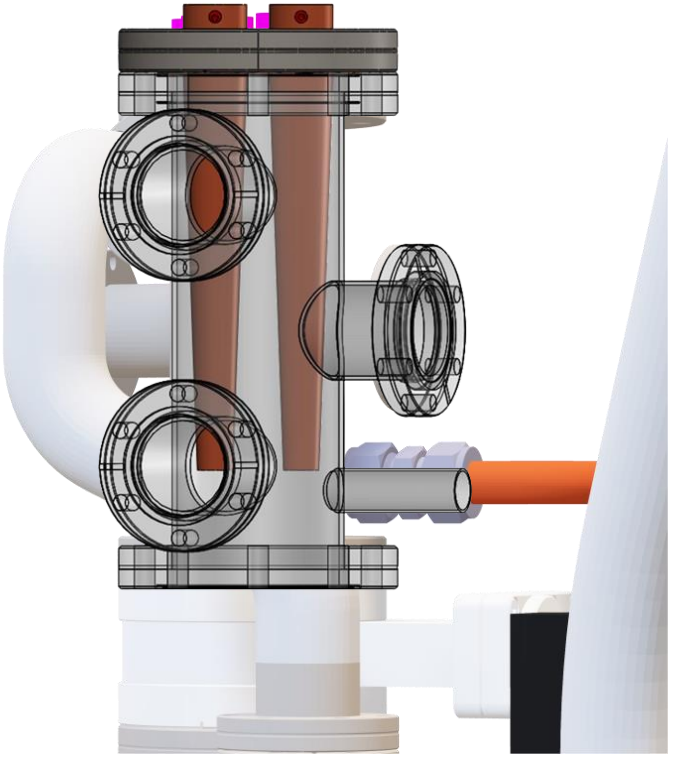
Cold trap



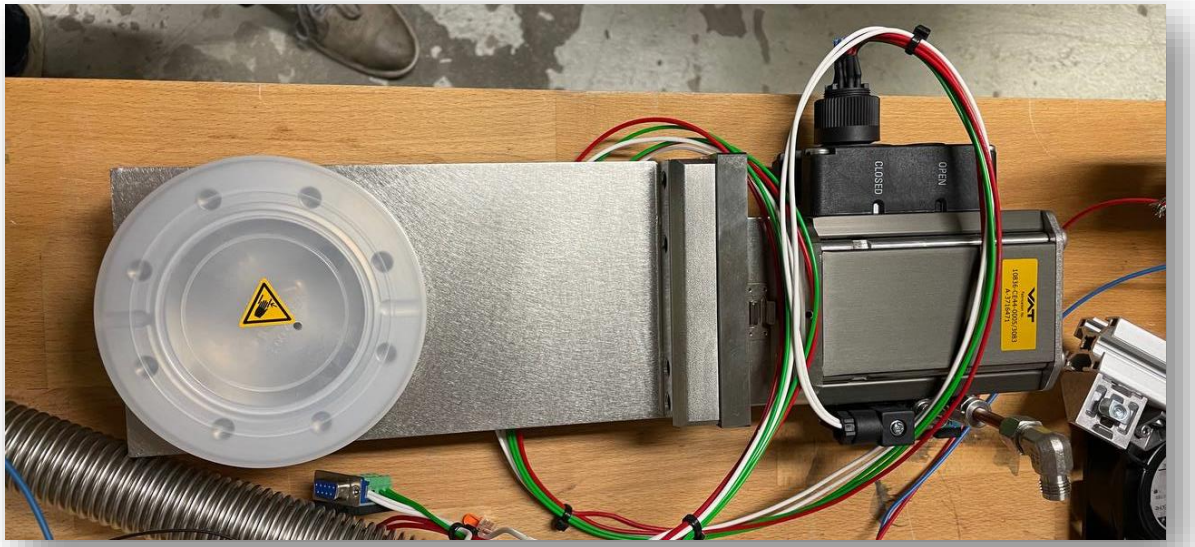
Extraction and capturing overview

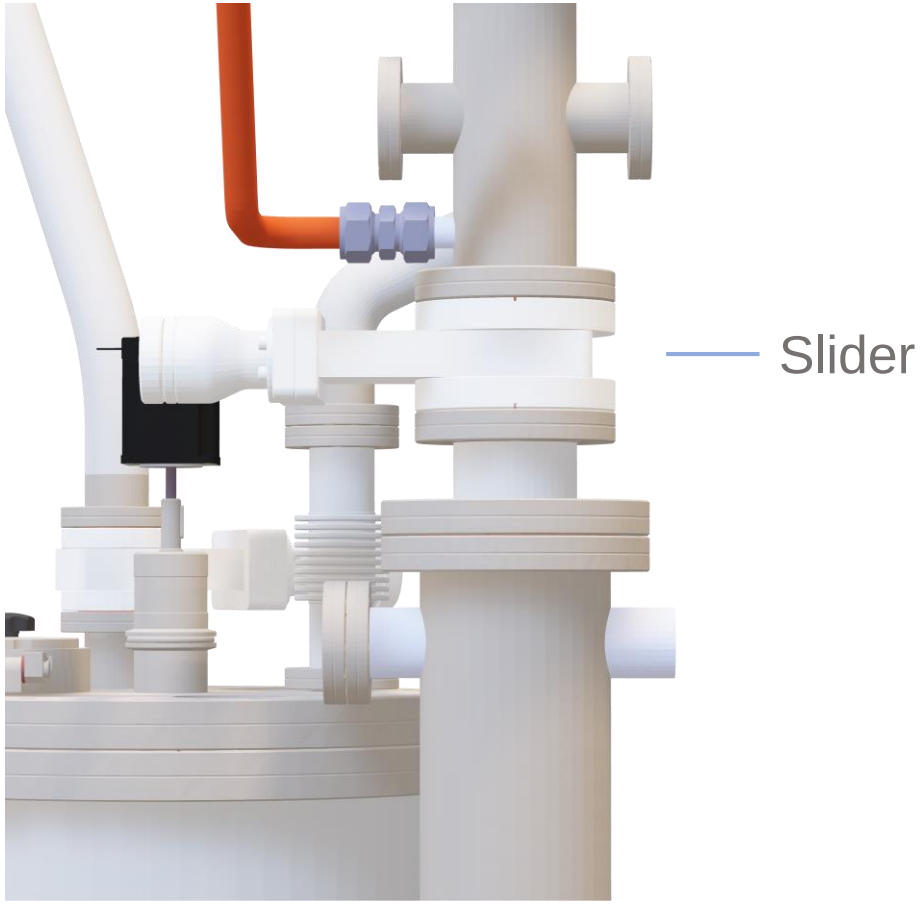


Cold trap

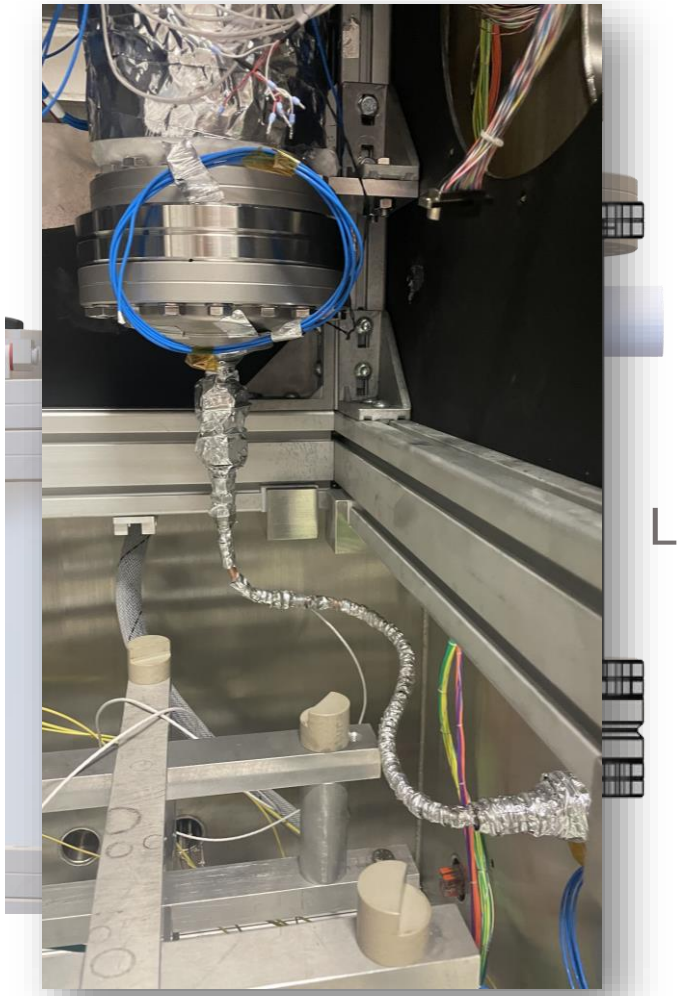


Extraction and capturing overview





Extraction and capturing overview



Liquefaction

System operations: Filling

- Icy regolith
- Regolith
- Water vapor
- Water ice
- Liquid Water
- Heat

System operations: Extraction and capturing

- Icy regolith
- Regolith
- Water vapor
- Water ice
- Liquid Water
- Heat

System operations: Delamination

- Icy regolith
- Regolith
- Water vapor
- Water ice
- Liquid Water
- Heat

Repeat until liquefaction chamber is full

System operations: Liquefaction

