Creating Closed Ecological Bio-regenerative Life Support Systems For Planetary Habitats, Space Vessels and Space Stations

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Introduction

What can be done to minimize the amount of material required from earth to create space based closed ecological life support systems? Supplies and materials for the crews on Skylab were sent up with the orbital workshop, and resupplied using the Apollo command modules as freight containers. Resupply of the International Space Station requires frequent missions by space freighters that carry up supplies by the ton, and are loaded up with solid waste products for destruction during re-entry. Resupply of life support materials will be a big cost factor for operators of future space stations, lunar shuttles and lunar bases. Closed Ecological Life Support Systems (CELSS) are being developed to decrease the amount of material that needs to be resupplied for space stations or planetary bases, and to allow for long duration manned deep space exploration missions. These systems require large amounts of materials and large volumes of space. They will be expensive to launch because of the mass involved, expensive to implement because of the volume of space required on the space ships and space stations, and expensive to operate because of the human labor that is required to operate and maintain these systems. Current plans for space stations and exploration vehicles are predicated on minimizing these parameters to control the cost of the missions. Smaller systems mean lower cost for launch, less volume on the vehicle and fewer man-hours for operation and maintenance, but it also limits the size of the crew for exploration missions, and the capacity of the space stations and moon bases, meaning they must still be supplied with materials form earth if they are to support rotating crews, visiting researchers or tourists above the limits of their CELSS. The major limiting factor is the mass required from earth.

I believe the best way to provide closed ecological life support systems to space stations and expeditions, large enough to accommodate the personnel needs of their missions, is to create a system that can be installed on a space based platform as a breeding system. A properly sized and configured closed ecological bio-regenerative life support system (CEBLSS) can be developed in an orbital facility and used as a breeder system to create all the components of a CEBLSS that can be isolated, removed and installed in space ships, space stations or planetary bases. This capability would reduce the cost of these systems since less mass would have to be launched from earth for new systems. This paper will explore the creation of a large scale hybrid CEBLSS for life support with these capabilities aboard a space station using both physical/chemical and bio-regenerative life support systems.

