Synergetic Material Utilization (SMU)

Lecture Politecnico di Torino – Management Course

Space Resources:
Water Extraction Technologies on the Moon (and Mars)

Luca Kiewiet (luca.kiewiet@dlr.de)
DLR Institute of Space Systems

Resources in Space - Introduction

- What is a space resource?
  - A recoverable resource, with a technology to take it, and has a use case.

- Definition of a resource varies widely:
  - Tangible resources like metals, oxygen, water etc.
  - Or more intangible resources like sunlight, vacuum, low(er) gravity, or even views from above.

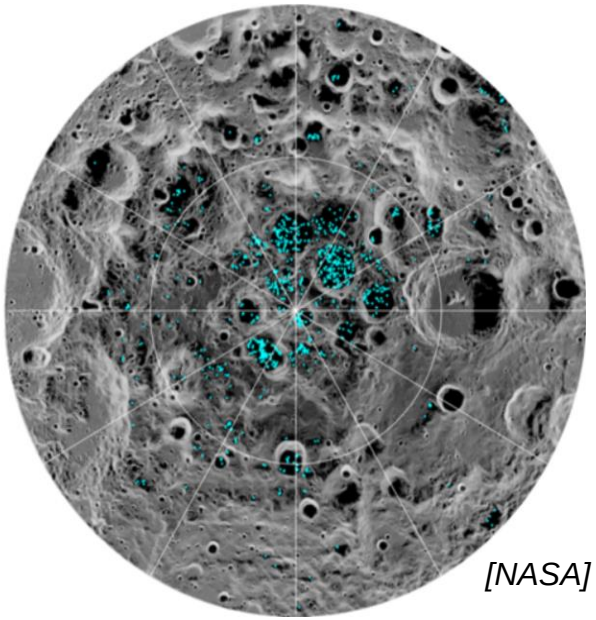
Background

- 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

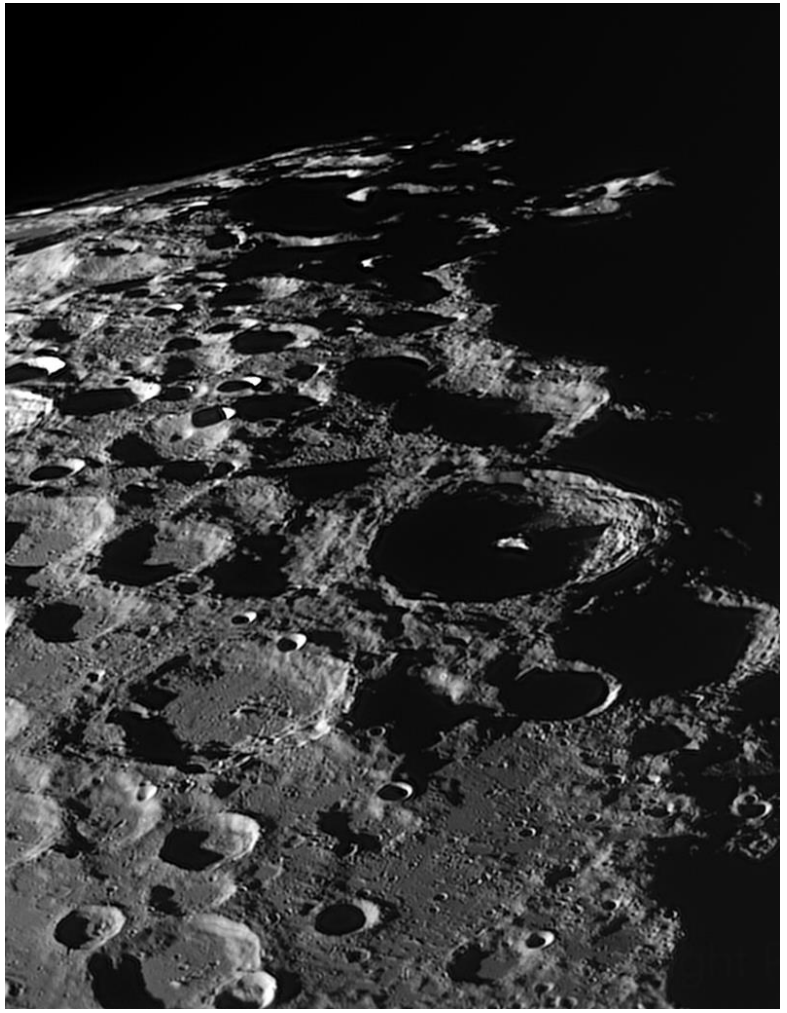
Problem Statement

- Lunar surface at the south pole:
