ENABLING SUSTAINABLE HABITATION AT THE LUNAR BASE. C.A. Mitchell[1*], A.J. Both[2], C.M. Bourget[3], C.S. Brown[4], R.J. Ferl[5], T.J. Gianfagna[2], H.W. Janes[2], T.L. Lomax[4], G.D. Massa[1], O. Monje[6], R.C. Morrow[3], K.O. Orvis[1], A.L. Paul[5], H.W. Sederoff[4], G.W. Stutte[6] , R.M. Wheeler[6], N.C. Yorio[6] 1. Purdue University, 2. Rutgers University, 3. Orbital Technologies Corporation, (ORBITEC), 4. North Carolina State University, 5. University of Florida, 6. Kennedy Space Center / Dynamac Corporation, * cmitchel@purdue.edu

Introduction: Central to a sustainable human presence on the moon and Mars-forward technology development is a life-support system that will keep lunar-outpost crews safe, healthy, and psychologically stable. Any life-support system has numerous components, but a central and limiting feature is food. Currently, we are limited to what can be brought from Earth. The food component adds an enormous amount of costly launch mass, generates a large amount of packaging waste that requires disposal, and provides a diet deficient in fresh fruits and vegetables. Adding a plant component to any space diet will have numerous benefits including flavors, textures, aromas, nutrients, and anti-oxidants along with the psychological benefits that living plants and fresh food provide. The atmospheric revitalization that plants also provide will reduce the load on physico-chemical CO_2 removal. Furthermore, demonstrating plant growth in an off-Earth environment will advance life-support planning for future missions and validate that plants and plant-based activities relieve feelings of stress and isolation while living and working in the extreme environment of the lunar surface. While plant growth on the moon seems highly desirable, several scientific and technical issues need to be explored before it can be affordable in terms of equivalent systems mass (ESM), a roll-up metric including launch mass, volume, power-and-cooling energy, crew time, and mission duration. A multi-pronged approach is needed to lower the ESM obstacle to growing crops on the moon.

Approach: The main ESM obstacle for establishing a "salad machine" on the moon is the energy required for crop production. Whereas sunlight ultimately provides energy to drive photosynthesis on Earth, the process of lighting plants becomes much more complicated on the moon, where radiation and micrometeorite hazards make protection of outpost modules a priority. When available, lunar sunlight could be collected, concentrated, and transmitted to a protected plant-growth compartment in a module. During the protracted lunar night and/or during periods of dust occlusion, LED lighting also offers promise, either as a supplement to transmitted solar light or as a sole source of light for plant growth. LEDs are small, durable, long-lived, increasingly efficient, and heat can be removed separately from where light is generated, so they are ideal for plant growth off Earth. By selecting wavelengths and color ratios optimal for plant growth and by applying light uniquely to all photosynthetic surfaces of plants, large increases in energy-use efficiency are possible. Targeted lighting to specific zones of crops, such as tomato-fruit clusters and surrounding leaves, would stimulate fruit production without concomitant increases in inedible plant parts. Additionally, automated lighting that irradiates only leaves that are actively photosynthesizing will yield further savings of energy and crew time. Combining solar and LED-based sources into a hybrid plant-lighting system has potential for synergistic reductions in ESM for a lunar salad machine.

Operating the habitat at hypobaric pressures will minimize air leakage to the external lunar vacuum and reduce ESM for structural mass. Plants grow well at hypobaric pressures, with adjustment of CO_2 partial pressure, but related conditions must be optimized for the lunar-habitat environment, including heat transfer from lighting systems. Regolith is an *in situ* resource that may be used as a substrate and further reduce ESM for plant growth, but must be tested for hydraulic conductivity, porosity, ion-exchange capacity, toxicity, and release of volatile compounds.

Outdoors on Earth, plants gradually developed environmental and genetic limitations to what and how much they can produce. For life-support purposes on the moon and Mars, both limitations can be overcome through targeted R & D. By identifying combinations and levels of environmental factors that overcome limitations to plant productivity, optimization protocols can be developed that improve the quality and quantity of crop outputs with lower resource inputs. Altering a plant's genetic makeup to produce needed compounds that are absent, increase the levels of desirable compounds that are present, or get rid of undesirable compounds are achievable goals for improving the nutritional content, safety, and health-related features of salad crops to support lunar-outpost crews. Genetically determined nutritional traits such as anti-oxidant content, flavor compounds, and lack of anti-metabolites are important targets for improving salad crops for the moon. Increasing stress tolerance, harvest index, and overall yield potential of crops to be grown within realistic, ESM-affordable growth environments are additional crop-improvement goals that will enable the move toward sustainable habitation at the lunar base.