System Requirements

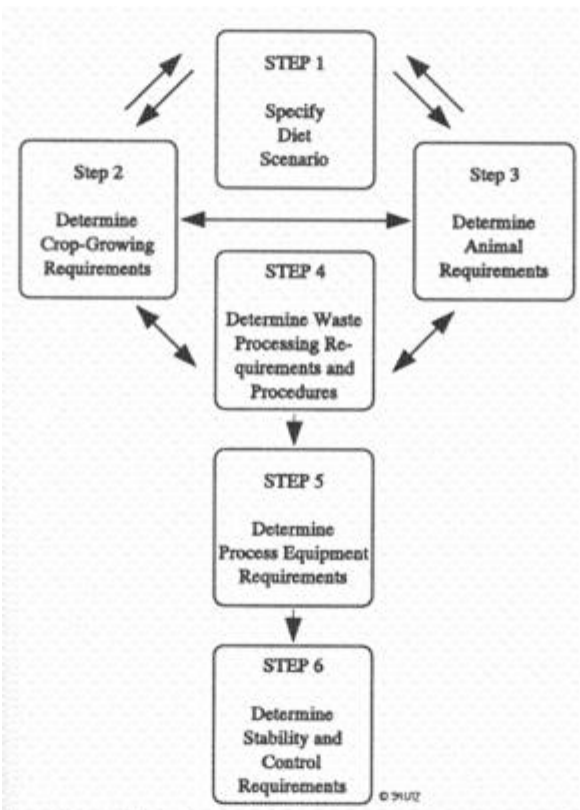


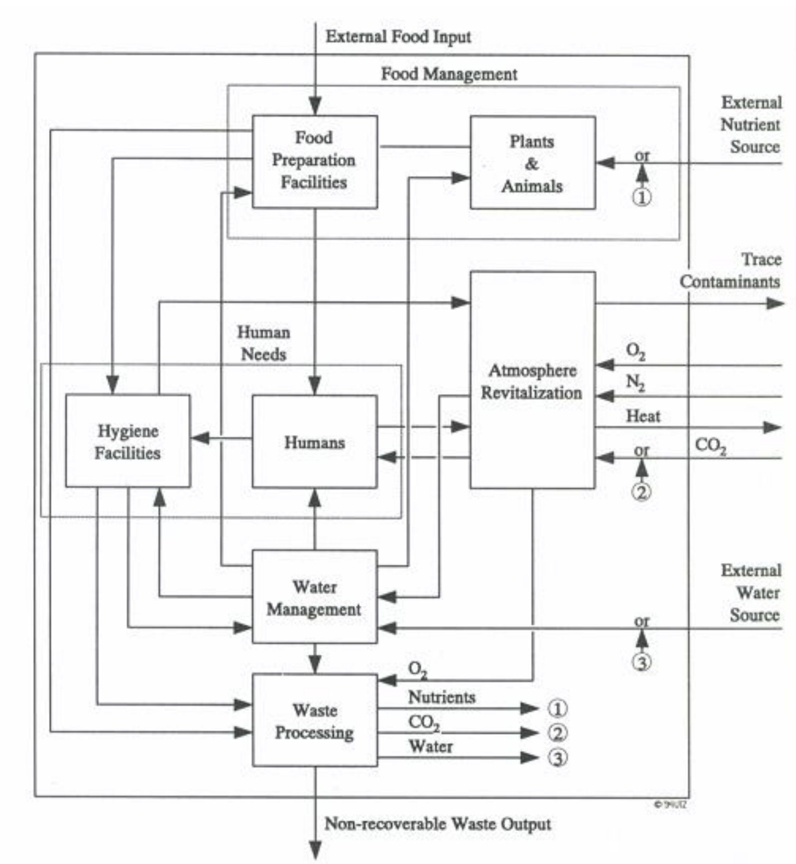
Figure 1: LSS Design Process

This is a multi-tiered system, since it must first provide a closed life support system for the crew that operates it, and then it must make the components required to export life support systems to other environments. This system and those it will create will be designed around the needs of the human inhabitants of the system. Several factors must be managed[6];

- Atmosphere: The system must manage the atmosphere, including controlling the gas components, tempurature, humidity, pressure and circulation. The system must also be able to sense and remove any contaminants from the atmosphere.
- Water: The system must manage the water supply, providing water for consumption by the systems living components, hygiene and cleaning, and the reclamation of water from system generated waste.

- Food: The system has to manage production and any storage of food for all the systems living components
- Waste: Waste must be managed, either recycled, stored or removed

The system has to have the highest closure index achievable, to eliminate or minimize materials required from outside the system. Any materials that are required for system replenishment should be available from space based resources. The system should provide for both the physiological needs of the crew and provide some measure of psychological comfort by enhancing their environment.



Part of the first phase of such a project is deciding how best to configure the system to meet the stated requirements, what applications or tasks will be required, and an analysis must be done to determine what components will best serve the needs of the required system. The system is then designed with these requirements in mind.

Figure 2: Life Support Functions and Interrelationships

System Components: Benefits and Contributions

Components include plant and micro algae systems, with results from their use in various experimental research (BIOS 1, 2 and 3), microbial systems, with results from several research efforts like the Micro Ecological Life Support System Alternative (MELLiSA), and aquatic systems, with results from research models like the Closed Equilibrated Biological Aquatic System (CEBAS) and the Controlled Aquatic Ecological Life Support System.

Gas exchange is the first crucial component of the system. Humans can only survive about 4 to 5 minutes without air, and only about 3 days without water. The primary component for gas exchange would be algae. Algal systems are the smallest of plant systems (microalgae), single celled, containing almost no inert or dead biomass, performing their tasks based on photosynthesis, requiring light and CO2 that it can get from the air to start the process, and Algal systems have been experimented with in the Bios experimental systems. They don’t have much to add in terms of food (some nutritional value, but no aesthetic value), but they can be an important part of both gas exchange and water recycling. Bios-1 was able to achieve a 20% closure index for the gas exchange between human and microalgae for CO2 and O2. Higher forms of plants contribute to the gas exchange and boost the water recycling, bringing the closure index for both air and water in Bios-2 to between 80% and 85%. Bios-3 increased the food provided by higher plants, and was able to increase the closure index even more, between 93% and 97% for food, air and water. Reaching these levels required the introduction of another element, microbial processing.