  - Generally temperature around 100 Kelvin, even as low as 20 Kelvin locally in craters.
  - Ultradeep vacuum, abrasive lunar dust, no comms, radiation, steep inclinations, low gravity etc etc.

- End goal of the water extraction is to separate the water from the lunar regolith and capture it.

- Water extractor devices should be focused on durability, efficiency, and reliability for future missions.

- However, solutions to one problem are the cause for other problems.
  - f.e. low thermal conductivity means you need to move/manipulate the lunar regolith, but this causes problems with abrasiveness.

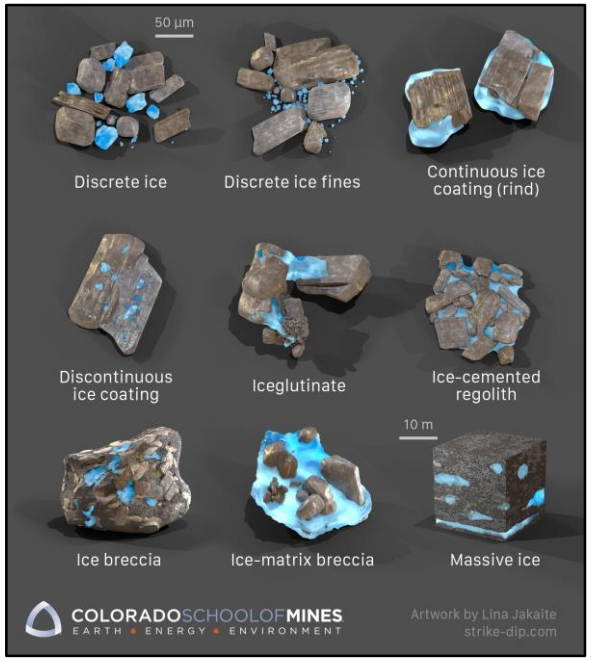


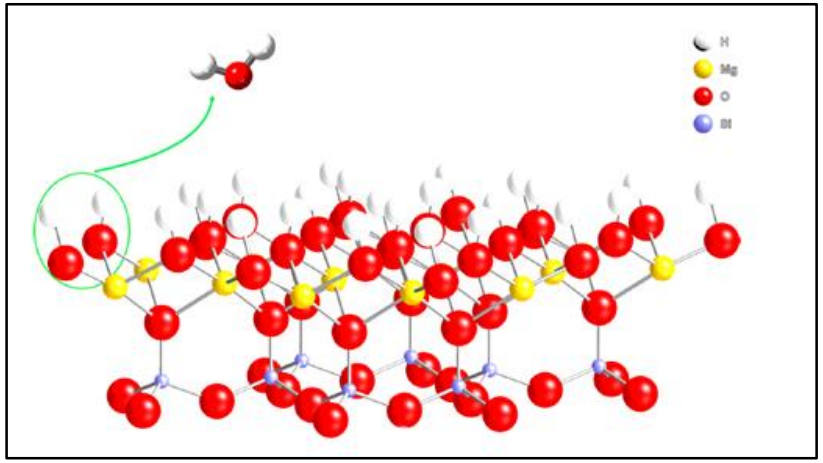
State of Water on the Moon

- 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.



