VOLATILE EXTRACTOR (PVEX) FOR PLANETARY IN SITU RESOURCE UTILIZATION (ISRU). K. Zacny[1], P. Morrison[1], V. Vendiola[1], A. Paz, [1]Honeybee Robotics, 398 W. Washington Ave, Suite 200, Pasadena, CA 91103, zacny@honeybeerobotics.com, [2]NASA Johnson Space Center,

Introduction: In Situ Resource Utilization (ISRU) is a term given to any activity that uses local resources to offset or enable the cost of bringing all the resources from Earth. In fact, numerous studies related to human exploration of Mars and the Moon indicated that sustainable human presence cannot be achieved without ISRU [1]. In addition, ISRU plays a significant role in commercial market; numerous companies are eager to mine space resources for commercial gain.

A low hanging fruit with respect to ISRU is volatiles and in particular water. Water can be relatively easily extracted just by heating the material. Water vapor can be captured on a cold finger and either processed or cleaned for different applications or electrolyzed into its constituent components: Hydrogen (H2) and Oxygen (O2). Liquid H2 and Liquid O2 can then be used in rocket thrusters as fuel (H2) and oxidant (O2). If the rocket uses different fuel (e.g. methane), O2 can still be used as primary oxidant.

In a conventional mining approach, feedstock is mined, transported to a processing plant, and valuable resource is extracted. This process is energy intensive and requires significant surface assets to perform different functions. Here, we present an alternative approach. Planetary Volatiles Extraction (PVEx) is an approach that combines mining and extraction into one step and eliminates energy intensive and time consuming "transport" step.

We developed three PVEx approaches: "Sniffer", Mobile In Situ Water Extraction (MISWE)/Auger, and Corer. All three are drill based, which helps with penetration of frozen material [2].

Sniffer: The Sniffer, shown in Figure 1, is a deep fluted auger with perforated walls. The Sniffer auger is drilled into subsurface to the target depth and left in place. The heaters embedded within the auger wall and flutes are then switched on to heat up and subsequently melt and/or sublime trapped volatiles. The idea is that the volatiles from the surrounding material would then flow through the holes within the auger, into the hollow auger and up into a cold trap on the surface. Hence volatiles would be 'pumped' directly from the borehole into a cold trap; akin to natural gas or oil recovery.

The main advantage of this approach is that the extraction occurs in-situ and in turn there is no need to capture or transport material. The main disadvantage is that a fraction of heat will be lost by unnecessarily heating surrounding material.

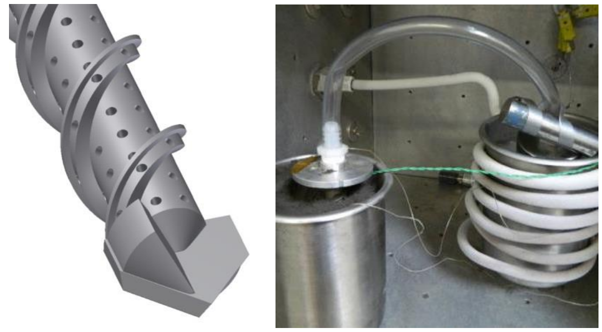

Figure1. PVEx: Sniffer.

MISWE: MISWE system¸ shown in Figure 2, consists of the Icy-Soil Acquisition and Delivery System (ISADS) and the Volatiles Extraction and Capture System (VECS) [3]. The ISADS is a deep fluted auger that drills and retains material on its flutes. After capture of volatile rich material, ISADS moves back into the VECS. VECS consists of a cylindrical heat exchanger (a cylindrical trap) and volatiles transfer system (a reactor).

The material on the deep flutes is then heated, water melts/sublimes and travels down the pressure gradient into a water collection canister (cold finger), where it re-condenses. After water extraction, the ISADS is lowered towards the ground and spun at high speed to eject the dry soil via centrifugal action.

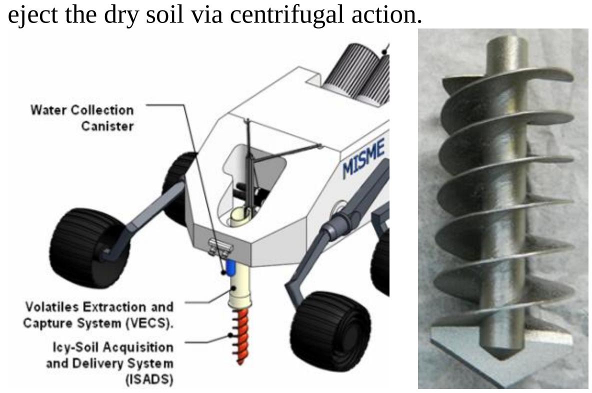

Figure 2. PVEx: MISMWE/Auger.

