ARCHITECTURE FOR A FARM IN A MOON VILLAGE WITH IN-SITU MATERIALS FOR INFRASTRUCTURE. A. C. Muscatello[1], J. D. Burke[2], R. P. Mueller[3], N. J. Gelino[4], B. C. Buckles[5], and D. V. Tompkins[6]. [1]NASA KSC, (Retired), 3655 Fodder Dr., Rockledge, FL 32955, tonymuscatello2020@gmailcom, [2]Jet Propulsion Lab (Retired JPL) and Moon Village Association, Pasadena, CA. 91104, jdburke@caltech.edu, [3]NASA KSC, UB-R1-A, Kennedy Space Center, FL 32899, rob.mueller@nasa.gov, [4]NASA KSC, NE-L-60, Kennedy Space Center, FL 32899, nathan.j.gelino@nasa.gov, [5]The Bionetics Corporation, LASSO-6720, Kennedy Space Center, FL 32899, rob.mueller@nasa.gov, [6]DIY Service LLC (DBA GrowMars), 2780 E. Fowler Ave. #418, Tampa, FL 33615, growmars2@gmail.com.

Introduction: Biological and agricultural methods of multiplying resource potential through the use of growing and replicating living organisms can provide a radical improvement in traditional In-Situ Resource Utilization (ISRU) which previously has focused primarily on non-leveraged use of indigenous resources. By harnessing the energy from our sun and using local lunar resources such as water, minerals, and waste CO_2 from human respiration and trash, or CO and CO_2 from lunar cold traps, it is possible to create even more resources such as food for humans and bio-polymer feedstocks which can be used as binders for lunar construction materials made from polymer composite concretes.

In this presentation we explore some of the required development for food production and feedstocks, including protection against hazards, automated planting and harvesting of crops, and maintenance of small animal herds.

Algal Biomass to Regolith Binder and Self-Replicating Greenhouses: Special attention will be focused on the production of farming infrastructure by using a polymer composite concrete based on the in-situ conversion of algae biomass to large quantities of polyethylene furanoate (PEF) which could be used as the polymeric thermoplastic binder when mixed with indigenous regolith fines and extruded in a three-dimensional (3D) printing process using robotic methods. By using in-situ resources, special lunar farming facilities and biological reproduction methods, the infrastructure can become self-replicating in space, therefore eliminating the constraints of launching infrastructure assets through the Earth's gravity well and landing them on the Moon, thereby enabling construction of the Moon Village for sustainable human exploration. The history of growing algae and other crops for space life support has been reviewed recently by Wheeler [1].

The production of the PEF binder for regolith begins with the growth of algae in small greenhouse blocks such as shown in Fig. 1 starting at the upper left. Each block can be rotated to follow the sun across the sky, if desired, as illustrated. Fig.1 at the bottom shows how the individual blocks can be assembled into larger structures that include interconnected water circulation channels in which the algae grows. The larger structures can be used to shelter gardens for growing crops, corrals for animals, and human habitation.

The process for conversion of algae into 3D printed greenhouse blocks or into additive for 3D printing is summarized below and in Fig. 2.

Fig. 1. Rotating and tesselating greenhouse blocks for growing algae to process into polymer precursor for 3D printing and regolith binder production.

The first step is to grow algae in blocks imported from Earth initially, then in 3D printed blocks using material made on the Moon (or Mars). The expected growth rate of the algae is 5 g dry algae mass per liter per day with a starting volume of 14 L in a 22 kg structure and a conversion efficiency rate of algal dry mass to new plastic mass of 20% (14 L x 5 g x 365 days x 0.20) / 22000 g = ~23%.). A conversion efficiency of 20% represents a conservative w/w carbohydrate composition of algal mass. An Earth-based system can produce enough feedstock to duplicate its own mass in two years. Depending on the latitude on the Moon, the rate would be similar or even faster given the absence of an atmosphere that would absorb some of the lunar sunlight. As with terrestrial photosynthesis, O_2 is a byproduct that could be used for life support.

