THERMAL WADIS IN SUPPORT OF RESOURCE-BASED EXPLORATION. Kurt Sacksteder, and Suleyman Gokoglu, NASA Glenn Research Center**,** Ramaswamy Balasubramaniam, National Center for Space Exploration Research**,** Anthony Colozza, Analex Corporation, Nantel Suzuki, NASA Headquarters**,** Robert S Wegeng and Josef Matyas, Battelle Memorial Institute

Successive American presidents have reshaped major aspects of the nation's space program according to their vision of the utility of the program to broader national imperatives including scientific, technological and geo-political leadership, national security, and the strength of the underlying industrial, academic, and educational communities. The recent presidential policy change in the approach to human space exploration may have been, in part, the result of the inadequately clear and quantitative objectives that are sufficiently compelling to establish for the president and his advisors the utility of human lunar exploration, focused only on the moon, to those overarching national needs.

Many in the space resources community, including scientists, engineers, entrepreneurs, economists and others, have arrived at the conclusion that identifying, locating, harvesting and processing of resources on the moon is possibly the most compelling theme around which to discuss why, when and how humans should return to the moon. While it is clear from ongoing data coming from the Lunar Reconnaissance Orbiter (LRO) and the other recent lunar probes that promising resources including water and other volatile species are present, the true abundance and accessibility of these materials cannot be quantitatively established without substantial and widespread in-situ prospecting assays and demonstrations of mining and processing - all in the challenging lunar environment. The potential significance of these resources is clear to lunar and planetary science, but also to the economic sustainability of human space travel to both the moon and beyond. Consequently, robotic "ground truthing" of orbital observations is essential to adequately informed determinations about the value of sending humans back to the moon.

Because it is unlikely that one or two robotic resource prospecting and processing missions could adequately evaluate the resource potential of the moon, advocates of completing a resource mapping must consider affordable ways this can be achieved. This paper discusses two aspects of improving lunar prospecting productivity: surviving the thermal challenges on the moon, especially the cold lunar darkness, and reducing the unit cost and size of individual rover-based assets to enable economies of scale in production and transportation.

The *Thermal Wadi* concept is an approach to utilizing modified lunar regolith as solar-thermal energy storage media that can be heated during periods of solar illumination and used as a thermal energy source for mobile assets during periods of darkness. Lunar regolith is modified to improve its thermal properties, then heated using a sun-tracking reflector. During dark periods, the reflector is reconfigured as a radiation umbrella to limit the radiative cooling to space of the thermal mass and the assets it warms.

Ongoing simulations[i,ii] of the thermal performance of the thermal wadi concept have suggested that in equatorial sites a thermal mass no deeper than 50 cm and heated during a 354 hour lunar day would sustain rover assets for the 354 hour lunar night within the working temperature range of conventional electronics. This protection is provided without requiring the rover to carry insulation or internal energy sources for nighttime thermal protection. Near-polar locations have irregular light/dark periods and thermal simulations have shown that for at least one such site, similar thermal protection can be built into a thermal wadi configuration.

Laboratory work has been conducted to experimentally validate the thermal property values used in the wadi thermal simulation, and to consider methods for modifying lunar regolith simulant to produced thermal mass. Among the methods are: using concentrated solar energy, resistive heating, or SHS reactions to melt and consolidate simulant into continuous slabs, and collecting partially metalized byproducts of ISRU oxygen production. Each method has advantages and disadvantages related to equipment mass and power consumption needed to form thermal mass with the needed properties.

Related thermal simulations of small lunar rover designs have indicated that as rover size decreases, the mass of energy storage capacity, i.e. batteries, needed for nighttime survival overwhelms any reasonable rover payload mass.[iii] Hence, offloading nighttime thermal protection from small rovers consequently provides instrument payload mass and allow the rovers to be smaller than they could otherwise be. Further reductions in rover mass might be realized by creating other simple lunar surface infrastructure, perhaps integrated with the thermal wadi, that offloads communication, battery charging

and other functions from a lightened rover. Moreover, standardizing rover design to utilize this distributed support infrastructure leads to the possibility of amortizing rover development cost, approximately $2M/kg -$5M/kg for contemporary Mars rovers, over what could be a fleet of affordable rovers.

Affordable distributed lunar surface infrastructure, including thermal wadis, that supports affordable lunar prospecting rovers provides a basis for lunar resource mapping that encompasses sufficient geographical diversity and intense local abundance and accessibility determinations. With detailed knowledge of exploitable lunar resources, governments and commercial enterprise will be able to make sound decisions about investing in the human return to the moon.

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[i] Balasubramaniam, R., Wegeng, R., Gokoglu, S., Suzuki, N., and Sacksteder, K., "Analysis of Solar-Heated Thermal Wadis to Support Extended-Duration Lunar Exploration," AIAA 2009-1339, NASA/TM—2010-216254, 47th AIAA Aerospace Sciences Meeting, Orlando, January 2009.

[ii] Balasubramaniam, R., Gokoglu, S.A., Sacksteder, K.R., Wegeng, R.S., and Suzuki, N.H, "An Extension of Analysis of Solar-Heated Thermal Wadis to Support Extended-Duration Lunar Exploration," AIAA–2010–797, NASA/TM—2010-216255, 48th AIAA Aerospace Sciences Meeting, Orlando, January 2010.

[iii] Thornton, J., Whittaker, W., Jones, H., Mackin, M., Barsa, R., and Gump, D., "Thermal Strategies for Long Duration Mobile Lunar Surface Missions," AIAA–2010–798, 48th AIAA Aerospace Sciences Meeting, Orlando, January 2010.