THREE LUNAR VOLATILES ANSWERS REQUIRED FOR THE DESIGN OF A SPACE EXPLORATION ARCHITECTURE. D. P. Gump, Astrobotic Technology Inc., 4551 Forbes Avenue, Pittsburgh, PA 15213, david.gump@astrobotictech.com

Introduction: A 2005 study for NASA by Transformational Space Corp. and Carnegie Mellon University [1] found that propellant produced on the Moon by robotic machinery would have a net present value twice that of the cost of delivering that machinery, assuming the maximum one percent volatiles concentration indicated by Lunar Prospector data. With LCROSS data suggesting volatiles may be six times richer, the rationale for basing space exploration architectures on lunar propellant production is even more cost-effective. Refueling space vehicles on the Moon, and exporting propellant to Earth orbit for use in Mars and NEO missions, will greatly affect decisions on how large "heavy lift" vehicles should be to support cost-effective exploration.

Agenda: The current Exploration Precursor Robotic Mission plan calls for a single lander in 2015 with an ancillary small rover servicing it. A similar expenditure (~$500 million) on prospecting rovers from commercial sources would provide a fleet of five to six machines capable of examining wide areas of both poles.

This fleet could answer three major questions that must be resolved quickly to plan future architecture.

1) *Which pole has the most economically attractive volatiles?* This will be governed by the richness of localized deposits, navigability of terrain, depth of overburden, and the availability of solar power and line-of-sight communications with Earth. Concentration of activities at one pole will reduce costs through the ability to specialize machinery types and to share backup capabilities, compared to dispersal at both poles.
2) *Do Partially Shadowed Regions outside crater floors offer economically recoverable volatiles?* Operation in PSRs by solar-powered robots does not require the bureaucratically complex and unpredictable approvals needed to utilize isotope-powered machines in crater floors, and thus prospecting and early production can be accomplished sooner. Recovery economics will hinge on the depth of overburden to be removed and the periodicity of illuminated phases.
3) *Does the concentration of volatiles vary significantly on a local scale, and what species are present?* Orbital surveys of volatiles, for example, have resolutions measured in tens of kilometers. Only multiple and wide-ranging surface expeditions can determine whether richer local concentrations are hidden within these multi-kilometer pixels, and the specific species that can only be inferred from orbital data. Volatile concentrations in crater floors, for example, may be skewed by the lopsided solar-wind-induced electric charge predicted for the sunward-side interior wall [2]. If richness varies at meter-level scales, more detailed prospecting is required than would be the case for uniform concentrations.

Approach: Cost-effective commercial robotic prospectors can be created that either survive through multiple night cool-downs to ambient levels, or which avoid night temperatures by circumnavigating the poles to stay in constant sunlight.

Rigorous testing cycles conducted at Carnegie Mellon University have determined that some batteries with non-aqueous electrolytes will return to normal functioning after two weeks at -180°C. One-time freezes of computer boards and solid state drives also have shown full function when warmed back to room temperature. This indicates that robotic surveyors could hibernate at a PSR during the period that sunlight is not available, or could hibernate along a route required to reach another PSR.

The alternate strategy of following the sun by circumnavigating the poles requires very little speed:

Latitude (degrees)	Circumference	Rover Speed	
	(km)	(m/s)	(mph)
89	191	0.07	0.16
87	572	0.22	0.49
85	952	0.37	0.83

When a prospector is out of line of sight communication with Earth, it will require either autonomous navigation capabilities as demonstrated by Carnegie Mellon's DARPA Urban Challenge winner, or a relay satellite.

References: [1] Gump, D.P., (2005) *t/Space Final Briefing to NASA, Concept Exploration & Refinement BAA*, 18-31. [2] Farrell, W.M. et al. (2010) J. Geophys. Res., 115, E03004, doi:10.1029 /2009JE003464.