- Icy regolith
- Regolith
- Water vapor
- Water ice
- Liquid Water
- Heat

Repeat until storage tank is full

System operations: Emptying

- Icy regolith
- Regolith
- Water vapor
- Water ice
- Liquid Water
- Heat

Experimental campaign

- Sets of test to be performed:
  - Basic functionalities (filling & emptying crucible, stirring, ice deposition…)
  - Extraction & capturing specific tests
  - Full system

- Experiment variables
  - Ice weight % – 5, 10 or 15
  - Sample mass – 5, 10 or 15 kg
  - Presence of volatiles
  - Cold trap temperature – 180, 200 or 220 K

Test goals

Basic functionalities tests	→	Overall system assessment
Extraction and capturing tests	→	Best operations strategy
Full system tests	→	Influence of each experiment variable

Expected results (Water Extraction and Capturing)

- The high-level expected results in summary are:
  - TRL 4-5 of water extraction and capturing technologies.
  - See the effectiveness of crucible and in-situ dome + heating rods design.
  - See improvement of stirring/mixing icy-regolith in terms of efficiency for extraction.
  - Understand how much contamination (dust particles and other volatiles) finds its way into the liquid water (input for purification).
  - Water.

Icy-regolith simulant sample production

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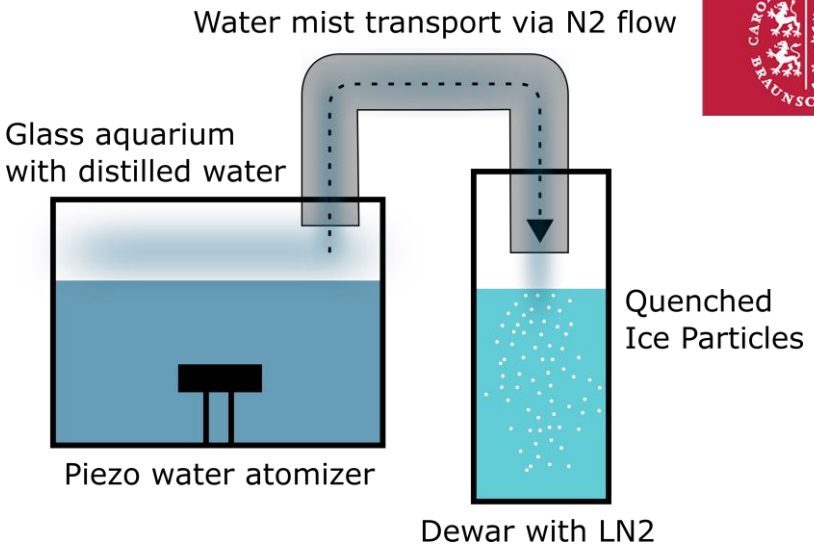
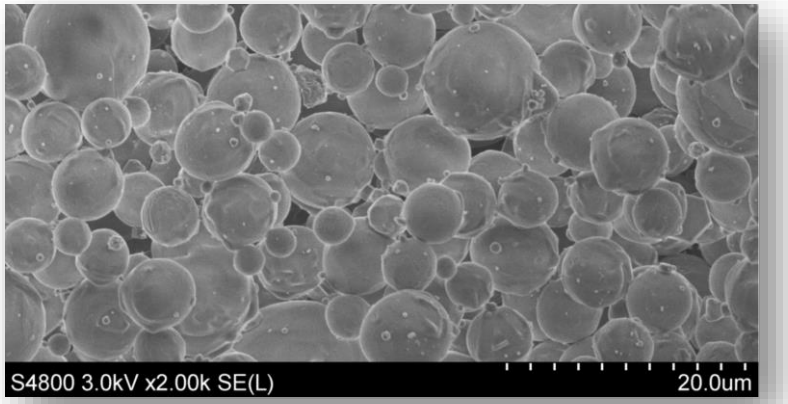
Lunar icy regolith simulant

