AN ISRU SYNTHETIC BIOLOGY PLATFORM FOR FOOD PRODUCTION IN SPACE. J. Cumbers, NASA Ames Research Center, Education Associates Program (USRA), Synthetic Biology Program, Mail Stop 239-20, Bldg N239 Rm 215, P.O. Box 1, Moffett Field, CA 94035-0001, USA. John.Cumbers@nasa.gov.

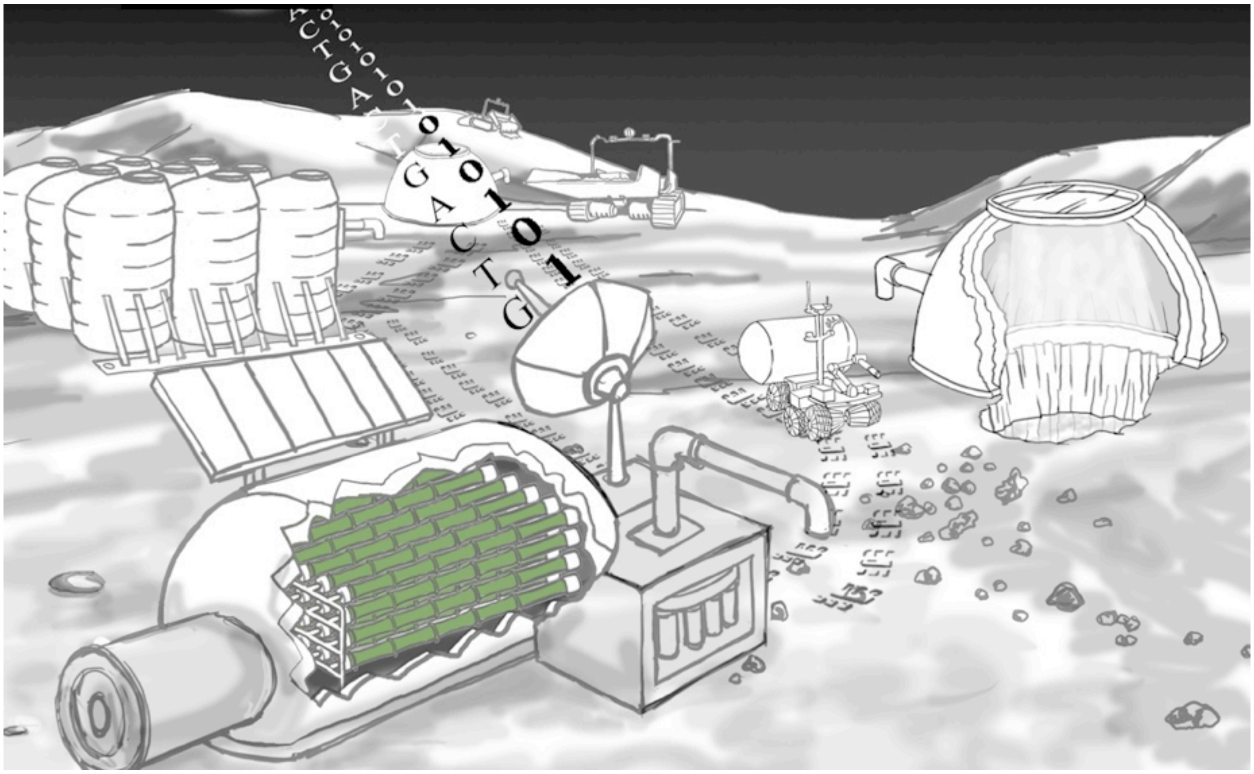

Figure 1: Concept mission involving the synthesis of food producing organisms *in situ* on the lunar surface.

Introduction: The production of food in space is one where biology offers a clear advantage over chemical or physical processes. This abstract outlines a scenario for food production on the moon using *in situ* resources.

