ISRU Technology Development for Extraction of Water from the Mars Surface. J. E. Kleinhenz[1], J. Collins[2], M. Barmatz[3], G.E. Voecks[3], S. J. Hoffman[4] and A. Gould[1]. [1]NASA Glenn Research Center 21000 Brookpark Rd. Cleveland, OH 44135, [2]NASA Johnson Space Center, Houston, TX, [3]Jet Propulsion Research Laboratory , Pasadena, CA, and [4]The Aerospace Corporation, Houston, TX.

Introduction: The goal of the NASA ISRU Technology Project is to develop and compare technology options for ISRU systems. For Mars technologies, the near term goal is an end-to-end demonstration of an ISRU propellant production system. The project is divided into several 'elements' focused on different ISRU subsystems including excavation, atmospheric CO_2 acquisition, and "soil" processing. The soil processing element involves extraction of water from raw Mars material, be it hydrated minerals or ice. Currently three in-house technologies are being developed for water extraction from hydrated minerals. For subsurface ice, the Rodriquez Well, or Rodwell, concept is the current focus.

As the ISRU project is in its first year, these concepts are all still in the early development stage. Here, each concept will be introduced with an overview and brief status. The hydrated mineral concepts are being designed using the Mars regolith properties based on the Rocknest samples from NASA's Curiosity rover. The water content is about 1.3% water by mass [1]. The goal of the soil processors is to produce 1.5 kg/hr. For all but the Rodwell concept, this will be achieved using three soil processing modules each capable of operating at 50%. The breadboard systems described here are subscale production systems.

Auger Dryer: The Auger Dryer concept, targeting hydrated granular material, is in development at NASA's Johnson Space Center in an effort led by Jacob Collins. The auger dryer was the concept used in the ISRU system model developed for the Evolvable Mars Campaign [2]. The concept is based on commercial techniques, and was incorporated into the ISRU system model using equations defined in [3]. Using that model, the auger dryer has now been fully designed into a breadboard system, which is currently in fabrication. A conceptual design is shown in Fig. 1.

Mars regolith is conveyed through a closed, heated auger assembly. Heat is generated via resistive heaters on the outer walls of the auger casing. The varying pitch of the auger flutes, along with a tall regolith column in the hopper, seal the system so that the evolved water vapor is pressure fed to the condenser.

The breadboard design includes two auger casing designs: a clear acrylic tube for flow and fullness measurements and a stainless steel casing for heating tests. The initial test set will examine the efficacy of the seal concepts, including the regolith column height and compaction and the auger flute design. The flow rates of material through the auger and parameters, such as auger fullness, will be measured for model validation. Finally, the heating tests will examine the thermal efficiency of the system including power input needed to achieve water release temperatures.

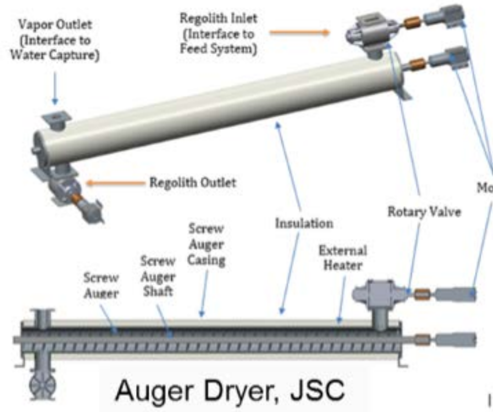

Figure 1. The Auger Dryer concept. An auger conveys hydrated mars regolith through a heated casing. Water vapor is driven to condenser as pressure builds.

Figure 2. The microwave processor breadboard system currently undergoing tests. Material is fed into a microwave cavity via a porous pyrex vessel.

Microwave Processor: Microwave heating of the hydrated Mars regolith is being examined at the Jet Propulsion Laboratory in an effort lead by Martin Barmatz and Gerald Voecks. Building on previous work [4], a breadboard system has been assembled (Fig. 2) and is currently undergoing verification tests.

Granular material is fed into a porous pyrex vessel contained in a resonant cavity. A magnetron is used to heat the soil, and the released water is drawn out via the pores in the regolith vessel. A fiber optic thermometer measures the temperature of the material in the microwave cavity. While initial tests were performed in batch mode, the new system is designed for continuous flow of material through the microwave cavity. A feed system to facilitate this is currently being designed in partnership with Honeybee Robotics.