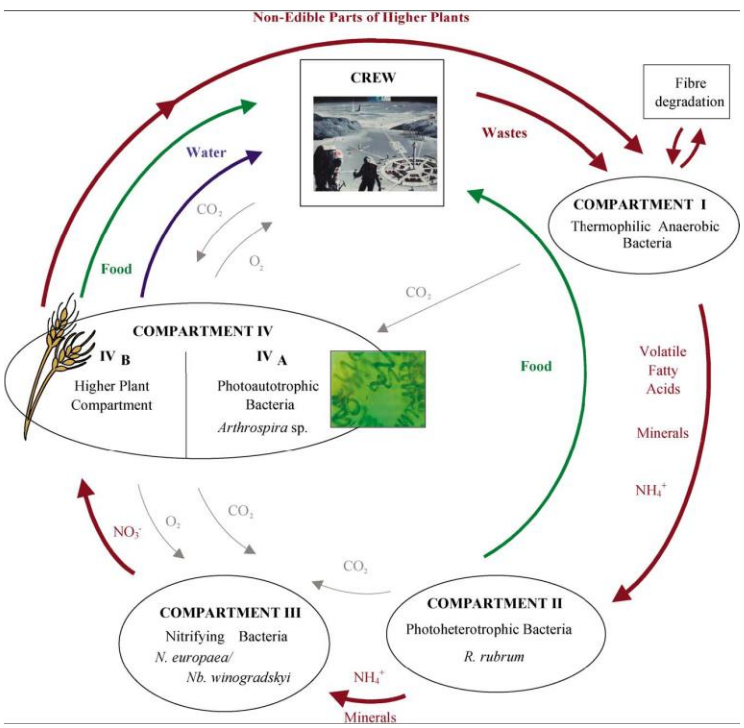


Figure 3: Scheme of the MELiSSA LOOP

Microbial systems have many uses in a bio-regenerative life support system. They can be used for both liquid and solid waste recycling, and they provide mineral and elemental exchange in plant growth mediums, whether soil or hydroponic. Some microorganisms remove organic contaminants from human liquid waste, providing additional filtering of water for plants. They also perform other tasks, like nitrogen fixing in soil or hydroponic solutions, and consumption/conversion of inedible biomass. Microbial systems are the largest bio system on earth, playing a major role in the ecology, and a crucial role in our CEBLSS. The Micro Ecological Life Support System Alternative (MELiSSA), seen in figure 3, is a microbial system designed by the European Space Agency to recycle liquid, gas and solid wastes during long duration space missions.