- Lunar regolith simulant by Lunex Technologies in Berlin
  - 75% Terrae – 25% Mare
  - 0 – 1 mm particle size
- CoPhyLab granular ice particles
  - Spherical particles with 2.4 ± 0.1 µm radius



Schematic setup of ice machine for production of granular ice particles

Lunar regolith simulant

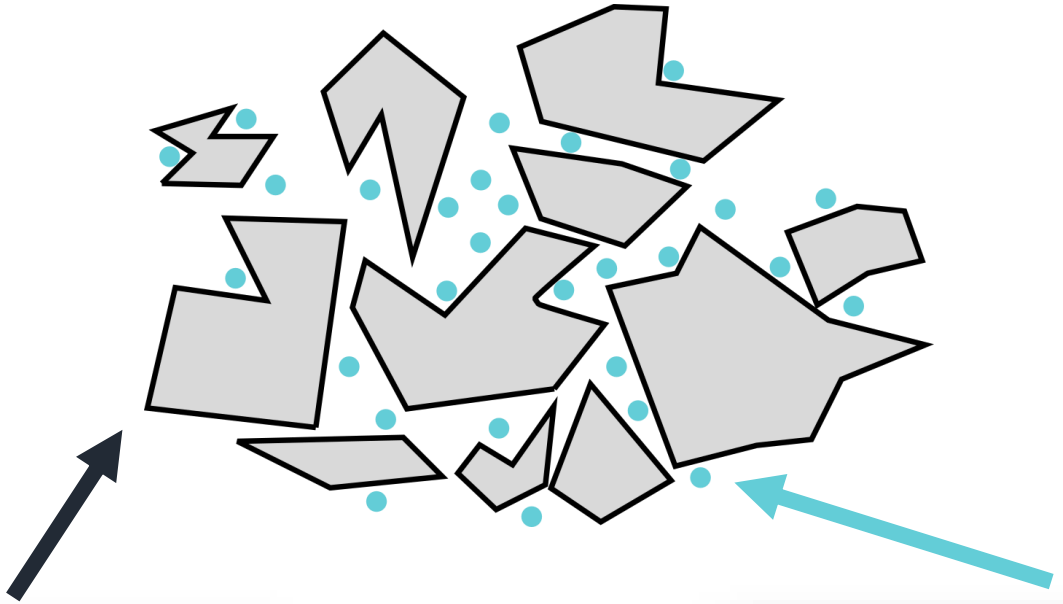


Scanning Electron Image of ice particles (Kreuzig et al. 2023)

