MANIPULATING THE PLANT-LIGHTING ENVIRONMENT TO ENABLE SUSTAINABLE HUMAN HABITATION ON THE MOON. G. D. Massa¹, C. M. Bourget², R. C. Morrow², C. S. Brown³, H. W. Janes⁴ and C. A. Mitchell⁵, ¹Purdue University, Department of Horticulture and Landscape Architecture and ALS NSCORT, 625 Agriculture Mall Drive, West Lafayette, IN 47907-2010, ²Orbital Technologies Corporation, (ORBITEC), 1212 Fourier Drive, Madison, WI 53717, ³North Carolina State University, Research Administration and Department of Botany, Campus Box 7570, Raleigh, NC 27696, ⁴Rutgers University, Department of Plant Biology and Pathology and Habitation Journal, 59 Dudley Road, New Brunswick, NJ 08901, ⁵Habitation Institute (HI)

In order to make human habitation requirements at the future lunar base more independent of resupply from Earth ($70K/pound Earth-to-Moon launch cost, 2004 $) and to prepare for more distant space destinations where regular resupply of life-support consumables is untenable, loop-closure technologies are required for sustainable living. Since human food cannot be synthesized productively by physico-chemical processes, it will be necessary to grow food crops to nourish crews and revitalize atmosphere at lunar bases as a test of habitat sustainability. Perhaps even more important in the near term will be to address human psychological needs for fresh food and to be associated with and/or responsible for the care and nurture of living, green organisms. Whether it be for fundamental gravitational and space-radiation research or for R & D to optimize sustainable space life-support systems or to satisfy human psychological needs, growing plants on the moon will be an integral part of future lunar and subsequent space bases.

Energy for plant lighting and thermal control has been identified as the single largest challenge for crop production in space. Direct utilization of sunlight on the lunar surface (i.e., lunar greenhouses) is unlikely because of the hard radiation environment, large diurnal thermal swings, very steep ΔP inside to outside, and dangers of micrometeorite penetration. Likewise, areas on the lunar surface without prolonged dark periods (e.g., 2-week-long lunar skoto-period) are extremely constraining to base location. Locating habitats below ground (berming, lava-tube caves, etc.) for the reasons given above will serve crew-safety needs as well as those of plants. The most likely plant-lighting scenario will involve some combination of electric lighting and piped solar light, when available. A small nuclear reactor is the most logical primary energy source for the overall lunar base for long-term operation and habitation.

The main focus of research conducted to date by the ALS NSCORT in collaboration with Orbitec has been to develop high-efficiency LED “lightsicles” that overcome the limitations of delivering light in the traditional, overhead mode to planophile crops that tend to close their foliar canopy and upper leaves subsequently shade lower leaves. Many small red or blue LEDs are mounted on printed-circuit “light engines” arranged along a straight shaft that can be aligned either vertically as individual light sticks within a crop stand, or reconfigured into a continuous, horizontal plane that can be mounted overhead for erectophile or rosette growth habits. Light engines can be energized individually from bottom to top of lightsicles as crop stands grow in height, and intensity of red and blue LEDs can be controlled independently. Thus, intensity as well as spectral balance of blended light can be varied as needed. Orbitec has been developing an automatic detection-and-switching system to locate the height or spread of the crop stand and switch light engines on or off appropriately so that photons are not directed toward empty spaces where they will not be intercepted by plant tissue. Much work remains to identify crop-specific lighting requirements while significantly reducing energy costs associated with plant lighting systems.

The major candidate crop species that will provide psychological support, a balanced diet, and/or experimental subjects for crews at the lunar base include staple crops (legumes and cereals), carbohydrate crops (tuber or storage-root crops), and salad crops (vitamins, minerals, anti-oxidants). Spectral, intensity, and photoperiod requirements have not been determined for representatives of these crop types growing under mixed light sources (e.g., piped solar and/or narrow-band LEDs), especially when grown for part of a cropping cycle under one light source and the rest of the time under another. Maximizing interception of relevant radiation is the key not only for saving energy, but also for obtaining the best crop output per unit energy input. Crops themselves need to be modified genetically in order to provide the best quality and quantity of nutritional value or bio-process feedstock under a given lighting regime. Traits favoring foliar absorbance of narrow-band light, completeness of dietary protein formed, lack of secondary products that interfere with flavor or bio-availability of edible biomass, high anti-oxidant content, high crop productivity in limited growth space, and continuous production cycles with low labor inputs are a few target goals for selecting, breeding, engineering, and/or environmentally inducing crop responses.

Improving the efficiency of plant-lighting technologies that are compatible with the lunar environment and its limitations will substantially reduce the Equivalent System Mass (ESM) costs of crop lighting systems to be deployed on the moon. Reducing the launch mass, volume, labor, and the power and energy required to light plants and reject associated waste heat will make it much easier to have productive food crops and achieve sustainable habitation for human crews on the moon and beyond. The multi-institutional, focused experimental approach of the Habitation Institute on plant lighting will help to remove a substantial obstacle to the lunar base becoming semi-autonomous, should the United States wish or need to exercise that option.