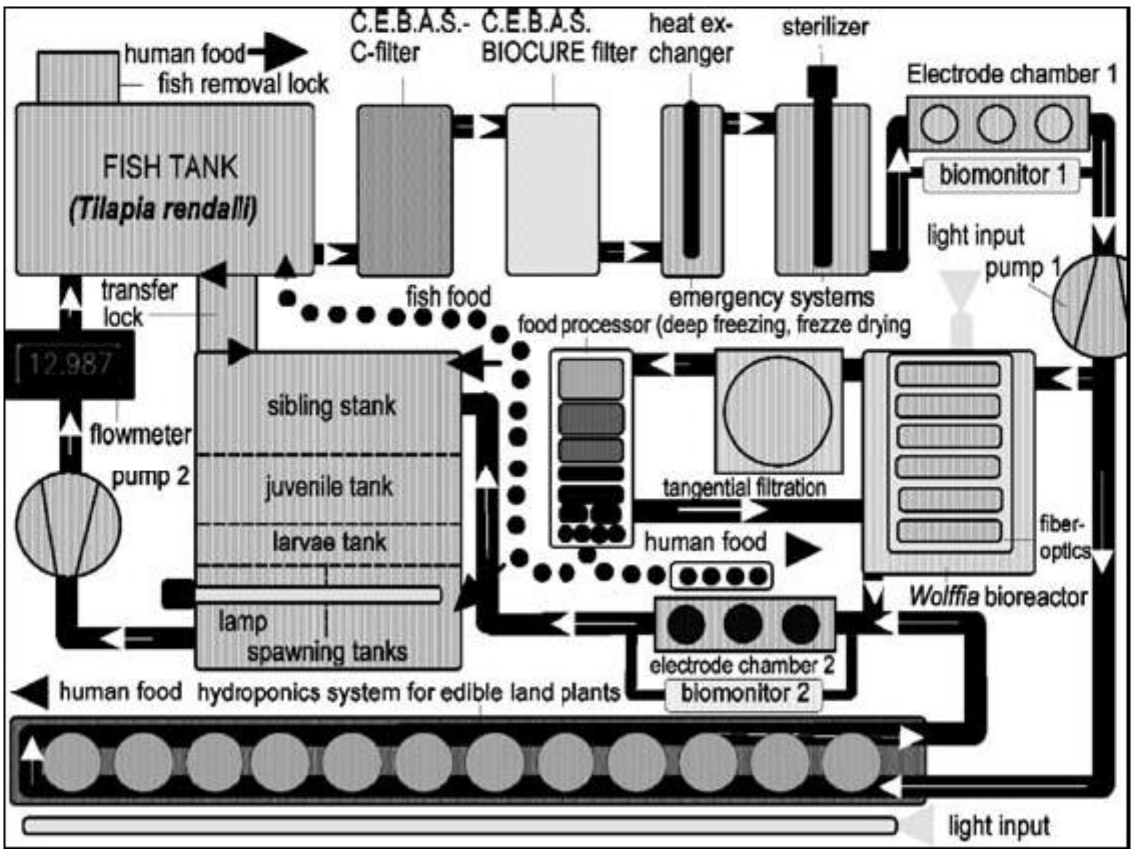


Figure 4: CEBAS System

Another system being developed is the aquatic BLSS, like the Closed Equilibrated Biological Aquatic System (CEBAS). These systems are complete in themselves, containing microbial systems for waste processing, animal systems (aquatic) for food, aquatic plant and algae systems for gas exchange and additional food, and a built in aquatic materials buffer.

Our system will require some physico-chemical systems to deal with the dead-end products, biomass that can't be converted by the microbial system or consumed by any of the living systems, to provide environment control for some of the CEBLSS modules.

Finally, the crew. Besides being the defining organism for the system, the life it is designed to support, they are also a critical component of the system. People both consume and provide liquids, gasses and solids within the system. They are the other half of the food and gas exchange cycle, and most importantly they are the intelligent control elements for the system.

There are varieties available for all these systems, for example green algae and bluegreen algae and several other varieties of algae, microbial systems closely joined with the aquatic systems or operating separately as a waste processing system separate from the aquatic system. How large an algal system to use, and what percentage of gas exchange should come from there and what percent from the higher plants? What other systems can be used to provide CO_2 besides people, how will nutrients be provided to the plants in the microgravity environment? These questions may be answered during preliminary research by trade studies, comparing one system configuration with another to find out which is optimal for the needs of this particular system.

Configuration Constraints: Physical, Environmental and Habitability

The proximity and hardware support requirements of the various system components, some of which need to be isolated from other, will be discussed. Some plans exist for similar systems for lunar bases. I will also consider habitability issues, like distributing some of the plant and aquatic system components within the living areas of the crew, for possible positive psychological effects and enhancements to the habitability of the crews living environment.

