ISRU: AUTOMATED WATER EXTRACTION FROM MARS SURFACE SOILS FOR SAMPLE RETURN MISSIONS.

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Summary: An in-situ resource utilization (ISRU) option for Mars sample return vehicles is to employ a Sojourner/MER sized bucket excavation rover that mines and extracts water from surface soils and delivers to the lander. A Sabatier reactor and electrolysis plant converts the water and Mars CO_2 atmosphere to methane and oxygen rocket propellant. Potentially this option would have lower mass and volume than imported propellants or hydrogen and could be adopted for human missions. This abstract proposes a mining rover to mine and extract water from the surface top 5 cm soil.

ISRU systems incorporated into sample return mission architectures have been proposed to avoid importing propellant mass for the sample return vehicle, significantly reducing the spacecraft payload mass thrown to Mars, [1] [2]. Three ISRU options have been proposed to manufacture rocket propellant, fuel and oxidizer, or oxidizer only, consisting of: (A) the manufacture of methane fuel and water by combining imported hydrogen and with the Mars atmosphere CO_2 in a Sabatier reactor. Electrolysis cracks the water to extract oxygen oxidizer; (B) the manufacture of carbon monoxide fuel and oxygen oxidizer from Mars atmosphere CO_2 using zirconia cell technology; and (C) the manufacture of oxygen oxidizer only from atmosphere CO_2 using zirconia cell technology. Option (A) has the problem of high volume and 'boil off' of stored liquid hydrogen in the lander. Option (B) has undeveloped and problematic ISRU and CO/O_2 propellant rocket engine technology, and finally option (C) saves 80% imported propellant mass. A mining and extraction rover could be mass competitive compared to these options.

Water availability: Evidence of significant water in the Mars surface soils in the form of ice particles or hydrated minerals, has been found by the 2001 Mars Odyssey [3] possibly up to 10% in places [4]. Viking measured up to 1% water content in soil, [5] [6], consistent with the Phoenix lander [7], detecting loose ice-cemented soil at a depth from 1 cm to 5 cm overlaying a hard ice-cemented material. The top 5 cm of the soil is loose and easy to dig, avoiding deeper hard permafrost material.

Mars Mining: Mars mining technology and methodology has been considered, [8] [9], using a front end-loader rover that excavates and transports material to a hopper on the lander. However this requires high self-autonomy and discharging processed soil is a problem. Alternatively, a bucket wheel excavator rover equipped with an onboard microwave heater and storage tank to excavate, extract and store water then discharging processed soil out the back is much more efficient and operates continuously with simpler automation. Refer to Figure 1 showing a standard bucket wheeled excavator/reclaimer used in the mining industry and Figure 2 showing a proposed equivalent machine and process diagram for Mars. When full of water, the rover returns to the lander for off-loading. The microwave heater is set at the natural frequency of water molecules thus targeting water only for heating. A radiator and pump condenses and pressurizes and feed the water to storage tanks.

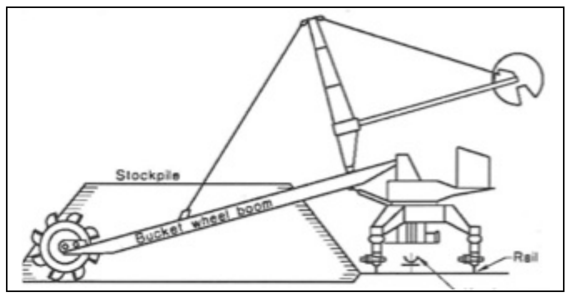

Figure 1: A nominal 1000 tonnes per hour capacity bucket wheel excavator/reclaimer. The machine long travels on rails or tracks while excavating, thus cutting material perpendicular to the direction of travel. It also slews and luffs. [10]

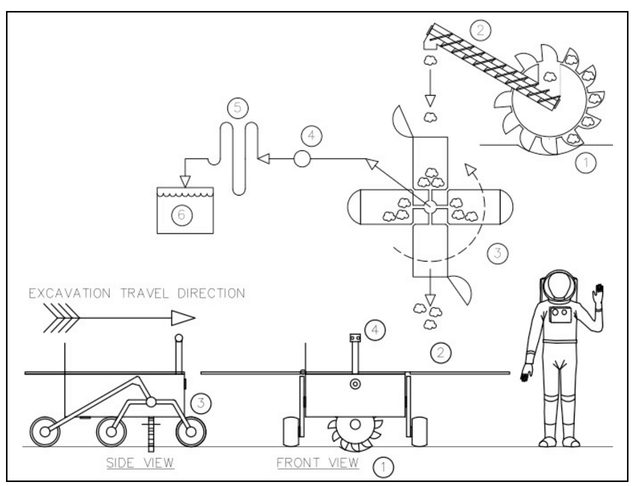

Figure 2: *Top:* The mining and water extraction process flow diagram with (1) the bucket wheel, (2)

screw conveyor, (3) 4 oven carrousel receiving, heating and depositing product, (3) water pump, (5) radiator and (6) water storage tank.

