QUANTIFYING ELEMENTS OF A LUNAR ECONOMY BASED ON RESOURCE NEEDS. J. B. Greenblatt[1], [1]Emerging Futures, LLC, 2726 Eighth St., Berkeley, CA 94710, jeff@emerging-futures.com.

Introduction: A lunar economy will be built upon *in situ* resource utilization and trade with other solar system locations. Elements must include human life support commodities (water, air and food that is maximally recycled) and basic structural and functional materials including metals, concrete, glass, plastics and industrial chemicals (H_2SO_4, NaOH, etc.). Propellant (e.g., H_2/O_2, etc.) will be essential for surface propulsion and material export, while solar photovoltaic (PV)-grade silicon will enable a lunar economy to expand by harnessing more power. Rare earth elements, uranium, and ^3He could be obtained with additional effort, enabling sophisticated metallurgy, catalysis, and nuclear fission and fusion capabilities.

Si, Ca, Mg, Al, Fe, Ti and O are abundant in lunar regolith, so materials containing them could be exported, along with ^3He. By contrast, H- and C-containing materials would be limited due to low lunar abundances, and may need to be provided from elsewhere, along with other elements in low abundance, as well as sophisticated products such as electronics, etc.

Approach: We use a combination of resource estimates for human life support, basic materials consumption on Earth, and energy and propulsion requirements to build a simple resource consumption model that is then constrained by lunar elemental abundance estimates to identify materials that could be imported or exported. We also constrain the area covered by solar PV to 0.1% of the lunar farside (~19,000 km^2), and consumption of the estimated lunar water resource (2.9 Gt) to ~0.01%/year (8,000-year lifetime). While this approach does not represent a rigorous economic assessment, it forms a starting point for planning a lunar economy. For details, see [1].

Reclamation of 99.5% of water is assumed, or ~10 times the current recovery rate on the International Space Station; advanced water purification approaches on Earth can already achieve >99% reclamation [2], so this goal is not unreasonable. Lower recycling rates of air, organics, surface propellant and other materials are assumed. Because aluminum represents an important part of the lunar economy but requires fluorine for processing, which is found in low abundances in regolith (~20-120 ppm), a recycling rate of 99.9% is required, along with inert, non-carbon anodes that are not consumed during aluminum production [3].

Results: We find that 50,000 people can be supported on the lunar surface, constrained primarily by lunar water. However, because of abundant solar energy and mineral resources, a large industrial capacity is feasible, providing exports to other solar system locations of ~300 Mt/yr of inorganic materials (metals, glass, solar PV, and raw regolith for shielding), sufficient for >170 million people in our simple assessment. The lunar surface population would consume ~17 Mt/yr of concrete, metals, industrial chemicals, fertilizers (N, P, K), air (O_2/N_2), carbon-containing products (food, plastics, structural plants), potable water, and H_2/O_2 propellant for surface mobility and energy storage during the ~14-day lunar night.

Propellant limitations. One key limitation is the lack of sufficient water for long-term space launch capability required for the assumed levels of exports. Instead, ablation of raw regolith is assumed using ground-based lasers to provide energy. This technology has been explored in the laboratory, with an estimated thrust coefficient of 500 μN/W at laser intensities of 10 MW/m^2 [4], resulting in a specific impulse of 121 s. Thus, for a delta-v budget of 2.7 km/s (sufficient to escape the Moon and reach the Earth-Moon L1 point or similar location), 21 kg of regolith and ~100 MJ of electricity are required per kg of exported material.

Gross Interplanetary Product (GIP). Based on the ratio of final energy consumption on the Moon (1.34 TW) to estimated 2015 global electricity consumption (12.4 TW) and Gross World Product ($76 trillion) (see [1]), we estimate an annual GIP of $8 trillion. In addition, the energy that would be produced in space from exported solar PV adds another 3.9 TW or $24 trillion.

Beyond the Moon. For sustaining human life and industrial activity in space, exports of food, air, water and chemical propellants would be required from other locations than the Moon, presumably asteroids and/or Mars. We have done similar calculations for Mars and determined that less than 0.1% of its surface area would be sufficient to produce these items from *in situ* resources for export to >170 million people.

References:

[1] Greenblatt J. B. (2017) Comparative analysis of human settlements on the Moon and Mars, Emerging Futures, LLC, tinyurl.com/la9wt4m. Summary infographic: spaceeconomy.spacevault.world/moonvsmars.

[2] Afrasiabi N., E. Shahbazali (2011) RO brine treatment and disposal methods, *Desalination and Water Treatment*, *35*, 39-53.

[3] Kvande H., P. A. Drabløs (2014) The Aluminum Smelting Process and Innovative Alternative Technologies, *J. Occup. Environ. Med., 56*, S23–S32.

[4] Lubin P. et al. (2014) Toward directed energy planetary defense, *Optical Engineering, 53*, 025103.