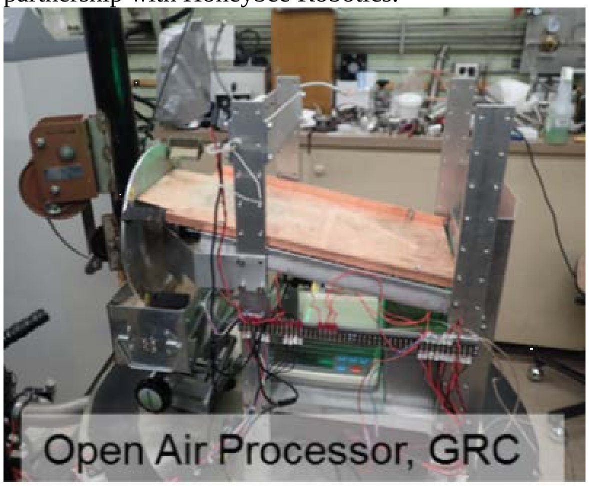

Figure 3. The open air processor uses a sweep gas of mars atmospheric 'air' to remove water vapor released from a heated inclined tray. A bucket wheel maintains a continuous flow of soil while vibration conveys it down the tray.

Open Air Dryer: The open air dryer has been in development at NASA Glenn Research center, with proof of concept tests performed in a Mars environmental chamber in 2017 [5]. The effort is currently being led by Julie Kleinhenz and Andrew Gould.

In this concept (Fig 3), a bucket wheel is used to retrieve granular material from a hopper, or directly from the surface itself, and dump it onto a inclined heated tray. Vibration conveys material down the heated tray continuously. Mars atmospheric gas is blown over the tray (duct not shown) to sweep water vapor into the condenser. The advantage of this sweep gas design (as opposed to a pressure driven system) is that it eliminates the need for reusable, high-temperature seals that must survive in a harsh, abrasive environment. While resulting in a more rugged design, a loss in water capture efficiency is expected.

Currently the effort is focused on model development and refinement. The model will be used to iterate the design for improved performance and appropriate scaling. Laboratory tests are currently ongoing to obtain the needed parameters for model validation. In conjunction with this, new design concepts are being incorporated and tested. A new vibration driver, and audio exciter, has been incorporated for more repeatable and controllable soil conveyance.

Rodriguez Well: The Rodriguez well (or Rodwell) concept targets subsurface water ice. Subsurface glaciers have been identified as shallow as 1 m [6]. Stephen Hoffman at NASA Johnson Space Center is leading the effort to adapt this terrestrial design concept to Mars applications.

Rodwells are currently in use at Antarctic field stations, so this concept has been demonstrated in full scale in terrestrial application. A subsurface ice sheet is accessed via a borehole. A heat probe is then used to melt and maintain a liquid 'well' within the ice. Water is pumped out of the well for use.

An initial case study of a Mars Rodwell system was performed in 2017 [7]. Even with the additional hardware needed to drill, pump, and maintain the well, the system estimates compared favorably to the hydrated regolith systems in [1].

The US Army's Cold Regions Research and Engineering Laboratory (CRREL) has developed numerical Rodwell model that is currently being leveraged by this project. However, it lacks considerations for unique Mars environmental conditions, such as pressure, sublimation rates, etc. The current effort is focused on obtained the needed parameters at Mars conditions and refining the model.

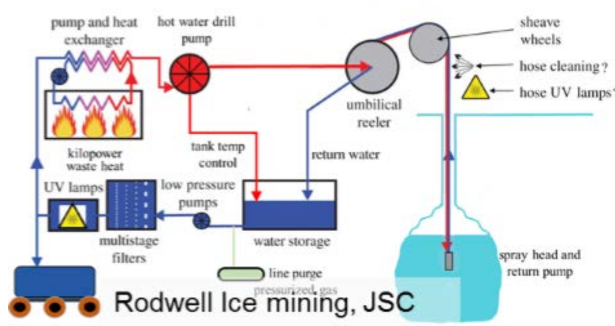

Figure 4. The concept for a Mars Rodriguez well that was used to generate intial system models in 2017.

References:

[1] Abbud-Madrid, et.al.(2016), http://mepag.nasa.gov/reports/Mars_Water_ISRU_Study.pptx [2]Kleinhenz, J.E. and Paz, A., (2017), AIAA SciTech Forum 2017. AIAA-2017-0423 [3] Waje, S. S., B. N. Thorat, and A. S. Mujumdar, Drying technology 24.3 (2006): 293-301. [4] Barmatz, M., Voecks, G., Steinfeld, D., Heinz, N., and D. Hoppe, 7th Space Resources Roundtable/PTMSS (2016). [5] Trunek, A.J., Linne, D.L., Kleinhenz, J.E., and Bauman, S.W. ASCE Earth and Space 2018 (In publication).[6] Dundas, C. et. al. Science, 359: 199-201, 2018. [7] Green, R.D, Gould, A.D, Kleinhenz, J.E., Linne, D.L., and Hoffman, S.J., AIAA Space 2018 (Submitted).