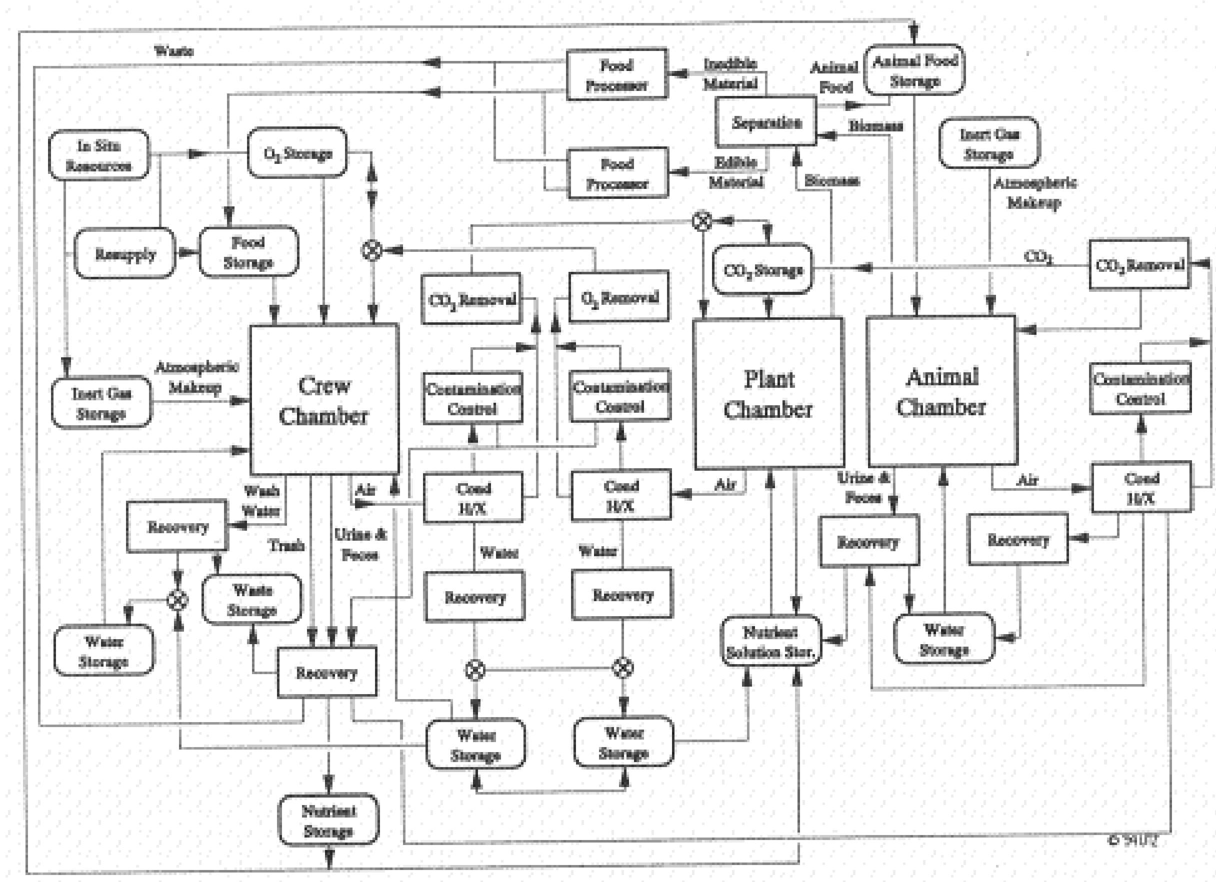


Figure 5: block diagram concept for a lunar base

The systems involved are Microbial, Algal, Aquatic Plants & Animals, Plants and Humans. Many of the systems will have to be maintained in so-called bio-reactors because of the micro gravity environment.

The microbial system will be partially distributed, with components integrated with the aquatic and plant systems. The primary microbial system for waste recycling will have to be isolated both to control the population, to maintain the habitability of the rest of the habitat (contain the odor) and to contain the system components in the microgravity environment. These will be the primary bio-reactors of the system. The microalgae will also be maintained in a similar module to control the growth medium, the lighting and the food supply for the algae.

The aquatic system will be maintained primarily for the animal supply and the buffer it will provide for the habitats water supply. This system might be distributed in various portions of the

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space station, providing aquarium views in some of the common areas, with the major aquatic container in the CEBLSS control area. The plants that are part of this system will be maintained for their aesthetic value and as part of the food supply for the animal portion of the aquatic system. The animals and microbial portions of this system will also be able to consume some of the inedible biomass from the plant systems.

Plants will also be distributed throughout the living areas of the space station, based on species. Most food crops will be located in a specialized area where the environment can be tailored for their needs, including light frequency, humidity, tempurature, and air circulation.