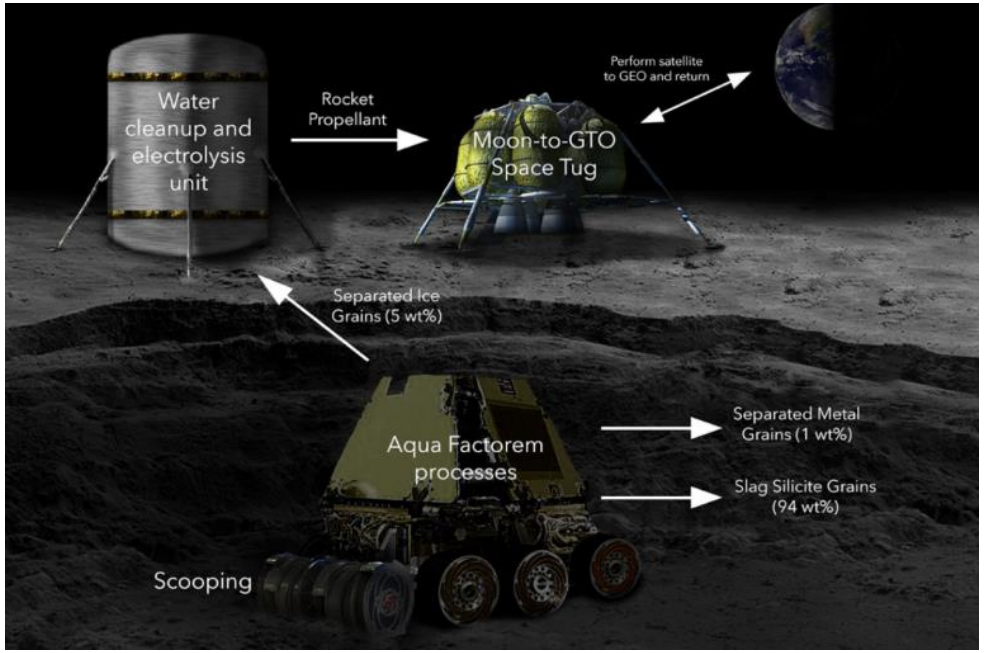


[Jones et al. 2020]

Water Extraction Methods

- Different methods exist, however, the most cited these days is the **thermal extraction** method.

- Another interesting method is to **mechanically seperate** the regolith from ice by grinding, pneumatic ballistic sorting, magnetic seperation, and/or electrostatic seperation.



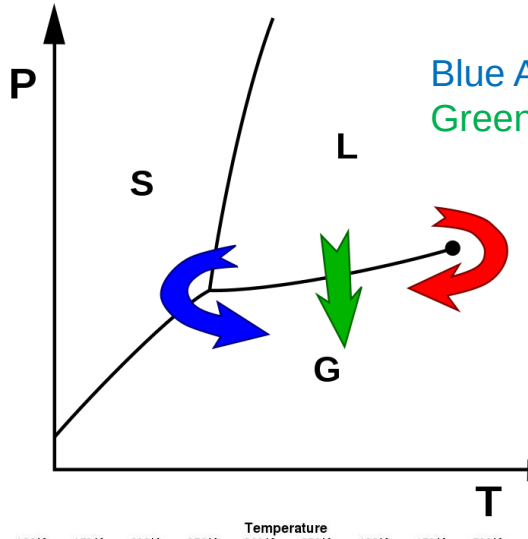
[Aqua Factorem - NASA and Jessica Woodward/UCF]

[Heated Dome Architecture - George Sowers/Colorado School of Mines]

