

PREPARING THE GROUND FOR A HELIUM-3 ECONOMY FROM A POLAR LUNAR OUTPOST.

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Introduction: Helium-3, deposited by the solar wind in the lunar regolith, may potentially be used as fusion power for terrestrial electricity and deep-space propulsion[1,2]. It could be a key resource in self-sustaining interplanetary economy, since the establishment of controlled d-³He fusion would endow this resource with a value of roughly \$3M/kg, assuming that fuel comprises 20% of the cost of \$0.10/kWh electricity. There are no terrestrial sources of ³He sufficient to sustain industrial-scale use. The value of a Helium-3 deposit, like that of any other mineral resource increases more rapidly than linearly with concentration. While the highest solar wind flux is found in Farside equatorial regions, mature, titanium-rich soils of the Nearside maria retain more of the solar wind, with the net result that the Nearside maria yielded the best ³He concentrations in the Apollo samples. Concentrations may be significantly higher in undisturbed regolith[3], giving the best lunar regolith an energy density about half that of gasoline. The polar regions are expected to be relatively barren of ³He, because of low solar wind exposure [4] and poor soil retention; so at first glance the Solar Polar lunar outpost recommended by NASA's Lunar Architecture Team (LAT) is unpromising for the characterization and development of this potentially important resource. However, there are several reasons to consider the value of a polar outpost in preparing for the large scale extraction of ³He:

If there's sunlight, there's solar wind -- including ³He. The implantation of solar wind particles is complicated on the Nearside because of the shielding effect of the Earth and its magnetic field. On the Farside, it is poor at high latitudes for the same reason that solar insolation is low at high latitudes-- the angle of incidence is high. However, just as locations of nearly-perpetual sunlight will be used for solar power for the lunar outpost, those same locations will have topography for which solar wind particles impinge at a low angle of incidence, and hence will have concentrations of solar wind particles comparable to those found at lower latitudes for similar soil types. The LAT notional outpost at Shackleton Rim has a well-illuminated Farside slope well-within the 3 km frequent local EVA radius of the power production and habitation zone [5].

Polar propellant enables regional sorties to lower latitudes for a variety of purposes. A polar outpost may be used to support sorties to lower latitudes to explore for the richest Helium-3 concentrations, and demonstrate methods of economical extrac-

tion. Re-use of prospecting equipment by use of Pole-generated propellant for these regional sorties would enable prospecting at many more sites than direct-from-Earth delivery of instrumentation, soil-handling equipment, and mobility systems. For example, a single-stage vehicle with a total Δv capability of 4.5 km/s would be capable of round-trip ballistic flight from a Polar outpost to 60 degrees latitude. The Farside, which has higher solar wind exposure at 60 degrees latitude than the Nearside maria, may then be searched for ³He-retentive soils which might yield higher concentrations of ³He than the Apollo samples. The southern margin of the Aitken Basin might be such a region, with relatively TiO₂-rich soils and high solar wind exposure.

The polar regions are *terra incognita*. The polar regions -- in particular the permanently shadowed regions -- were unexplored by landed craft even during the first epoch of lunar exploration. The net effect of low solar wind fluxes, but low surface temperatures, on ³He retention is empirically unknown

Operational experience is as important as He-3 concentration. If ³He mining becomes commercially attractive, it will require large amounts of mining equipment subject to wear and breakdown. A sustained presence at the Pole, available for repair and refurbishment of equipment, is a better operational model for large-scale, long-term mining operations than isolated robotic testbeds which are abandoned when broken; as in terrestrial mining, the goal is to reduce the number of on-site human labor hours per unit of recovered resource. Initial capabilities at the outpost will include regolith excavation and transportation demonstrations/pilot operations.

Characterization of Polar Solar Wind deposits: The two most economically interesting solar wind volatiles, H and ³He, may be detected either by a mass spectrometer, which requires complicated sample acquisition and handling systems, or more simply or by making use of the same nuclear reaction: $n + {}^3\text{He} \rightarrow {}^4\text{He} + \gamma$. H is detected by measuring the ratio of thermal and epithermal neutrons incident on ³He-filled scintillation counters, while ³He could be detected by directing a neutron generator into the soil and detecting the gamma rays given off by this reaction using the same gamma ray detector used for H detection. Such commercially available neutron generators have a mass of 8 kg and peak power of 60 W [6], with further optimization for spaceflight possible. This system could identify other potentially valuable trace elements as well.

The science of resources can lead to resources for science. As on the Earth, economic motivation can place people and scientific equipment in multiple remote locations in the search for economic value, on a scale which is not supported for solely scientific regions. We suggest that exploring for ^3He and other resources is an opportunity to learn not only about the solar wind and lunar soil properties, but also about lunar geology and environment, including dust and radiation properties, in many locations.

References: [1] Wittenberg, L. J., et al. (1992) *Fusion Technology* 21, 2230; other papers from <http://fti.neep.wisc.edu> [2] Santarius, J. F., and Logan, B. G. (1998). *Journal of Propulsion and Power* 14, 519 [3] Schmitt, H. H. (2004), *Space Resources Roundtable VI*, LPI Contribution #1224. [4] Swindle, T. D. et al. (1992) *LPS XXXIII*, 1395 [5] Lavoie, T., "Lunar Architecture Overview," from *Implementing the Vision: 2nd Space Exploration Conference* [6] for example, model ING-17 from Del Mar Ventures, San Diego, CA, www.sciner.com