Corer: A Corer based volatiles extractor, shown in Figure 3, is a dual wall coring auger [4]. The outer wall is an auger with shallow flutes. It's made of low conductivity composite material (e.g. carbon fiber). The inner wall is perforated and covered with heaters. The corer penetrates subsurface and captures a core inside. Heaters are then turned on and heat up the core within the core. As a result ice melts and sublimes; volatiles then flow within the annual space between the inner conductive cylinder and the outer insulating cylinder (auger), down the pressure gradient into a cold trap on the surface.

The main advantage of this approach is that heat is concentrated within the auger, and because the outer auger surface is insulating, the efficiency is high. Since the coring system cuts only a small annulus, the drilling efficiency is higher than those of the full faced drills.

Figure 3. PVEx: Corer.

Test Results: We conducted hundreds of tests inside a vacuum chamber using JSC-1a soil simulant (Table 1, Figure 4). We found that Sniffer does not work because volatiles tend to escape up the soil and into the vacuum. The MISWE is a distant second in terms of water extraction efficiency and energy conversion efficiency. The Corer is the best in terms of volatiles extraction and energy efficiencies. The Corer also requires less energy to penetrate subsurface (than MISWE or Sniffer) since it uses coring bit and not full faced bit.

Table 1. Trade study

		Sniffer	MISWE	Corer
Data Points		5	16	15
Energy Efficiency [Whr/g]	**Min**	1.8	1.3	1.5
	Max	83	5.4	4.4
	Avg	**36**	**2.6**	**2.2**
	StDev	30	1.0	0.8
Water Recovery [%]	**Min**	0.1	18	31
	Max	4.6	78	87
	Avg	**1.2**	**44**	**65**
	StDev	1.7	16	17
Rankings		**3**	**2**	**1**

Figure 4. Captured water from Corer.

PVEx Corer Design: The Corer system takes advantage of TRL6 Resource Prospector (RP) drill for its deployment. The drill head itself is arranged in such a way as to allow for volatiles to flow straight up through the drill head and into a cold finger (no swivels are needed).

For example, to meet the 30 kg/day water goal for Mars ISRU, the system would need one rover with four Corer systems assuming in-situ material has 12 wt% water saturation. In an ideal scenario (no losses), the needed energy per daily operation would be approx. 3.7 kWh. Of this 3.7 kWhr, 3.4 kWhr would be in the form of heat and in turn could be provided by a Radioisotope Thermal Generator or RTG [4]. The exact power needs would need to be worked out based on the mission profile.

Currently, the system is being developed to reach TRL 5 by 2018, via NASA SBIR Phase 2 funding. One of the goals of the Phase 2 research is to leverage existing heat energy from the rover's RTG power supply.

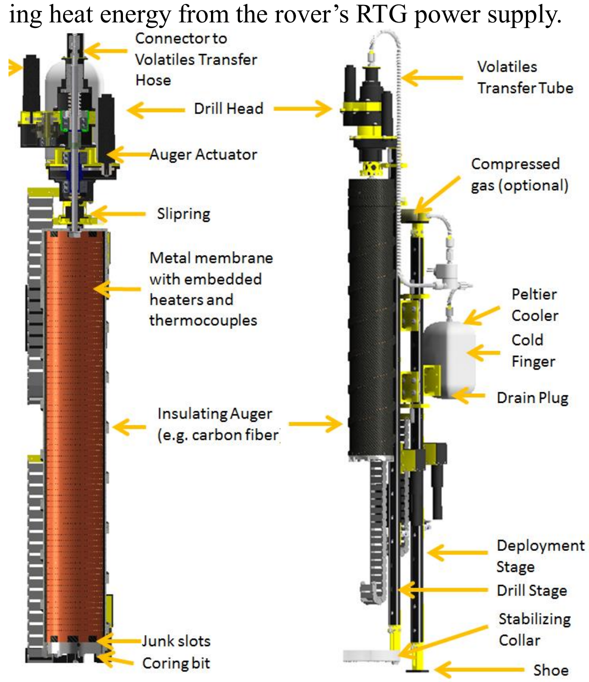

Figure 5. PVEx-Corer Design.

References: [1] Sanders et al. Comparison of Lunar and Mars In Situ Resource Utilization for Future Robotic and Human Missions, AIAA Aero Science, 2011. [2] Paulsen, et al., Testing of a 1 meter Mars IceBreaker Drill in a 3.5 meter Vacuum Chamber and in an Antarctic Mars Analog Site, AIAA SPACE 2011; [3] Zacny et al., Mobile In-Situ Water Extractor for Mars, Moon, and Asteroids ISRU, AIAA Space 2012; [4] Zacny et al. Planetary Volatiles Extractor (PVEx) for In Situ Resource Utilization (ISRU), ASCE Earth and Space 2016.

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