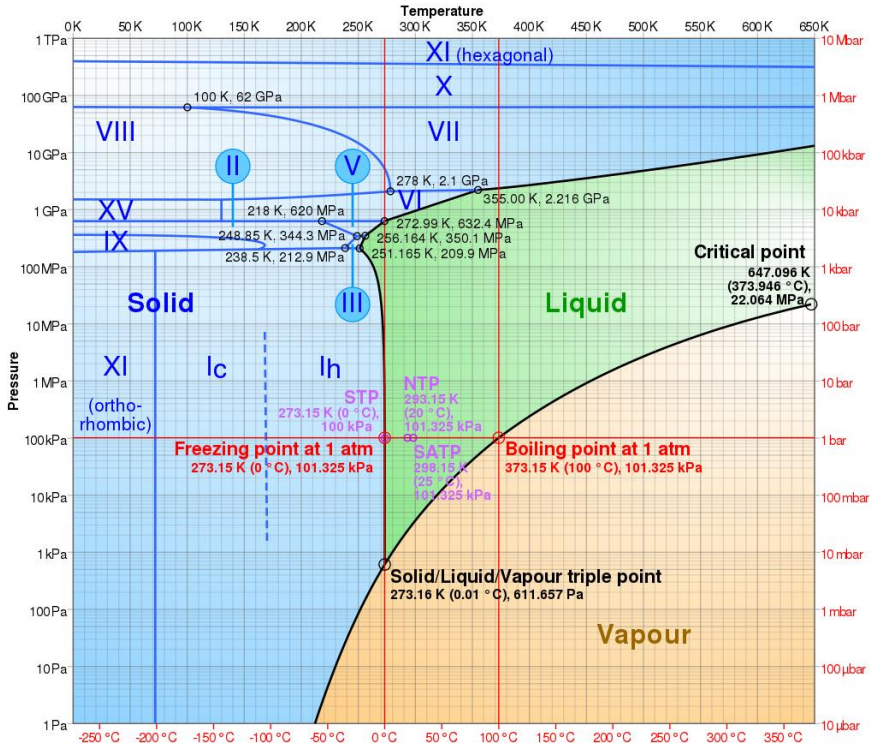
Thermal Extraction - Concept

- Thermal Extraction means heating the sample until volatiles are outgassing from the regolith. This can be applied to:
  - Loosely adsorbed water molecules,
  - Ice particles,
  - Water trapped in minerals.
- With various degrees of heat needed for each.

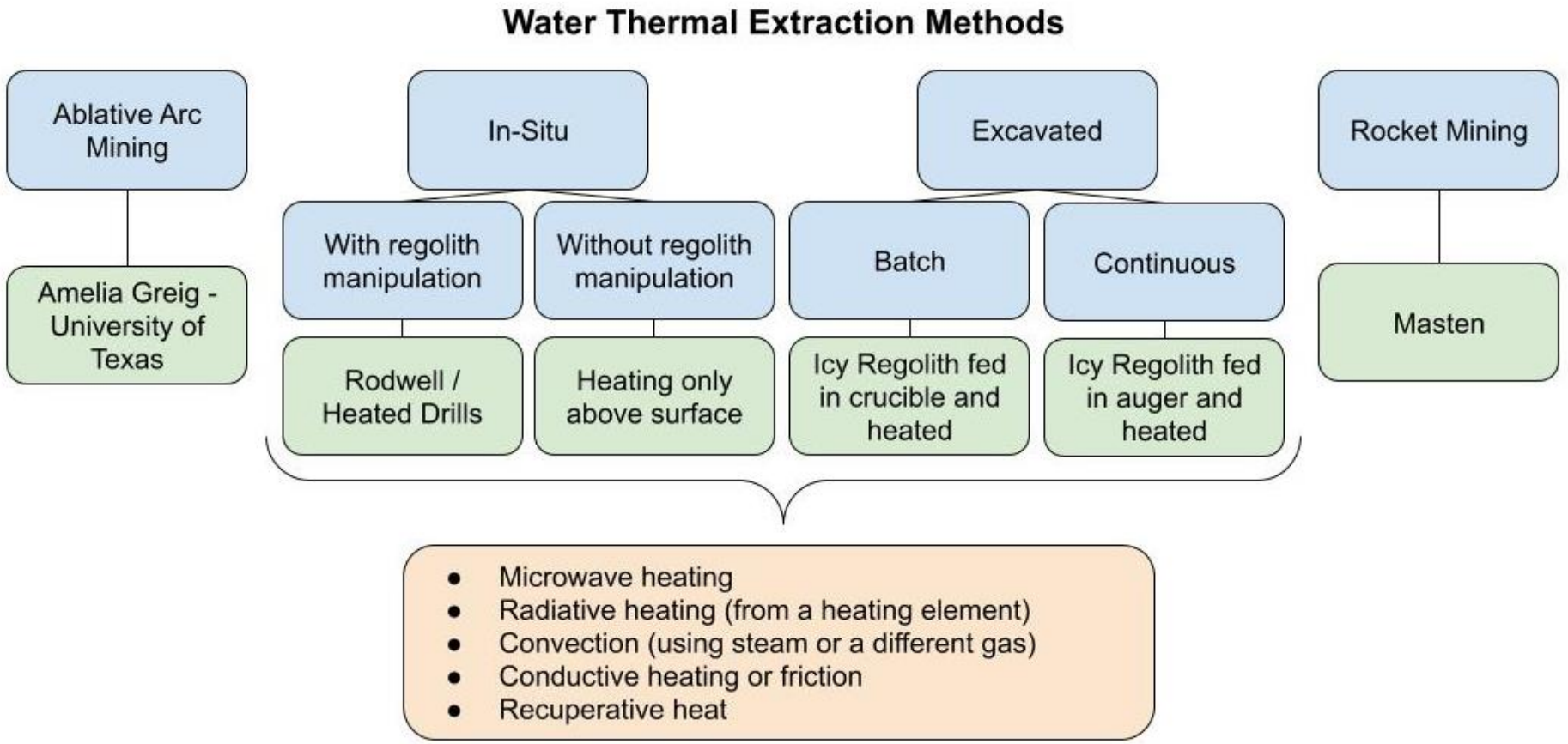
- The most effective method to extract the ice particles would be through **sublimation**, considering the pressure and temperature of the native environment are already low.