A monitoring system will also need to be created that monitors all portions of the system at all times to keep the human system operators informed of the systems health. This system would consist of cameras monitoring the various system components, pressure, volume and tempurature measurements for various system components, ph level of the bio-reactors and plant growing medium,

System Buffers And Live Storage

These systems must be very robust and resilient, especially systems meant for long duration deep space exploratory missions. This section will discuss creating and maintaining system buffers above and beyond what is required to maintain the systems closed loops, and possible procedures for rebooting the system in case of a failure caused by loss of part of the system from an accident, like a meteor strike or accidental contamination.

Most contaminants and toxics on earth are absorbed into the sea or the soil, where they are broken down and eventually (sometimes hundreds of years!) made harmless. The enclosed environment inside a space station or planetary base can also become contaminated with particles or materials from the structural components of the station, or a buildup of materials from any of a thousand systems onboard. There is always heat, light, stray energy and radiation to feed unexpected reactions between elements of the environment. Physico-Chemical devices and filters can become the onboard buffers to handle this type of contamination. Physico-chemical counterparts to most of the BLSS system can be included in line with their BLSS counterparts to act as emergency backup should any of those systems need to be relieved or taken offline for repair, cleaning or regeneration.

This system should use as input not only the people aboard the station but the waste from all other orbital stations and local shuttles, and any materials that can be gathered from space based resources, like asteroids or comets. This will be required to maintain a system production balance beyond what is required to maintain a closed loop for the crew of the station.

The system will generate more material than can be used by the crew of the station because of the additional input from outside the system. Some of this excess will be stored to provide a supply buffer in case of emergencies, some will be stored to provide supplies for other ships, like earth-lunar shuttles, small lunar bases, other space stations, or shuttles to the Lagrange areas or any other destinations in CisLunar space. Still other supplies will be stored for use in building CEBLSS systems for deep space expeditions (like voyages to Mars) or planetary bases.

The CEBLSS basic materials exchange loop (without input from outside the system) should be capable of providing for more people than it takes to operate the system. The station will require other crew members to operate and maintain the other station systems, and may also house visiting researchers.

For all its grand size, modern technology and multiple bioms, Biosphere 2 was not able to meet the physiological and psychological needs of the eight people who lived in the system for 2 years, and that was with a huge support staff right outside the walls. This was mainly due to the diet of the crew, chosen for its supposed nutritional value, with no thought to any psychological trauma that was caused by the diets austerity and lack of variation. The diet also did not fully meet the nutritional need of the crew, since part of that need was a certain amount of calories each day to not only perform their duties but live a ‘normal life’ after the days work was done.

Research Methods

This system must be researched by experimentation, similar to the BIOS-1,2, and 3, the Biosphere 2 and the CEEF. Isolated facilities can be set up in controlled environments in orbit to test various configuration of the system components, then in one integrated orbiting environment to work out the configuration for the final system. Mathematical modeling will be important since these systems will eventually have to be created for differing capacities, and mathematical models will be required to size the requirements for different size systems. Many of these systems have not been used in any large scale in a microgravity environment, and the equipment built for research done on earth will probably not be adequate for space based systems. A system using physico-chemical systems designed to match the configuration of the final CEBLSS system would allow the CEBLSS system to be brought online one section at a time.

Breeder Systems

If a system can be developed that meets the requirements as stated, then it will be possible to create a system that can be installed on a space based platform as a breeding system to create the living and hardware components for systems that can be installed on space stations, long voyage ships and the first planetary bases. This capability would reduce the cost of these systems since less mass would have to be launched from earth. The use of space based resources for some of the system components will also reduce the cost of the primary system and the systems created from it.

The easiest way to equip a client system would be with components from the working system. Since all parts of the system were installed in parallel with physico-chemical systems, it will be possible to take systems offline, replace them temporarily with their mechanical counterpart, remove the system component and install it on the client system. The removed component can be regenerated from materials in storage aboard the breeder station, and replaced.

Conclusions and Recommendations

Research into these areas needs a higher priority and budget than are currently allocated. Solving these issues before the return to the moon will greatly reduce the time required and the cost of establishing a permanent lunar base, increase the habitability of space stations for crews, researchers and tourists, and allow for larger crew sizes for expeditions to Mars and other deep space research, exploration or development missions.

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