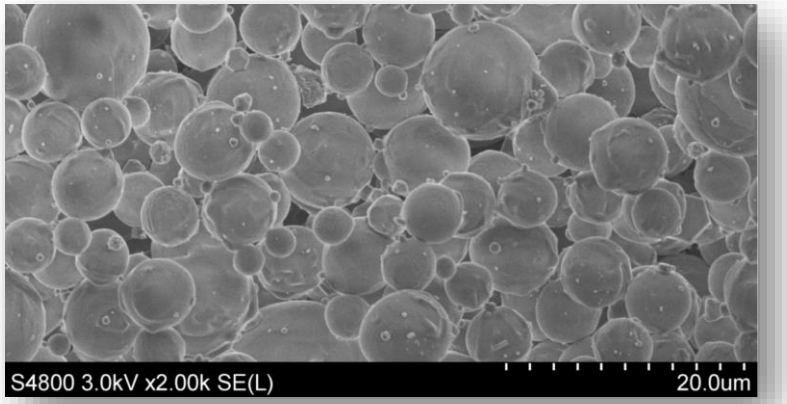
Lunar icy regolith simulant

Unfused discrete icy regolith

- Heat transport through ice is minimal
- Very low thermal conductivity



Lunar regolith simulant

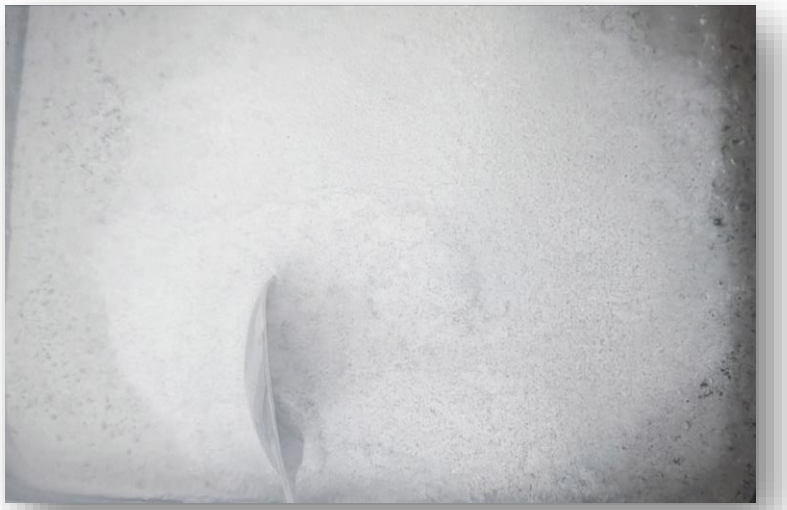


Scanning Electron Image of ice particles (Kreuzig et al. 2023)

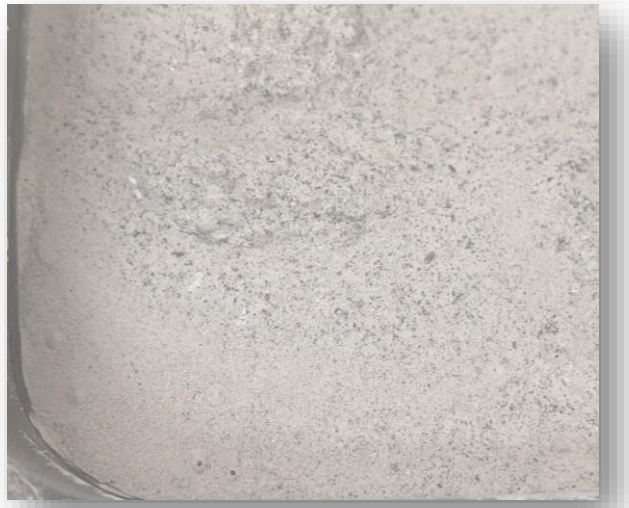
Lunar icy regolith simulant

- Addition of water-soluble contaminants easily possible e.g. methanol
- Mixing of ice and regolith in LN2-slurry
- LN2 will evaporate quickly

mm-sized ice clumps occur when using ice dried without LN2



Unmixed regolith-ice-LN2 slush



Icy regolith after mixing

Icy regolith after LN2 dried off

Water Purification Subsystem

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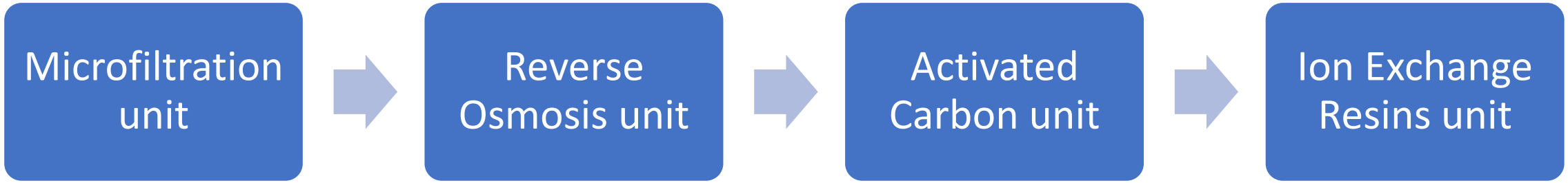
Water purification and storage subsystem

Main design features:

- Consuming less than 1 gram of consumables per kilogram of product water
- Achieving target product water to feed ratio >95%
- Achievin target product water quality fo electrolysis applications and/or drinkable water