Blue Arrow = Sublimation
Green Arrow = Vaporization



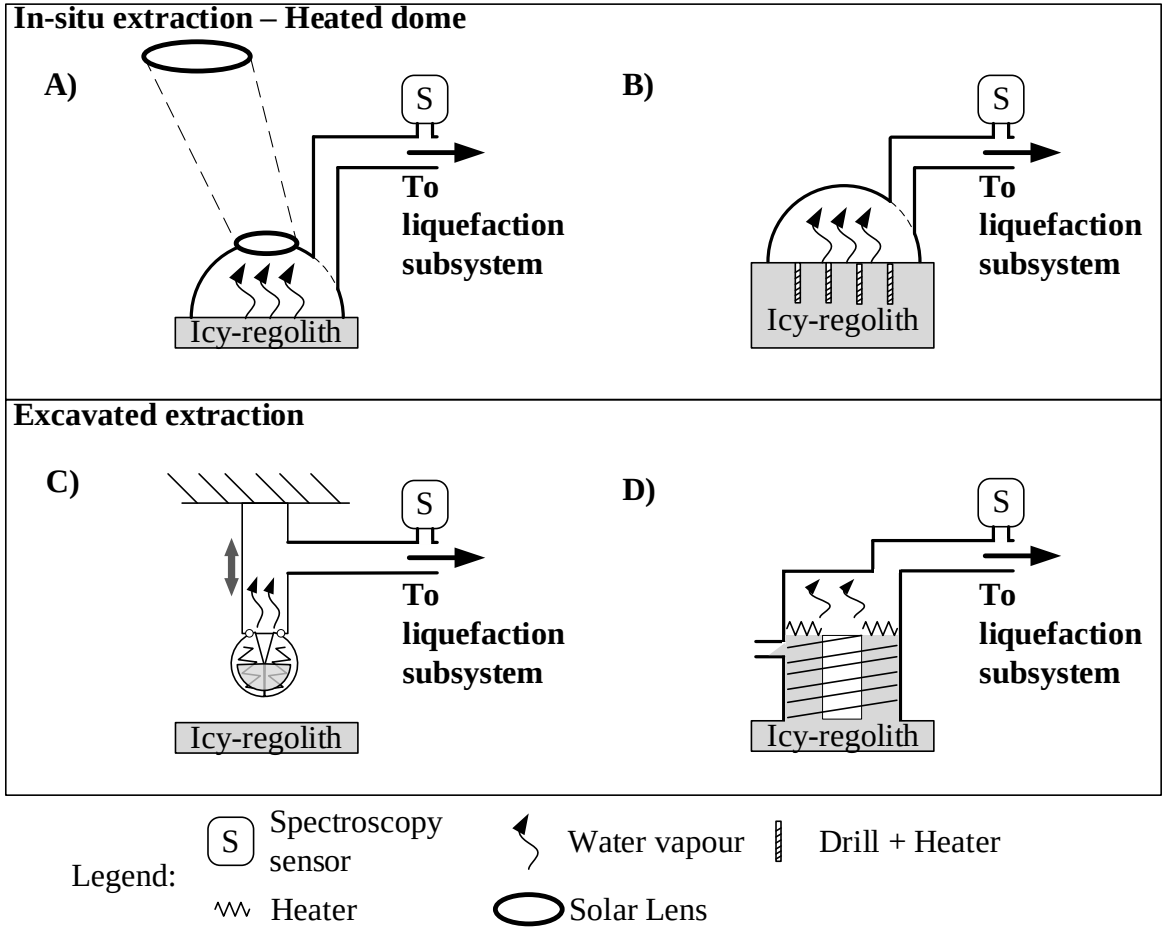
Overview Thermal Extraction Methods



In-Situ Extraction & Excavated Extraction

- In-Situ Extraction:
  - Extracting the water vapour directly from the soil without gathering it.
  - Redirecting sunlight from crater rim.
  - Heating rods placed in the soil.

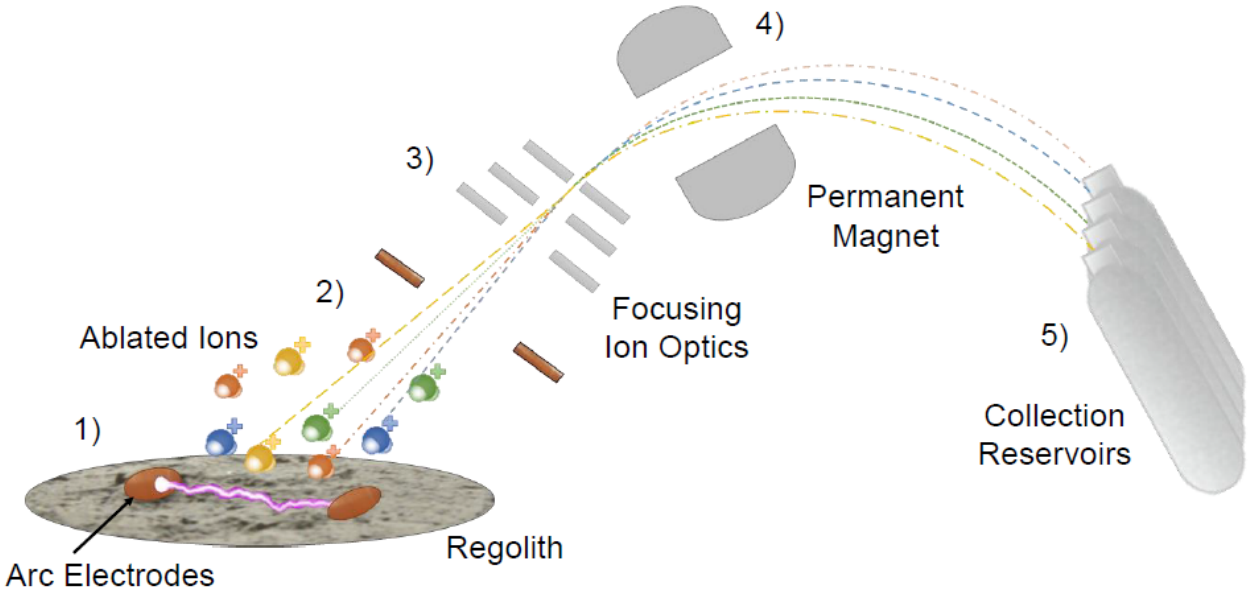
- Excavated Extraction:
  - Placing icy-regolith in a reaction chamber.
  - Extract water in batches.



Ablative Arc Mining

- Developed by Amelia Greig from the University of Texas.
- Ionize material (regolith) and guide ions to containers.
- Allows for simaltaneous collection of different resources.

Simultaneous extraction, capture, and storage of multiple regolith volatiles in a single, mobile system for lunar or Martian ISRU.



