RESOLVE - Starting Point for Partnerships in Lunar & Mars Resource Characterization

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Abstract. The mystery and controversy surrounding the possibility of finding water/ice at the lunar poles of the Moon based on the interpretation of neutron spectrometer data from Lunar Prospector and radar data from Clementine raises questions that both Science and the Human Exploration proponents want answered. From the Science perspective, the determination of lunar volatiles and in particular the increased hydrogen concentration detected at the lunar poles was identified as an important objectives for lunar exploration and understanding the history of the Moon, Sun, and the solar system. From the Human Exploration perspective, the potential for large concentrations of assessible water opens up possibilities for utilizing in-situ resources, known as In-Situ Resource Utilization (ISRU), to implement a sustained and affordable human exploration program of the Moon and beyond through production of propellants, fuel cell reagents, and life support consumables for lunar surface operations and mobility, and Earth-Moon transportation. Both the Science and Human Exploration proponents agree that a mission to the lunar poles to obtain 'ground truth' data is the only means to conclusively answer the questions of whether water/ice exists, how much, what form, and where did it come from.

In 2005, NASA initiated the Regolith and Environment Science & Oxygen and Lunar Volatiles Extraction (RESOLVE) project, and is currently developing hardware under the NASA Exploration Technology Development Program (ETDP). The purpose of the project was to begin developing technologies and operations that would answer the fundamental science questions, such as 'What resources are available on the Moon, where are they, what form, and where did they come from?' as well as critical engineering questions, such as 'How will we mine these resources, what chemical extraction processes are the most practical and efficient, and what are the engineering challenges to be faced in this environment?'. To answer these questions, RESOLVE consists of five modules:

1. Excavation and Bulk Regolith Characterization (EBRC): Consists of a 1 meter long core drill with ability to transfer the core, measure and cut the core to desired length (25 cm) for all material hardness expected, and crush the sample down to 1 mm. This unit will help determine material/regolith geotechnical properties, determine volatile release due to crushing, and obtain the sample for further analysis and processing.
2. Environment and Regolith Physical Characterization (EPRC): Consists of an integrated optical camera and Raman spectrometer. This unit will allow the characterization of the fine grain particulates in the lunar soil, such as mineral and chemical composition and in-situ size distribution.
3. Regolith Volatile Characterization (RVC): Consists of a large multi-use heating chamber with regolith fluidization capability and a gas chromatograph (GC) coupled with a Mass Spectrometer (MS). This unit will examine the form and characteristics of hydrogen, water, and other potential volatiles bound in the lunar regolith.
4. Regolith Oxygen Extraction (ROE): Consists of a large multi-use reactor with fluidization capability, hydrogen flow, and high temperature operations (900 C). This unit will demonstrate the ability and performance of hydrogen reduction to extract oxygen from the lunar regolith
5. Lunar Water Resource Demonstration (LWRD): Consists of hydrogen and water capture beds, cold finger for water collection visualization, and alkali water electrolyzer. The unit will demonstrate the ability to separate and store hydrogen and water from volatiles or oxygen production, and to split water into hydrogen and oxygen. The unit will also visually demonstrate the presence of lunar water.

At the start of the RESOLVE project, there were no lunar mission concepts or requirements to base the design and selection of instruments upon, nor was it known whether it would include a rover. Therefore, the RESOLVE package is being designed to be small (<100 kg) and as low power (<100 W) as possible to operate on a lander or rover; designed to operate autonomously since direct line-of-sight communication with Earth may not always be possible during the mission operations; and include a sample acquisition device to provide material for the volatile extraction, oxygen production, and regolith characterization objectives. The project was originally planned to be performed in two phases: Phase 1 included designing and building an Engineering Breadboard Unit (EBU) and Phase 2 included designing and testing a Flight Prototype Unit (FPU) to technology readiness level 6 (TRL 6) before completion of a lunar robotic mission Preliminary Design Review. The RESOLVE project completed Phase 1 in June, 2006. Since the U.S. Robotic Lunar Exploration Program (RLEP) #2 mission to the lunar pole is currently cancelled and development funding is limited, the RESOLVE project has deferred development of the FPU and is taking lessons learned from the EBU to develop a more compact and integrated EBU2. Working with the NASA ETDP Surface Mobility project, RESOLVE will be integrated onto a rover currently being developed by Carnegie Mellon University (CMU) and NASA Glenn Research Center (GRC) in two stages. Stage 1 involves integrating the RESOLVE core drill and sample transfer device on the CMU/GRC rover for field testing in 2007, and Stage 2 involves integrating the complete RESOLVE EBU2 on an upgraded rover for a field demonstration in late 2008.

The RESOLVE project is being performed by a small team consisting of lunar scientists, flight hardware, terrestrial mining, and ISRU processing experts from NASA, JPL, academia, and industry (US and International). Due to limited funding, lunar scientists and ISRU engineers were purposefully selected to examine both the science and engineering implications of sample extraction and processing techniques and operations, and to select a limited number of technologies and instruments for integration into the RESOLVE unit that could meet the goals and objectives to the maximum extent possible. However, it is recognized that if an actual mission is flown to the lunar poles for science and/or exploration purposes, a greater suite of instruments on a mobile platform is desired. Instruments that have been identified that could greatly enhance and expand the current capabilities of RESOLVE include: a more capable MS for integration with the GC for species and isotope characterization; Neutron Spectrometer for hydrogen detection and drill site selection, Ground Penetrating Radar or seismic sensors for subsurface characterization; Mossbauer Spectrometer and/or XRD/XRF for further mineral/chemical characterization above Raman, and vision and/or lidar systems for drill site selection and surface mobility navigation. Incorporation of these new instruments into RESOLVE or onto the CMU/GRC rover and potential partnerships with industry, academia, and international space agencies is an area of near-term interest for possible collaboration and incorporation into Stage 2 or beyond field demonstrations.

Because the regolith and water characterization and extraction hardware and operational techniques under development may also be used to answer similar water resource questions on Mars, RESOLVE may be the first step in regolith ISRU development for the moon on US or International Partner led lunar missions and for Mars as well. Experience for the design, development, test, and eventual flight of RESOLVE would also provide critical data and experience for subsequent robotic and human ISRU missions. This paper will provide a status on the accomplishments and work completed in the RESOLVE project and in integration of RESOLVE onto the CMU/GRC surface mobility unit for field testing.

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PRINCIPAL AUTHOR'S BIO

Gerald Sanders currently serves as the Project Manager for ISRU in NASA ETDP program, the Principal Investigator (PI) for the RESOLVE project and past co-PI on the Mars in-situ propellant production Precursor (MIP), and is the NASA ISRU lead for the Lunar Architecture Team and architecture planning activities.