RESOURCE CONSIDERATIONS FOR ENABLING SUSTAINABLE TRANS EARTH HABITATION.

D. C. Barker[1], [1]MAXD, Inc., PO Box 58915 Houston TX, 77059.

Introduction: In addressing the feasibility and utility of resources derived from non-terrestrial bodies, one must succinctly answer the question as to why and then how such activates should be initiated in the first place. In all likelihood, suitable economic drivers are not likely to exist until 1) terrestrial supplies are depleted and a resource needs remain that outweigh all intrinsic costs, or 2) a minimum an growing population of humans live off Earth at locations which either have nearby resources or acquisition and transportation of those resources proves relatively easy. Therefore, the primary use of non-terrestrial resources will most likely be levied for the sustainable development of non-terrestrial human settlement and infrastructure.

Given the why regarding resource needs, the two resources that can arguably be considered the most pragmatic and useful, promoting sustainability, safety and long term cost effectiveness for any human habitation efforts are water and easily managed construction materials.

Need to Focus Efforts: Before considering specific resources, we should remark that exploration goals and assumptions need to be aligned due to increasingly limited funding. In order to focus efforts, future planning should follow pragmatic goal directed strategies. Such a methodology is basically contradictory to the historical competition associated with selecting basic science and mission designs. The fundamental scientific questions, such as how and why ice is where it is, must be made complementary to resource prospecting, and should not be a prerequisite for driving or enacting human settlement of these bodies. Rather, to safeguard from a "flags-and-footprints" outcome, the long term goal should be to nurture and grow human settlements with the objective of permanent habitation in mind.

Primary Resource Needs: Any discussion on resource acquisition must begin with the assumption that appropriate initial energy sources will be available for extraction, processing and storage.

Both water and regolith can be considered multipurpose resources, no matter the location, yet water is probably the most important because as a consumable it fulfills multiple intrinsic needs, including: life support (hygiene, hydration, atmosphere and radiation shielding) and fuel (oxygen, hydrogen, and where sufficient CO_2 is present, methane via the Sabatier process). Once adequately producible quantities of water are identified, base infrastructures and systems can be designed less stringently by allowing for a minimum amount of leakiness, i.e., architectures do not need to be overly complex or fully regenerative and consequently are more cost effective.

Easily extracted and managed construction materials refers to unconsolidated regolith that is devoid of bedrock or large boulders. Given production line extraction and processing, the material can be heated to further extract volatiles, separated, bagged and used in berm or lose covering material for habitats in order to enhance radiation shielding and thermal control. Ultimately, insitu sintering of such material should be used to construct foundations and structures. A final pragmatic feature of surface regolith that should be considered, nearly as highly as those addressed above, is the actual geochemical composition of this unconsolidated material. For the Moon, areas with higher concentrations of glassy material may contain a relatively wider array of elemental abundances useful to enhance sustainable human habitation. On Mars, a variety of hydrothermal deposits may similarly contain useful metals or volatiles needed to sustain self-sufficient habitation.

Unconsolidated regolith is ubiquitous on both the Moon and Mars, therefore it remains to quickly and accurately quantify the availability of easily extractable water as the primary driver for any near term site selection and base construction. As water can be considered them most important resource, progressive Lunar and Martian data collection histories have highlighted the distribution of potential ice reservoirs and therefore initial prospecting considerations have been accomplished.

Moon Water: Water ice can theoretically exist on the Moon in areas of permanent shadow. The suggestion of surface volatiles, and ice specifically, began to take form in the early 1960's [1, 2]. With Clementine, in 1996, imagery indicated that several thousand square kilometers of ice could exist in the permanently shadowed regions near the Moon's south pole in the bottom of deep craters [3]. Ice lifetimes within these "cold-trap" craters has been estimated to be on the order of billions of years given that temperatures are expected never rise above 100ºK (-173ºC) [4].

The Lunar Prospector's 1998 neutron spectrometer results indicated large water-bearing region at the north pole. Expanding on these results, the Chandrayaan-1 spacecraft, launched in 2008 carrying the Moon Mineralogy Mapper and Mini-SAR, examined extremely cold dark areas providing estimates on volatiles, including water ice, that could be present in quantity [5].