1) Ablate and ionize regolith using an electric arc
2) Direct to collection system with electric fields
3) Focus the ablated regolith into a collimated ion beam using ion optics
4) Pass though a controlled magnetic field to sort ablated material by mass
5) Place dedicated collection reservoirs in direct path of elements
6) Contain system in a single mobile surface crawler for wide-area mining

Rocket Mining

- Developed by Masten Space Systems.
- Uses a ‘’nozzle’’ and a rocket engine placed on the lunar regolith to blast and sublimate any volatiles inside the soil.
- Then, a vacuum pump and several seperation technologies collect the water vapour from the rocket engine and the ice from the soil.

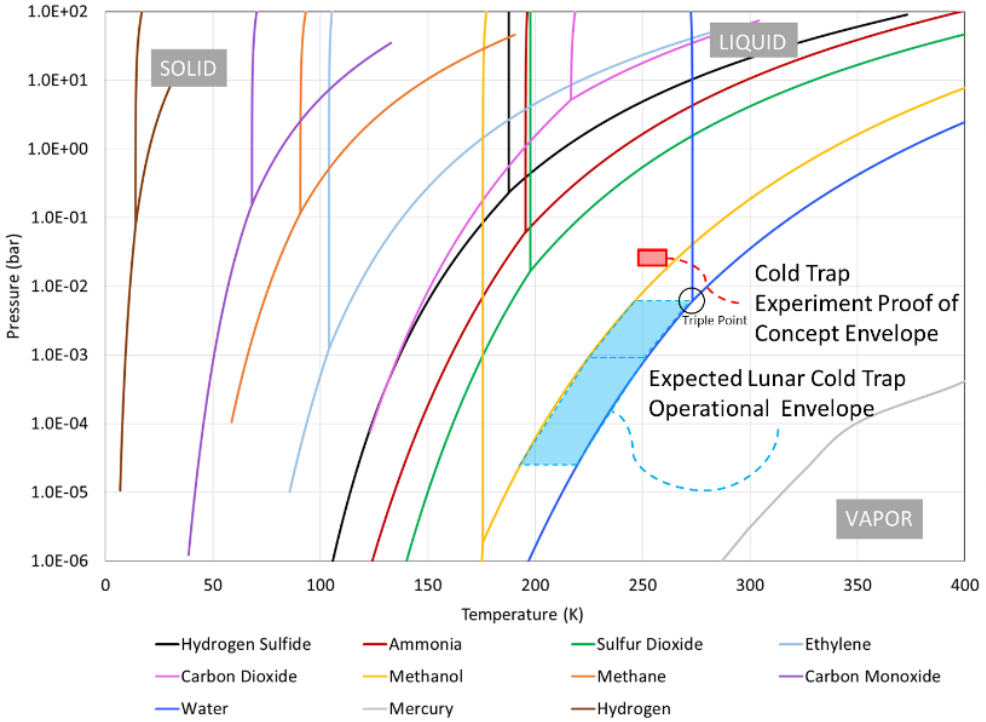
[Masten Space Systems]

Water Vapour Capturing Systems

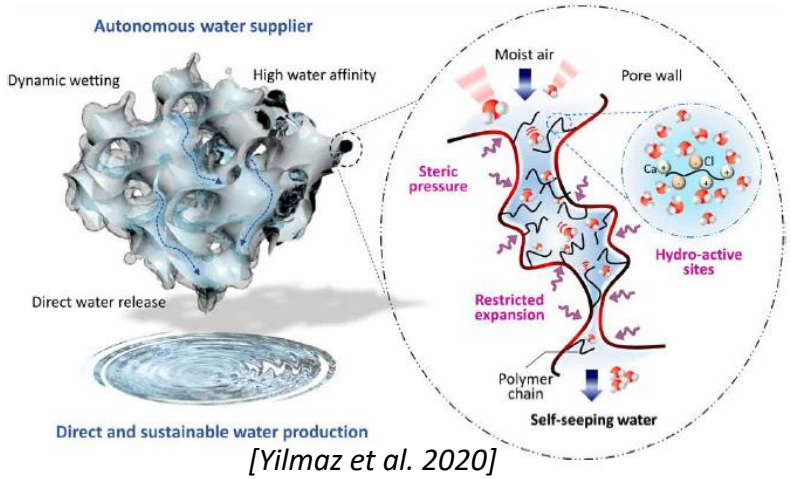
- Knowledge about capturing (or liquifaction) subsystems is rather limited currently.