Bottom: A 50 kg/hour capacity bucket wheeled excavator, with (1) bucket wheel arranged perpendicular to direction of travel, (2) the 4 m^2 solar array and (3) adjustable height wheel carriage system.

Assumptions:

Excavation quantity: We considered benchmark assumptions to calculate the mining capacity summarized as: (1) a sample return rocket requires 1 tonne propellant consisting of 200 kg methane fuel (CH_2) and 800 Kg oxygen oxidizer (O_2); (2) all the CH_2, H_2 and O_2 oxidizer is from 850 Kg water extracted from the soil. Mars atmosphere is the source for carbon. Thus, assuming 1% water content, we require to mine 85 tonnes of soil or approximately 40 cubic metres of excavation.

Power: A 300 mm diameter bucket wheel with 50 mm wide buckets excavating 50 kg per hour of sand has been trialed [8]. It used only 0.5 watts continuous power, peaking at 0.95 watts during excavation. However ice-coagulated soil similar to the Viking and Phoenix landing sites would use greater power but not significantly greater power. Microwave heaters are 60-65% efficient for converting input electrical energy to thermal energy to heat water. Thus a simple power estimate to heat 0.5 kg per hour of liquid water within 50 kg of soil 100 °K, excluding ice phase and phase changing issues changes is approximately 100 watts. We also assume the rover requires approximately 100 watts to operate and travel. Hence, from these very preliminary assumptions, an allowance of 300 watts provided by a 4 m^2 solar array could be a design benchmark power specification for the rover to operate and mine soil at 50 kg/hour capacity. Further design and testing will be required to support these assumptions.

Capacity: If we assume 6 hours per day excavating at 50 kg/hour operation containing 1% water, then 3 kg water per day would be extracted. Assuming the rover can store 50 kg of water before unloading in a 20 day cycle then it would require nominally 340 days of mining to extract 850 kg of water.

Rover Geometry and control: It is preferable to excavate perpendicular to the direction of travel [9], thus applying excavation forces perpendicular to the wheels ensuring wheel traction is maintained.

Geometry: Hence the bucket wheel is best located between the rover wheels, part within the rover chassis and the rest projecting into the subsurface as shown in Figure 1. The wheel buckets discharge product into a screw conveyor that transports and deposits it into microwave ovens rotating on a carousel, ensuring continuous filling, heating, and dumping of processed product.

Control: The rover would be programmed to ideally mine a series of furrows, if the terrain allows, driving and excavating in a straight line before turning around and travelling in the reverse direction and then repeating the pattern. Height adjustment would be required to maintain its digging depth of 5 cm. This could be provided by a height adjustable wheel carriage system guided by a laser rover-ground clearance sensor. The rover would also need to sense and recover from collisions between the bucket wheel and subsurface rocks.

Mine Operation: A mine site clear of rocks and obstacles is preferable and the rover would first need to map the obstacles and mining area prior to commencement of mining. A combination of imaging and a laser distance-measuring instrument providing a 3D image map through image pixel software manipulation by mission control. Earth controllers would use this map to program the rover travel and furrow excavation to great detail. The overall efficiency of the rover mining process a function of the image map accuracy. Thus, the mine rover operation would have less unknowns and more manageable control than the current MER system.

Conclusion: A Sojourner/MER sized bucket wheel excavator rover that mines and extracts water from the top 5 cm of soil could be used for sample return missions or for human exploration. The rover provides the mined water to an ISRU plant on the lander and made into rocket propellant. The initial key investigation areas to demonstrate the concept advantages are to confirm the rover power usage and mass. The rover mining operation would require an image mapping system, employing a camera and laser distance-measuring instrument, methods of controlling the bucket wheel digging depth and subsurface and surface obstacle detection.

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