LUNAR WATER REQUIREMENTS FOR CISLUNAR TRANSPORTATION. D. G. Bienhoff, 8455 Chapelwood Court, Annandale, VA 22003, dbienhoff@cox.net.

Introduction: Two companies are currently planning for commercial operations on the Moon: Shackleton Energy Company and Bigelow Aerospace. Shackleton Energy Company wants to mine the Moon's water ice resources to provide propellant to transportation systems operating from the Moon, in cislunar Space, and departing low Earth orbit (LEO) for destinations beyond the Moon's orbit[1]. Emplacing habitats on the Moon and leasing them to sovereign Space agencies, corporate entities, and other organizations is the next step in Space development for Bigelow Aerospace[2]. For these endeavors to be successful Shackleton Energy Company needs propellant customers and Bigelow Aerospace needs an operational cislunar transportation system. In addition, Shackleton Energy Company needs to know how much production capacity might be needed to size their water production equipment and facililities. A reusable cislunar transportation architecture sized to deliver 25 metric tons (t) of cargo from the Earth to the Moon's surface using Earth-supplied propellants to support a permanent, continuously occupied, lunar facility provides insight into required lunar water production rates.

Conceptual Reusable Cislunar Transportation Architecture: The Reusable Cislunar Transportation Architecture (RCTA) comprises two propellant depots, three in-Space transportation vehicles, propellant tankers, and personnel carriers (Figure 1). The propellant depots are located in LEO and Earth Moon Lagrangian point 1 (EML1). A Reusable Aerocapture Transfer Vehicle (RATV) is based at the LEO propellant depot and is used to deliver cargo, propellant, and/or personnel to the EML1 depot; it uses an aerobrake and Earth's atmosphere to reduce its perigee velocity upon return to LEO. A Reusable Circumlunar Transfer Vehicle (RCTV) and Reusable Lunar Lander (RLL) are based at the EML1 propellant depot. The RCTV carries the RLL with cargo and/or personnel to the Moon from EML1 along a circumlunar trajectory. As the vehicle stack approaches the Moon, the RLL separates from the RCTV and descends to the lunar surface while the RCTV continues around the Moon and returns to EML1. A returning RLL rendezvous with a RCTV as it passes the Moon to be delivered to EML1.

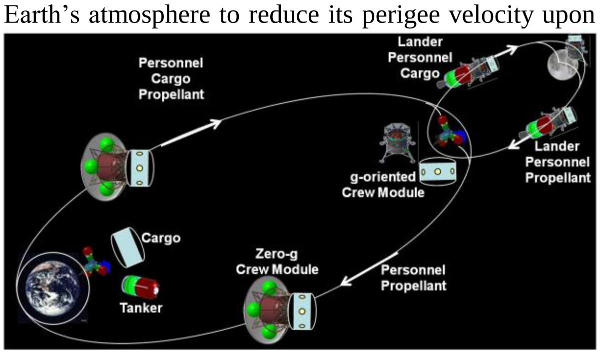

Figure 1. The Reusable Cislunar Transportation Architecture provides logistics support to Bigelow Aerospace's planned human lunar facility and provides a customer for Shackleton Energy Company's lunar propellant production operations.

Lunar Water Production: The first propellant production level in transitioning from Earth-supplied propellant to Moon-supplied propellant begins with propellant required for RLL departure from the Moon. The next production level is defined by RATV Earth-return mission. RCTV and RLL propellant to leave EML1 for the Moon define the next production demand levels. Maximum water production is needed when and if all propellant for RCTA vehicles is provided from the Moon.

Another factor in lunar water production requirement is the RCTA propulsion systems. Rocket engines operating at oxygen to hydrogen mixture ratios (MR) of 5.5:1 or 6.0:1 are the most likely near term solutions. Rocket engines capable of operating at stoichiometric mixture ratio (8:1 for oxygen;hydrogen) may become available in the near term. At mixture ratios less than stoichiometric more water must be produced than propellant required. This results in 2.5 or 2.0 kg of oxygen byproduct for every 9 kg of water produced given mixture ratios of 5.5 or 6, resepectively.

Finally, annual water production requirements are a function of the number and type of missions flown between LEO and the lunar surface. Missions may only deliver cargo to the surface, they may carry personnel round trip, or they may deliver cargo and personnel but return with only personnel. Propellant delivery missions to EML1 from the Moon or LEO are also required. Two crew and two cargo missions or two crew and cargo missions per year were considered for this paper.

Propellant requirements for RLL departures from the Moon are 9.2 t per cargo delivery and 12.8 t per personnel rotation based on 450 second specific impulse rocket engines. Applying the same specific impulse to all RCTA vehicles and using only lunar propellant production requirements are 145 t per personnel rotation mission, 223.5 t per cargo delivery mission, and 292 t per mission if crew and cargo are carried together.

Since every nine tons of water produces one ton of hydrogen and eight tons of oxygen and if the RCTA vehicle engines operate at stoichiometric mixture ratio then water production rate equals propellant required. However, at a 5.5:1 engine MR and the same propellant mass requirement, water production must be 38.5% higher than propellant usage as only 6.5 t of useful propellant is obtained per 9 t water. Therefore, lunar water production requirement ranges from 25 – 61 t/yr for RLL departure missions and 809 – 1020 t/yr for the entire RCTA providing two personnel rotations and two 25-t cargo deliveries per year (Figure 2).

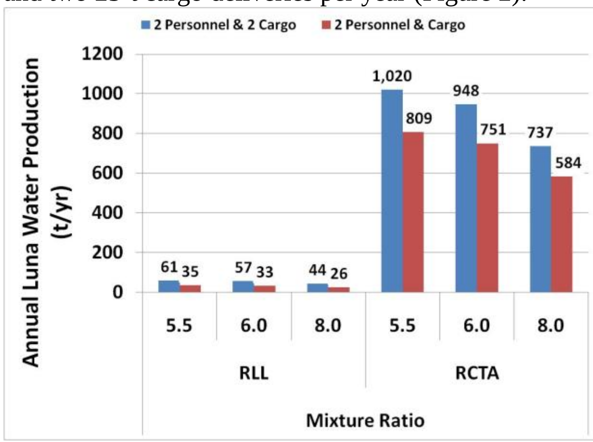

Figure 2. Lunar water production is dependent upon rocket engine mixture ratio and how logistics missions are implemented.

References: [1] David L. (14 April 2011) Space.com http://www.space.com/8217-private-moon-bases-hot-idea-space-pioneer.html. [2] Wall M. (13 January 2011) Space.com http://www.space.com/10619-mining-moon-water-bill-stone-110114.html.

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