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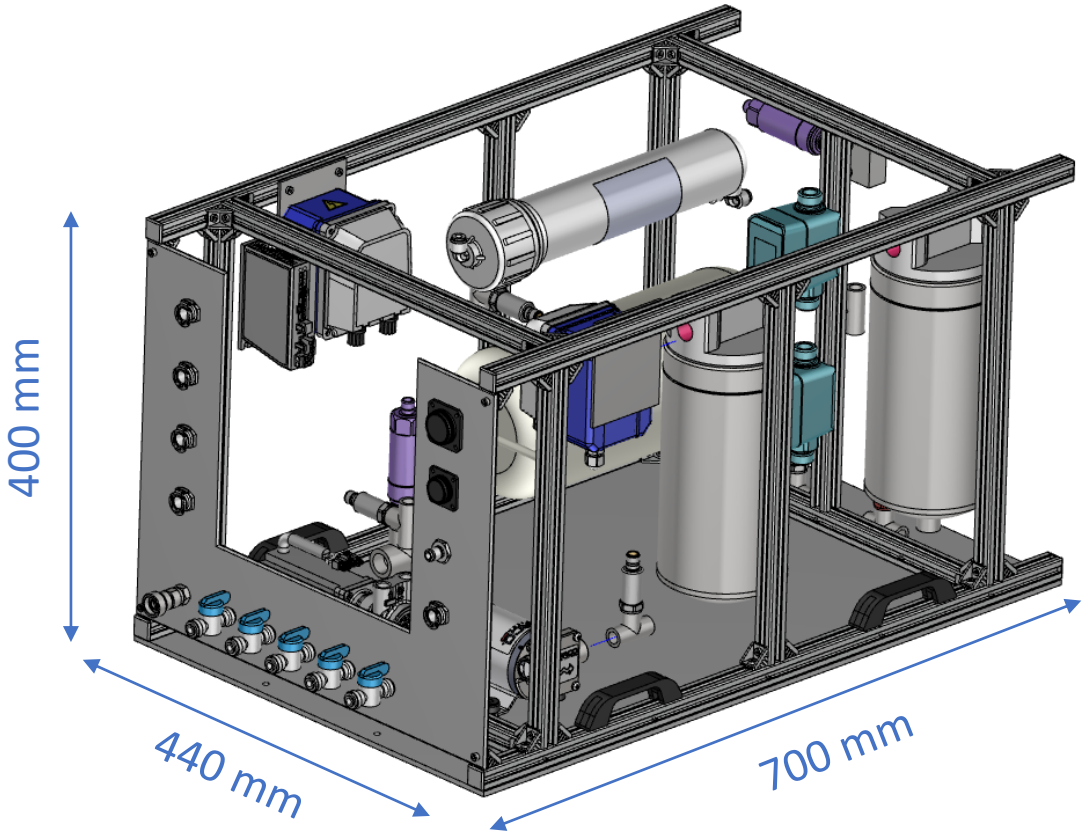
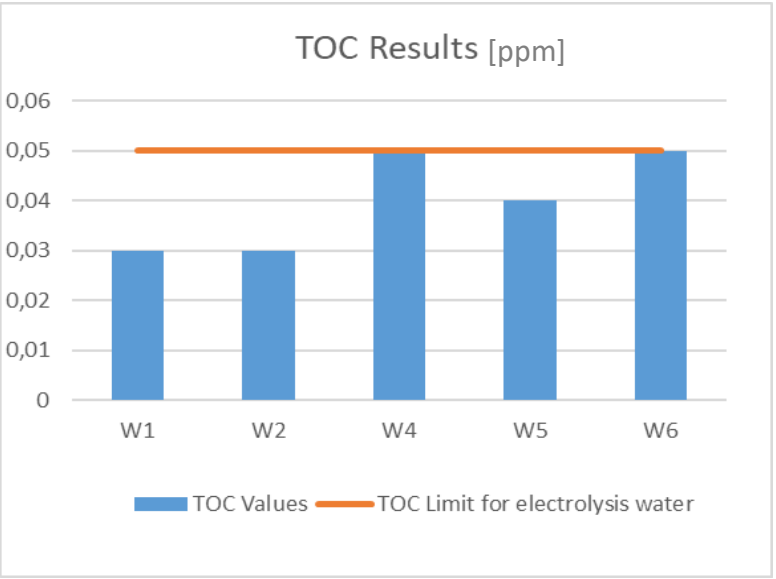
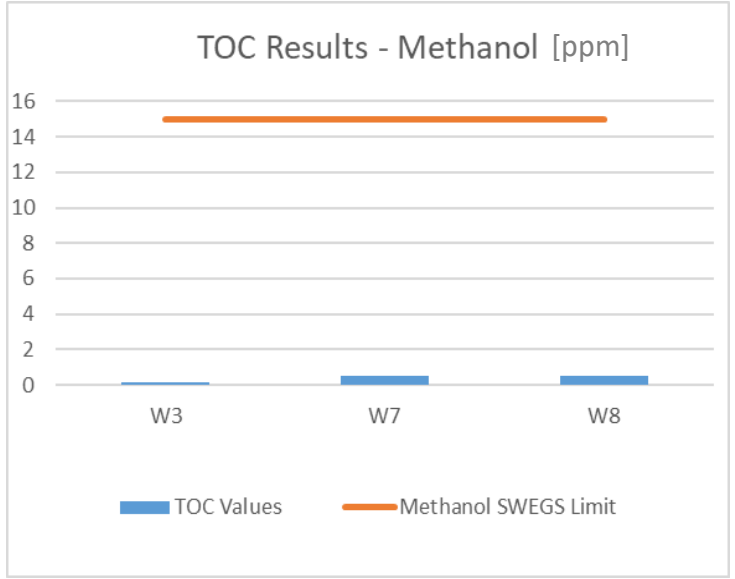
Water purification and storage subsystem