- Most cited is the use of a cold trap.
  - However, cold trap would require a large amount of energy, which scales exponentially with desired mass caputre.

- Another method is to use passive membranes, where vapour is condensated and drips down.
  - Here the abbresiveness of lunar regolith might cause lifetime issues though.

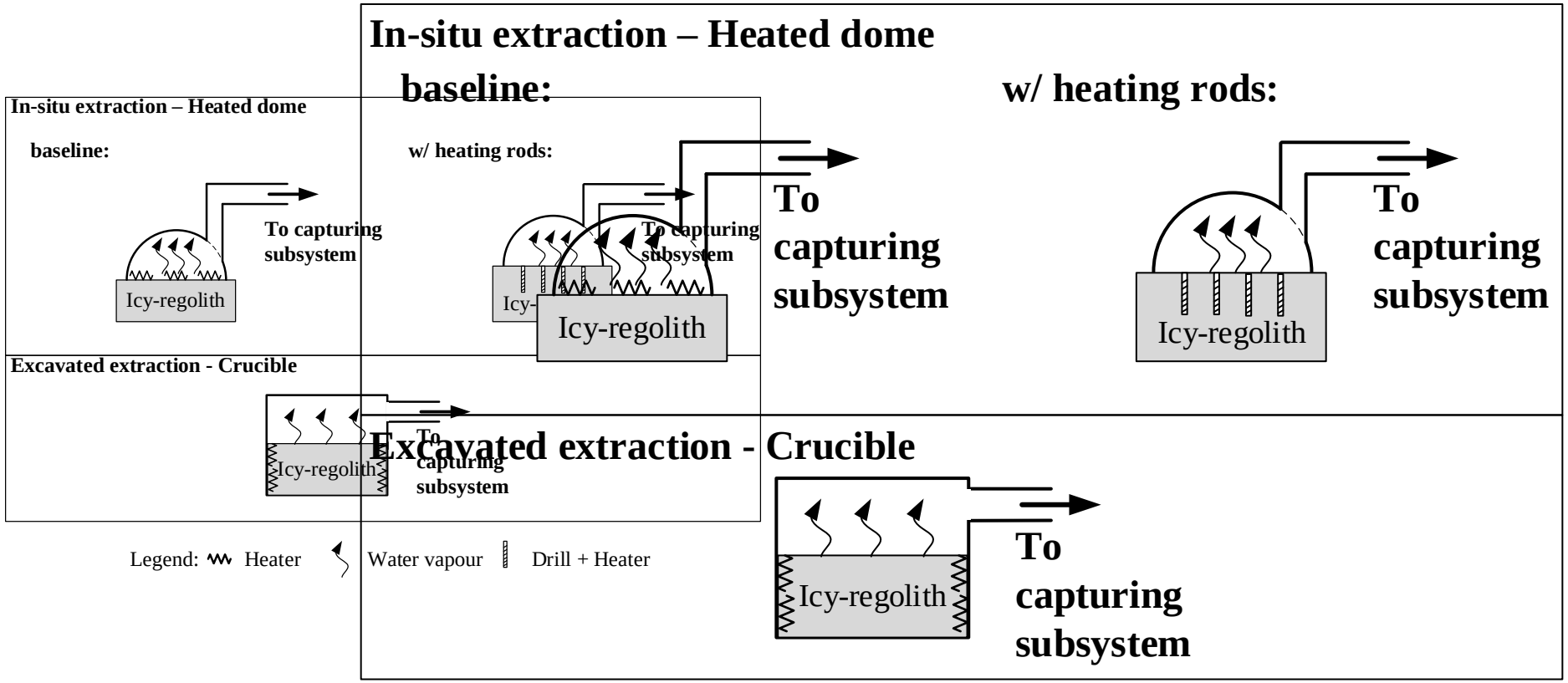


[Holquist et al. 2021]



[Yilmaz et al. 2020]

Questions?



Legend: Heater Water vapour Drill + Heater