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Year in review

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Space resources

In-situ resource utilization (ISRU) facilitates planetary exploration by drawing needed resources, such as water, from the local environment. Developments this year include technologies for prospecting, drilling, excavating, processing, and manufacturing. The most widely reported news was the April announcement by Planetary Resources that it is joining Shackleton Energy and Google Lunar X-Prize teams Astrobotic and Moon Express in creating commercial business plans to bring the natural resources of space within humanity's economic sphere of influence.

In July, the Third International ISRU Analog Field Test brought many tons of technology to the tephra slopes of Mauna Kea, Hawaii. The analog test was performed jointly by NASA and the Canadian Space Agency with support from industry, academia, and the Pacific International Space Center for Exploration Systems. The test simulated a 7-day lunar RESOLVE polar ice/volatiles mission and combined robotic science/prospecting instrument and operation evaluations.

The RESOLVE (regolith and environment science and oxygen and lunar volatile extraction) payload was carried by an Artemis Jr. rover to a 2,750-m elevation site near Hale Pohaku. RESOLVE presently includes a neutron spectrometer and near-infrared spectrometer to locate volatiles in the regolith, a 1-m drill to sample the subsurface, an oven to heat samples for analysis, and a mass spectrometer/gas chromatograph to identify the volatiles driven from the regolith grains by the heat.

MMAMA (Moon and Mars analog mission activities) events occurred at 3,350-m elevation at Apollo Valley. The volatile analysis by pyrolysis of the regolith project analyzed tephra samples with a mass spectrometer to identify minerals, using samples prepared by the mechanized sample processing and handling system. A Juno II rover carried ground-penetrating radar and a magnetometer to compare robotic mapping to human surveying, and a miniaturized Mossbauer spectrometer and a combined miniaturized Mossbauer and X-ray fluorescence spectrometer to assess the equipment capabilities in the field. The rover, with its innovative wheel design, traversed 5 km without failure over extremely rough terrain.

Meanwhile, NASA's Small Business Innovative Research project is helping advance several ISRU technologies including a gas chromatograph/mass spectrometer for RESOLVE by Creare Engineering, a concept for combined ice drilling and water extraction from Moon, Mars, and asteroid soils by Honeybee Robotics, a microchannel Sabatier reactor by UMPQUA Research, a carbon dioxide electrochemical reactive capture device by Reactive Innovations, and a microgravity regolith transfer concept by Grainflow Dynamics.

In the large vacuum chamber dedicated to tests involving large amounts of regolith simulant at NASA Glenn the soil bin rests in the lower, fixed base of the chamber.

Engineers at NASA Glenn are reworking a Mars hopper concept, switching its propellant from atmospheric carbon dioxide to methane produced by mixing Martian atmosphere with Martian groundwater. A ballistic hopper smaller than the Mars exploration rovers could carry a suite of science instruments, along with its own propellant production plant, and hop 2 km every 30 days. To test the feasibility, a gas-gas, self-throttling propulsion system was tested to simulate the burn-coast-throttling-burn profile needed for a ballistic hop on Mars.

Also at Glenn, a 6.5-m^3 vacuum chamber has been dedicated for tests involving large amounts of regolith simulant. A 0.7-m^3 simulant bed was installed and pump-down procedures developed, and methods to remotely till and compact the simulant have also been demonstrated. Currently, a 1.2-m-long drill tube is being installed.

In September, NASA and the University of Texas at El Paso officially opened the Center for Space Exploration Technology Research at UTEP's College of Engineering. In-situ resource utilization is a major research direction of this center, including combustion of regolith/metal mixtures for structural materials production on the Moon and Mars, extraction of volatiles from lunar regolith, and remote sensing approaches to resource discovery and characterization.

by **Leslie Gertsch**