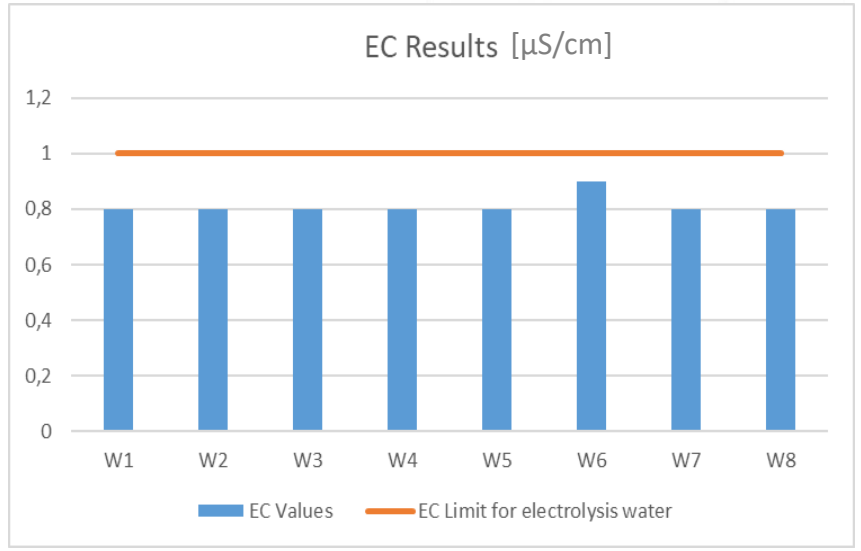


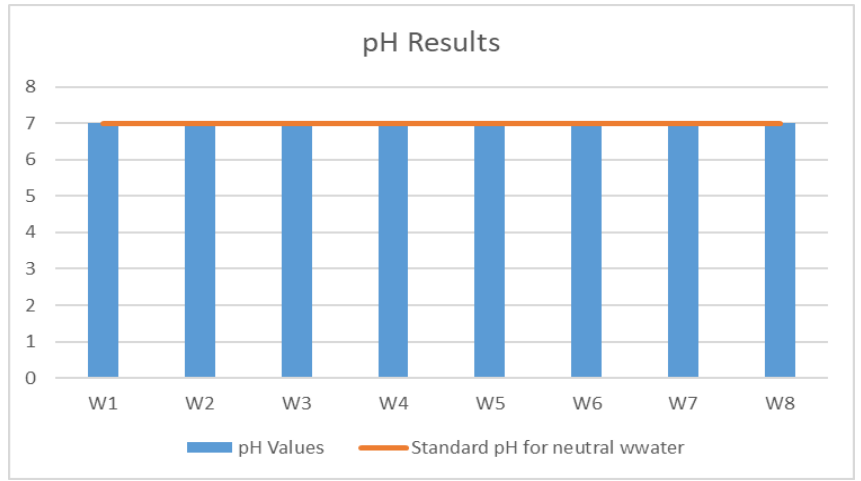
Water purification and storage subsystem

- Results of preliminary experiments with different raw water simulants
- Ultra-pure water contaminated with combinations of regolith, ammonia, sulfur dioxide and methanol









Outreach

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Dissemination, exploitation and communication

- Press releases
- Project flyer
- Podcast miniseries
- Videocast miniseries
- Next Nature exhibition
- Website: luwex.space