Launched in 2009 and still returning data, the Lunar Reconnaissance Orbiter (LRO) also detected substantial hydrogen signatures [6] in shadowed craters using the Lunar Exploration Neutron Detector (LEND) (Fig. 1). Its sister experiment, the Lunar Crater Observation and Sensing Satellite (LCROSS) impacted Cabaus crater emanating an impact plume containing a significant water spectral signature [7]. Most recently, March 2016, LRO neutron data analysis demonstrated that the Moon's spin axis had been perturbed and that apparent hydrogen deposits at each pole had been displaced accordingly showing an evolution of such deposits over time [8].

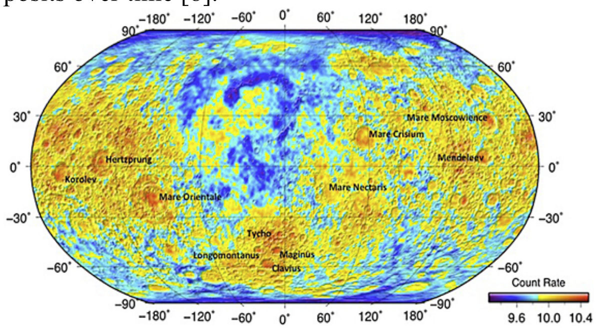

Figure 1. Epithermal neutron counting rate variations suggest variability in water content among craters [6].

Yet, given all these observations and interpretations, there remains a substantial uncertainty as to the abundances and utility surrounding the hydrogen signatures, and actual measured and producible quantities of easily extractable lunar ice or water remain to be identified.

Mars Water: Arguably, and in particular regarding sustainability, Mars is a much better location for human settlements based on current observations and understanding regarding the distribution and location of substantial and needed resources.

To date, outside the planet's polar caps, the most reliable indication of subsurface water ice deposits come from the 2001 Mars Odyssey spacecraft gamma-ray spectrometer (GRS) neutron data [9, 10] (Fig. 2).

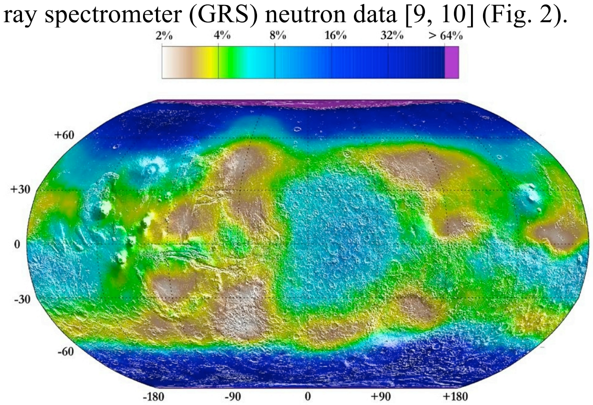

Figure 2. Estimated lower limit of the water content derived from energetic neutrons in the top meter of regolith on Mars (NASA/JPL/Los Alamos National Laboratory).

Other reliable indicators include ice uncovered by the arm and landing thrust from the Mars Polar Lander [11]; several recent high latitude impacts that exhumed visibly transient ice deposits and finally there are the transient crater wall gully features.

Landing sites for Mars based on a primary resource mining criteria of water were recently presented at the First Landing Site Workshop for Human Missions to the Surface of Mars in Houston [12], and a community consensus towards focusing on this resource seems to be afoot. The proof will be realized in the forward development of survey missions which synergize prospecting with basic science interests.

Discussion: Currently no *proven reserves* of needed extraterrestrial resources have been identified anywhere and this knowledge gap is perpetuated by a haphazard willingness of governments, organizations and investors to engage in dedicated prospecting efforts on these bodies. One expected deterrent towards extraterrestrial investment is that the majority of resources extracted in space will be used in space and never returned to Earth, precluding the conventional return on investment (i..e, a classical chicken before the egg scenario).

The moon is only a few days from us and yet we have not sent any substantial prospecitng instrumentation for nearly 3 years. A proposed mission, the Resource Prospector Mission, was slated for 2018, but its implementation remains to be actualized. This author envisions a pessimistic path forward for human return, settlement or resource acquisition when routine access to examine our closest celestial neighbor remains limited. Understandably more difficult, Mars prospecting is equally deficient if we are to locate resources needed to commit to and appropriately design architectures for any human undertakings on the surface of Mars.

Advanced prospecting initiatives are required, both surface and subsurface, to adequately enhance global scale resolution of known and unknown resources. Additionally such initatves should provide enhanced, high resolution measures on sub-kilometer scales in order to minimize the risks inherent (both financial and astronaut occupational) in landing and base site selection.

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