Water and volatiles on the moon: Previous studies of lunar ISRU indicated that there was no role on the moon for biology unless enough water or carbon dioxide was discovered [1,2,3]. The Clementine [4], Moon Mineralogy Mapper [5] and Lunar Crater Observation and Sensing Satellite or LCROSS [6,7] have all now established firmly that there is a large amount of water ice to be found on the moon, both in the permanently shadowed craters of the South Pole [7] and in the subsurface of the North Pole [5]. As well as water, the plume thrown up by the LCROSS impact indicated the presence of a number of other elements as shown in Table 1. When compared to the elements required for life (S,C,H,N,O,P and S) it can be seen that nearly all are present in the lunar ice, including significant amounts of carbon containing molecules (0.4 % by mass). This evidence makes the lunar ice a valuable commodity, not just because of the elements that it holds, but because of the possibility of using these elements for biological ISRU.

Compound	Chemical name	% Relative to H_2O	% by total mass
H_2O	Water	100	5.60
H_2S	Hydrogen sulfide	16.75	0.94
NH_3	Ammonia	6.03	0.34
SO_2	Sulfur dioxide	3.19	0.18
C_2H_4	Ethylene	3.12	0.17
CO_2	Carbon dioxide	2.17	0.12
CH_3OH	Methanol	1.55	0.09
CH_4	Methane	0.65	0.04
OH	Hydroxide	0.03	0.002

Table 1: *Compounds identified by spectroscopy in the LCROSS ejecta plume* (Colaprete et al. 2010).

Food from lunar resources: For long-term settlement of space, self-sufficiency is a necessity and food production is one area that neither chemical nor physical methods can provide a solution for. The amount of dry food required per person per day is around 682 g [8]. A shielded or underground bioreactor could be used to grow the cyanobacterium Spirulina (*Arthrospira platensis* and *Arthrospira maxima)* on the lunar surface using these *in situ* resources [9]. Spirulina is sold on Earth as a dietary supplement and is a complete protein source with approximately 50% protein content by mass [10]. 2.67 kg of carbon dioxide would be required to produce 682 g of food (80% of PAR photons X 78% used for carbon fixation X 10 % Glucose per photon X Mass CO_2 X (Glucose mass / CO_2 mass) = max total biomass). If a 4-day batch cycle were run in a 682 L bioreactor, enough food could be produced per day to feed a single astronaut. This setup would require 682 L of water which could theoretically be obtained by processing 12,179 Kg of lunar ice regolith every 4 days which would also provide 14.61 kg of CO_2 [9]. Energy for this bioreactor could come from solar or nuclear power.

This technical demonstration above would show that food can be produced from *in situ* resources on the lunar surface. Synthetic biology could then come into play as a technology for improving the nutritional content, flavor and texture of the Spirulina.

Synthetic biology: Synthetic biology is practically a massless technology for engineering complex function into biological organisms. Once a genome synthesis device is placed on the surface of a moon or a planet, new organisms could be designed, built and tested for functionality on Earth. For example, a new version of the genome could be designed to produce organisms with higher protein content, or to taste better. Once demonstrated to have an enhanced ability, the new sequence for these updated organisms could be then sent to the destination of choice where the organisms could be synthesized *in situ.*

References: [1] Johansson (1995) Space Resources, NASA SP 509 (Vol. 3, p. 222-237). [2] Brown et al. 2008, In 37th COSPAR Scientific Assembly. Montréal, Canada. (p. 383). [3] Dalton, B.P. & Roberto, F.F. 2008, *Lunar Regolith Biomining: Workshop Report*. [4] Nozette et al., (1994) *Science,* vol. 266, no. 5192, pp. 1835-1839. [5] Pieters, C.M. et al. (2009) *Science,* vol. 326, no. 5952, pp. 568-572. [6] Colaprete et al. (2010) *Science,* vol. 330, no. 6003, pp. 463-468. [7] Schultz, P.H., et al., (2010). *Science,* vol. 330, no. 6003, pp. 468-472. [8] Held, J., (2007). *International Journal of Logistics,* vol. 10, no. 4, pp. 351. [9] Montague, M, et al., International Journal of Astrobiology, in press. [10] Pandey, J.P. & Tiwari, A. 2010, *Journal of Algal Biomass,* vol. 1, pp. 20.