ISRU POTABLE WATER HARVESTER FOR ASTRONAUT MISSIONS.

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Introduction: Water is a fundamental source for human life, and its bulk usage is inevitably necessary for any permanent human presence in space. As future astronauts venture off to hostile environments, they still rely on basic life support needs such as potable water. However, they shouldn't have to bring everything with them if their destination contains the resources on site. In-situ resource utilization (ISRU) significantly reduces the cost, mass, and risk of sustained human activities beyond Earth.

Potable drinking water is fundamentally linked to human health and survivability. Investigations are underway to quantify this precious resource in our solar system [1], [2], [3] that has the potential to change the entire strategy for lunar and eventual Martian settlement development. Future mission concepts must include a robot that harvests spacewater rather than send from Earth the water that a crew requires. Intelligent robotic operations can take advantage of the local resources in shared autonomy with astronauts.

Concepts in the literature propose ways to extract water and volatiles, but most of them suggest strip mining strategies that are bound to irreparably damage and deface the pristine extraterrestrial surface terrain. This proposal looked for elegant solutions; cleaner autonomous system designs less prone to adverse surface effects like dust eliminate major operations concerns.

Proposed Instrument: A robotic induction furnace presents a simple, robust, and promising method to harvest water for such purposes. The furnace would operate at a temperature sufficient to release water vapor from the regolith. Induction allows heating from above without excavation by appropriately setting the skin depth of the magnetic field. Water ice will sublimate in the low-pressure surface environment, so the instrument must operate under these conditions.

Figure 1 illustrates a preliminary concept of this harvester design. An induction coil at the surface would be shaped so that the magnetic field penetrates several centimeters into the regolith or rocks. Upon heating the low-pressure trapped water, the sublimated vapor would rise and be captured by the harvester enclosure. Some lateral water transport is acceptable as there is a likelihood when the roving harvester moves that this water will eventually be forced upwards. The harvester enclosure should implement passive thermal control and be shaped like a whiskey still to promote phase change at the top and deposition in the arm region. Once full, the harvester would interface with a transfer seal in the storage unit. The storage tank interior should be maintained at a pressure and temperature to allow for liquid water. The harvester arm would experience this environment change and the collected ice would liquify and fall into the tank.

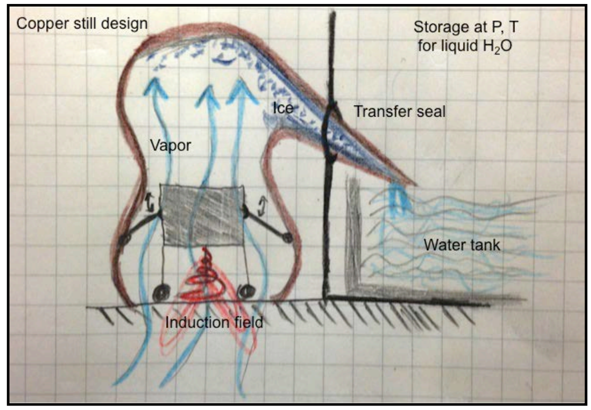


Fig. 1: Robotic induction furnace vaporizes embedded water and captures using whiskey-still geometry to promote phase change. Transfers potable water to storage when full.

Figures 2 and 3 illustrate the area and time requirements to harvest lunar water for three crew sizes. Assuming that the regolith is 2% water by weight and that water is present in a 1 cm thick subsurface layer, a robot could travel the necessary area to collect the 12 L per person per day [4] for a 100 person crew to become self-sustainable [5] in roughly one month. Habitat architecture could incorporate water storage to provide radiation protection. Closed-loop water recycling could minimize requirements for water resupply.

Systems for use on the Moon should be created first and tested on site as a testbed for eventual deployment at Mars.

This proposed mission concept focuses on a water-harvesting instrument. It does not cover system requirements of a rover to host this instrument payload [6]. Robots for surface operations such as the K10 Planetary Rovers from the Intelligent Robotics Group at NASA Ames – which already include chassis, navigation, communication, power, and control systems – have exhibited promising capabilities in field tests [7].

Instrument Requirements: An ISRU water harvesting instrument requires a central processing unit and a suite of sensors working together to take measurements, provide observations, and use data in feedback-loop operations. Onboard calibration should maintain sensor accuracy in accordance with mission constraints and published standards. Thermal controls should maintain proper internal operating environment.