The low mass input of fertilizer needed to support highly functional biological life support schemes supplying food and oxygen were recognized early in space exploration, but is complex to implement into a fixed closed loop scheme. By incorporating generic biomass carbon fixation with in-space manufacturing with a known carbon-negative fixation process into plastic with O_2 release, plastic manufacturing provides a clear direction without biological complications. Also accomplished is increasing usable structure and solar capturing area for an increased rate of O_2 production. Only 10-20 square meters are needed for O_2 production per person for life support [1] and only 2.52 kg of fertilizer is required per year per square meter for plant growth. [2]

Based on prior bio-polymer research [3], a system that could enable carbon feedstock isolation from algal biomass, monomer synthesis and purification, and polymer production is feasible. A component could be developed for a scaled and automated synthesis process to take the raw biological material to relevant plastic polymer such as PET (polyethylene terephthalate) or PEF (polyethylene furandicarboxylate).

The processing steps to make the polymer are [3]: (1) Dried algal biomass distillation to produce furfural, (2) Furfural oxidation to 2-furan carboxylate (FC), (3) Reacting 2-furan carboxylate (FC) with carbon dioxide and cesium carbonate (Cs_2CO_3) to produce furan-2,5-dicarboxylic acid (FDCA), (4) Producing polyethylene furan dicarboxylate (PEF) from FDCA and monoethylene glycol (MEG) which can be derived from ethanol, (which is an already proven process with algal culturing).

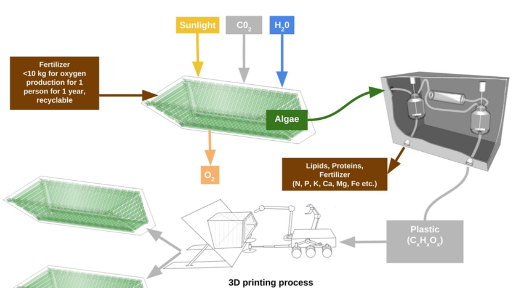

Fig. 2. Steps for growing algae and processing into more greenhouse blocks and useful byproducts, such as lipids, proteins, fertilizer and minerals.

A key issue for this process is the availability of CO_2 on the Moon. On Mars, this is not an issue because the atmosphere of Mars is >95% CO_2 which can be collected via a number of methods. On the Moon, there is about 82 ppm carbon in the regolith, which could be collected by heating, generating CO, CO_2, and methane. PEF ($(C_8H_6O_5)_n$) contains 0.527 kg carbon per kg of PEF. This would require heating 6,433 kg of regolith to generate the CO_2 needed for the PEF alone. Four times more is needed for the other biochemical products. This is not feasible if the sole purpose is to make the CO_2. If the regolith were heated to produce O_2 via hydrogen reduction for the crew and propellant, the O_2 yield would be 64 kg (1%), making the CO_2 production sound potentially feasible.

If the Moon Village is near polar lunar volatile deposits, CO at ~0.7 wt.% and CO_2 at ~0.12 wt%, as detected by the LCROSS impactor [4], become a potential resource if water and other volatiles are being extracted, which may be required for life support, farming, and algae growth if the costs of importing terrestrial water are too high. Each kg of volatiles-bearing regolith would yield 7 g of CO and 1.2 g of CO_2 containing a total of ~3.3 g of carbon. This amount is too small to make a significant impact. A better source of CO_2 is respiration by the astronaut crew at 1 kg/person/day. A crew of four would produce 1.1 kg carbon/day, which would yield up to 1.67 kg of PEF per day after correction for an 80% efficiency, including conversion of all bioproducts. Another carbon source is crew trash and waste at ~5.8 kg/day for a crew of four [5] which yields ~4.1 kg carbon/day if processed through incineration/gasification [5] with supplemental oxidation to convert small amounts of methane and CO to CO_2, resulting in ~6.2 kg of PEF per day, a significant amount. Combining carbon from respiration and waste appear to be the largest lunar sources for producing ~7.9 kg/day of PEF binder for 3D regolith construction and building more greenhouse blocks. Additional carbon will become available with more crew, crops, and farm animals as the lunar farm is expanded. We note that some of the CO_2 in the lunar farm and habitat atmosphere from respiration and from the waste will be needed to support crop growth, though inedible crop materials could be recycled into CO_2 along with the waste. Further analysis is needed to establish the feasibility of this process and will be discussed during the presentation, but it currently appears to be promising.

References: [1] Wheeler R. M. *Open Agriculture 2.1* (2017): 14-32. [2] Drysdale, A. et al. (2008) *Adv. Space Res.* 42, 1929-1943. [3] Kucherov, F. A., et al. (2017) *Ang. Chem. Int. Ed. 56.50*, 15931-15935. [4] Colaprete, A., et al. (2010) *Science 330.6003,* 463-468. [5] Anthony S. M. and Hintze P. E. (2014) *44th ICES*.