PLANETARY VOLATILES EXTRACTOR (PVEX) FOR IN SITU RESOURCE UTILIZATION (ISRU). K. Zacny[1], K. Luczek[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) relies on using local resources for sustaining human presence and robotic operation and in turn reducing burden of transporting supplies from the Earth [1]. In a more conventional ISRU approach, feedstock is mined, transported to a processing plant, and valuable resource is extracted. Planetary Volatiles Extraction (PVEx) is an alternative approach that combines mining and extraction into one step and eliminates energy intensive and time consuming “transport” step. We investigated 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 system, shown in Figure 1, is a deep fluted auger with perforated walls. The Sniffer is drilled into subsurface and left in place. Heaters embedded within the auger wall and flutes are switched on to warm up and sublime volatiles. Volatiles from the surrounding material flow through the holes and into the hollow auger and up into a cold trap on the surface. Hence volatiles can be ‘pumped’ directly from the borehole into a cold trap; akin to natural gas recovery.
The main advantage 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 pumped into the auger will be lost in the surrounding material through conduction.

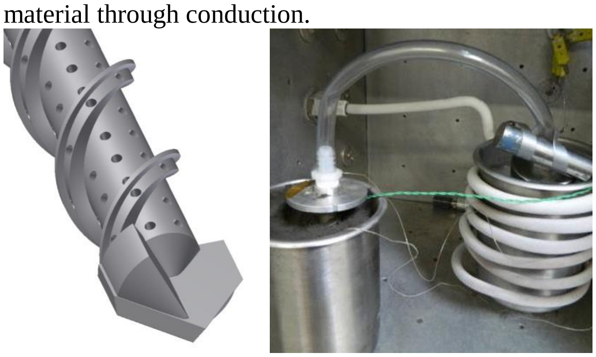

Figure1. PVEx: Sniffer.

MISWE/Auger: MISWE¸ 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. The VECS consists of a cylindrical heat exchanger and volatiles transfer system (a reactor). The material on the deep flutes is heated, water sublimes away and moves 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.

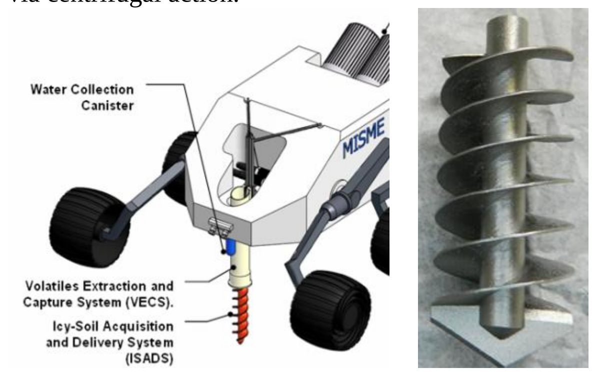

Figure 2. PVEx: MISMWE/Auger.

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 turned on, heat up the core and sublime volatiles within the core. Volatiles then flow within the annual space between the inner conductive cylinder and the outer insulating cylinder (auger), and 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 very well, because volatiles tend to escape up the soil and into the vacuum. The MISWE came in second in terms of water extraction efficiency and energy conversion efficiency. The Corer turned out to be the best approach in terms of volatiles extraction and energy efficiencies. The Corer also requires less energy to penetrate subsurface than MISWE using full faced auger, rendering it a more efficient approach in terms of drilling.

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 some of the subsystems already developed and tested under relevant conditions. In particular, the drill head and Z-stages are based on the Resource Prospector (RP) drill. 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).

The Corer's outer auger uses a low thermal conductivity carbon fiber-reinforced outer auger to minimize heat flow into the surrounding formation. The inner wall of the Corer, on the other hand, consists of perforated copper sleeve/tubing with embedded heaters from Mesoscribe.

The system design also includes a compressed gas tank, which can be replenished from the ISRU system. The tank is used as a contingency in case the Corer holes clog and a puff of gas is needed to unclog the holes.

To meet the 30 kg/day water requirements for Mars ISRU, the system would need one rover with four Corer systems assuming in-situ material has 12 wt% water saturation. 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].

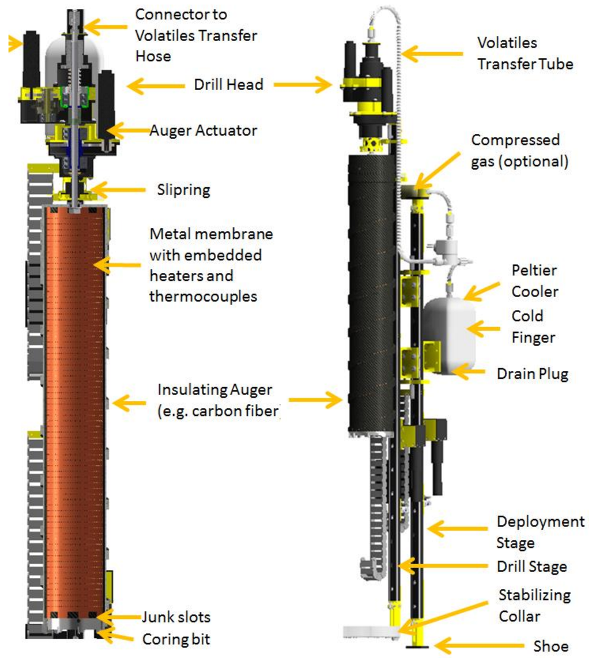

Figure 5. PVEx-Corer Design.

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.