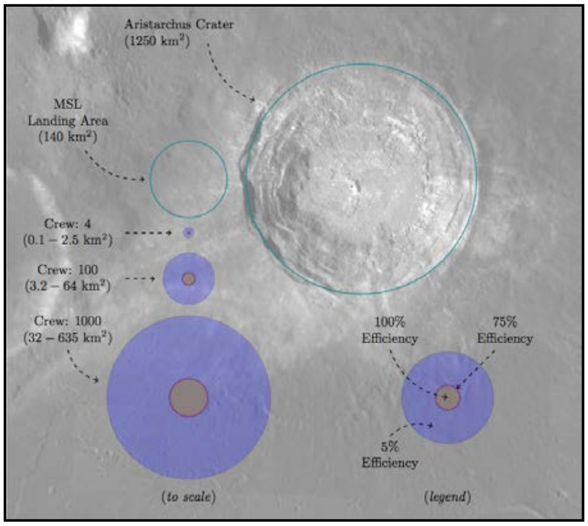
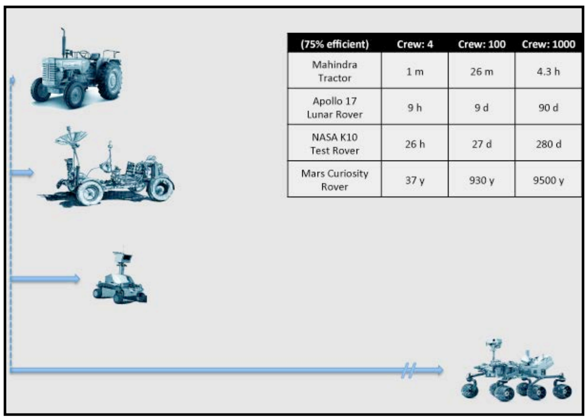


Fig. 2: Surface area required for self-sustainable harvest.



(75% efficient)	Crew: 4	Crew: 100	Crew: 1000
Mahindra Tractor	1 m	26 m	4.3 h
Apollo 17 Lunar Rover	9 h	9 d	90 d
NASA K10 Test Rover	26 h	27 d	280 d
Mars Curiosity Rover	37 y	930 y	9500 y

Fig. 3: Time required for rovers of various speed capabilities to travel the harvest area.

Fault tolerance is minimal because successful operation directly effects human survivability, and graceful degradation should occur slowly enough to allow for deployment of replacement devices prior to failure. Instrument design shall include parallel redundancy where possible.

Induction Furnace. This component should release water vapor from icy regolith and hydrated minerals. A magnetometer should monitor the magnitude and direction of the induced magnetic field. A power measurement sensor should calculate voltage, current, power, and AC frequency to regulate the magnetic field. A temperature sensor should measure furnace temperature, instrument internal ambient temperature, and ground surface temperature.

Water Composition. The harvester should include water phase, potability, and isotopic composition sensors. A remote-sensing H_2O phase detector should detect how much ice deposition has occurred in the arm. After reaching a threshold, the instrument should verify potability and then alert the rover to return to the storage area to transfer collected water. An isotopic composition sensor should report scientific data to study the water's cosmic origin – though secondary to harvesting, this would provide unprecedented data to researchers on Earth. A single spectroscope could meet the three water sensor requirements.

Water Storage. Load cells placed in the instrument's support structure can be arranged to detect the increase in system mass due to water collection in the arm. The long-term potable water storage tank should include a filtration element and be kept at a regulated temperature and pressure to allow for liquid water. Flush mount diaphragm pressure sensors which monitor the ratio of liquid to vapor can be used to calculate the volume of liquid water. Non-potable water should be stored separately for other habitat uses.

Future Studies: 1) Computational simulations of releasing bound water from regolith simulants and minerals via induction heating, and 2) Engineering design, construction, and testing of an induction furnace and water storage tank which accomplishes this task.

Conclusion: Water is vital to human life. In-situ operations enable long-duration, self-reliant human exploration with less mission risk because resources are in place. Developing elegant, simple, yet robust water harvesting and storage capabilities closes a key technology gap for human exploration employing in-situ resource utilization.

Harvest areas are small enough that one rover sent early could collect a self-sustainable reserve of water in a feasible mission time frame.

An ISRU water harvester has the potential to answer questions of scientific interest related to: (a) collecting water in lunar and martian surface environments, (b) cosmic origin of water based on isotopic composition, (c) induction skin depth design, (d) water release mechanisms from hydrated minerals (e) mission volume requirements of regolith and water, (f) ISRU instrument design, (g) low-power induction furnaces, and (h) nuclear-powered instrument design.

References: [1] Clark RN et al. (2011) J. Geophys. Res., 116, E00G16. [2] Colaprete A, et al. (2010) Science 330, 463. [3] Leshin LA, et al. (2013) Science 341, 1238937 [4] Bamsey M, et al. (2003) Adv. Space Res. 43, 1256-1274. [5] O'Handley D, et al. (2000) NIAC Research Contract 07600-052. [6] Orenstein NP (2012) LPS XLIV, Abstract #1843. [7] Fong T, et al. (2008) AIAA Space Conference.