Investigating the Effects of Product, Market, and Transportation Propellant on the Efficiency/Economics of Lunar Water Derived Propellant. N. J. Bennett[1] and A. G. Dempster[2], [1, 2] Australian Centre for Space Engineering Research (ACSER), University of New South Wales (UNSW), Sydney, NSW, 2052, Australia. (Contact: nicholas.j.bennett@student.unsw.edu.au)

Introduction: We hope lunar derived propellants will play a role both in a continuing human presence on the Moon and in facilitating cislunar activity of all kinds. Both water and regolith oxygen could play a roll, but to avoid a treatment for relative costs we restrict this analysis to water products. We perform the analysis and present the results in economic terms, taking the role of a commercial lunar propellant enterprise. However, this approach is dual to an efficiency analysis, which we believe would reach the same conclusions.

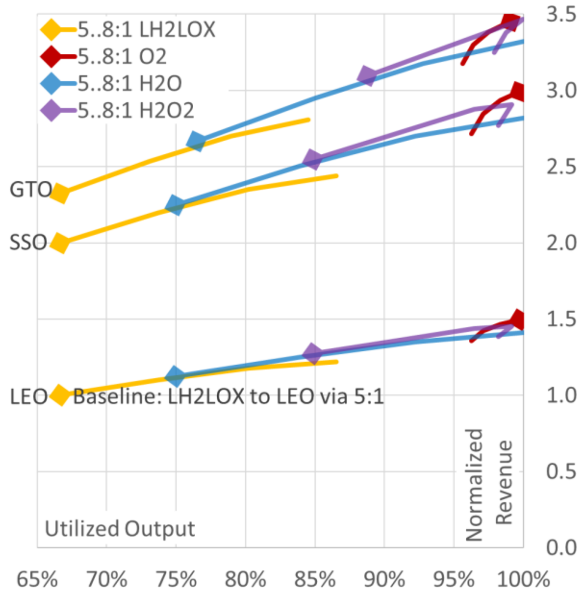

Figure 1: Utilized Output x Normalized Revenue/Utility of Products, Markets, and O:F ratios

Products: Once obtained on the lunar surface water can be used to produce several propellant products, most commonly hydrolox. Choosing regular (5.6:1 oxidizer to fuel) hydrolox as a product ensures a significant opportunity loss; 27% of the mass of procured water is excess oxygen, if this is discarded it represents significant implicit underutilization of infrastructure investment. The excess oxygen is orders of magnitude greater than any reasonably conceivable life support demand; this observation motivates investigating what happens if the propellant product is oxygen, or other high oxygen propellants one can produce from water. Hydrogen peroxide is a useful green station keeping propellant, and there is the prospect of solar and electric water engines.

Markets: LEO is a commonly analyzed market for lunar propellant, but GTOs and SSOs are also likely. Many satellites are in very similar orbits in SSOs, and so there is potential for aggregated demand. About 20 GTO orbit ratings occur annually, and we can generalize to HEEOs, like LDHEOs, as interplanetary staging orbits. One must burn propellant to deliver propellant, so each market has different transportation costs from the Earth or the lunar surface. Transportation propellant requirements allow us to derive delivered mass fraction of lunar production and the utility of delivered product.

Transportation Propellant: Apollo's J2 engine varied its O:F ratio between 5.5:1 and 4.5:1 to tune thrust and propellant burn up. We analyze the effect, but not the practicality of higher O:F ratios (up to water stoichiometric). One potential stumbling block that has been called out is higher combustion temperatures. However, for an expander cycle engine like the RL-10 one of the factors that limits size is that the heat exchange area available to power the pumps scales more slowly than the combustion chamber volume and mass flow, hotter combustion might allow larger engines.

Conclusions: Our conclusions can be read off Figure 1. Unsurprisingly it pays to sell in high energy orbits, but, an appropriate choice of product and transportation O:F ratio can boost revenue/utility by 50% over the baseline "sell hydrolox". Oxygen in HEEOs seems the most compelling product given current hydrolox engines. Oxygen could contribute to any transportation use-case in cislunar space, including interplanetary injections. Adding high O:F ratio engines to the lunar tankers allows close to maximum revenue/utility to be extracted when supplying H2O and H2O2. Only when hydrolox customers also use high O:F ratio engines is it desirable to supply hydrolox. Finally, if a lunar enterprise can compete against Earth hydrolox then it has a significant incentive to develop high O:F engines, it then has the capability to expand into providing both transportation services that use lunar surface water more efficiently and the engine technology itself.