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The Role of Plants and Algae in Near-term Life Support Systems

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Hybrid life support systems combining physico-chemical processes with plants and algae are needed to support larger crew sizes than those found on ISS for enabling the development of a vibrant cislunar economy. The use of photosynthetic organisms is essential because they can make use of freely available solar radiation. Recycling inedible biomass produced by plants and algae involves closing the carbon loop of life support systems.

Nomenclature

BLSS = bioregenerative life support system
ECLS = environmental control and life support
CDRA = carbon dioxide removal assembly
ISS = International Space Station
MSFC = Marshall Space Flight Center
TCCS = trace contaminant control system
PC = physico-chemical
VOC = volatile organic compound
ULA = United Launch Alliance

I. Introduction

LIFE support systems based on resupply or physico-chemical (PC) regeneration of materials are limited to small crews and short duration missions[1], which is appropriate for space stations and transit vehicles. In contrast, larger and more complex BLSS systems are envisioned for establishing permanent bases on the moon or Mars that support large crew sizes[2,3]. Future BLSS designs must be efficient, robust and stable; composed of processors (e.g. plants, algae, the crew) and storage reservoirs (eg. cabin atmosphere, food and waste storage, nutrient reservoirs) that mimic the material flows in the Earth's ecosystems[4,5]. Most BLSS designs utilize bioregenerative methods for providing food, oxygen, water, and waste recycling. These two approaches (ECLS vs BLSS) not only differ in scale, but more importantly, they differ in the components and processes (e.g. PC vs biological) used for providing the various life support functions required by the crew (e.g. air revitalization, water recycling, etc).

The difficulty in constructing viable life support systems for colonizing space lies in the fact that they must be constructed to function within the mass, volume and power limitations of spaceflight. Furthermore, they must be safe, reliable and modular. The initial designs of the Space Station Freedom were to benefit from bioregenerative methods for on-orbit closure of resource loops[2]. However, the final implementation of the flight-rated ECLS on ISS Node 3 includes only regenerative technologies chosen after extensive down selection and integrated system testing at MSFC[3]. The current ECLS architecture can support a crew of 6, but still requires resupply of food and consumables, it produces brine from urine, does not recycle solid wastes, and the carbon loop is not closed. This system will have to be modified to support the development of a vibrant cislunar economy. United Launch Alliance's (ULA) CisLunar-1000 vision proposes to deploy a crew of 20 in the next 5 years, rising to a crew of 300 in 15 years[6]. New life support concepts must be demonstrated to sustain these large crew sizes in cislunar space.

In near-term missions supporting manned crews larger than on ISS, a hybrid life support system utilizing both PC and biological technologies will be needed. New opportunities will exist as commercial ventures seek to profit from lunar bases, lunar mining, space tourism, and mining near-Earth asteroids. This paper presents a framework based on closing the carbon loop to help guide where the biological technologies can interface with PC systems.

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II. Approach

A. Hybrid BLSS - Philosophy

In hybrid life support systems PC technologies can function at the same time as biological technologies. In past designs the BLSS was entirely composed of biological technologies mimicking Earth's processes making integration of the overall system extremely complex. In the hybrid approach the arguments change from 'How will the biology replace the PC technology?' to 'How much will the biological system contribute to the overall architecture?'. This approach is more flexible and can be scaled depending on whether the life support is deployed as a surface system or as a station in a Lagrange point.

Plants and algae are photosynthetic organisms that produce biomass when supplied with light, CO_2, water and nutrients. Since only a portion of this biomass is edible, recycling the inedible portion becomes an exercise in managing the carbon loop on the entire BLSS. As on Earth, recycling biomass can become a valuable source of nutrients and soil for plant growth.

Recently, a diversity of commercial crew modules that can dock to a station have become available and this capability could be expanded to having dedicated modules for different functions. For example, a stand alone food production module could be developed that interfaces with an existing ECLS. The goal is to eliminate the need to incinerate resources (waste) in re-entry vehicles simply because our life support architecture is not designed to handle it.

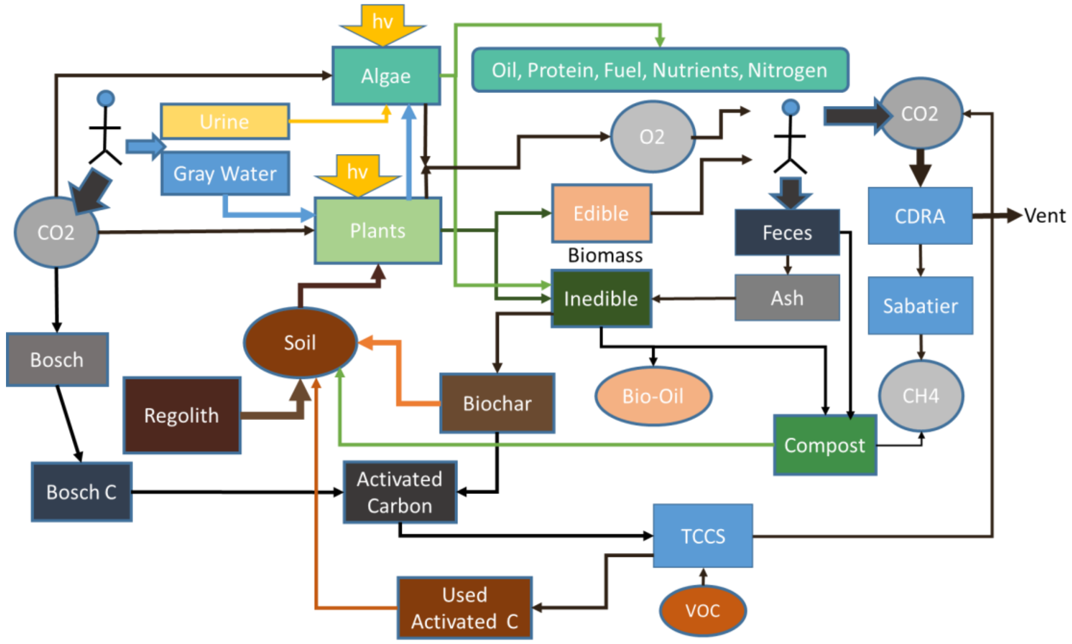

Figure 1. Hybrid bioregenerative life support system architecture – the focus is to close the carbon loop. The approach is to combine plant and algal modules with existing ECLS technologies.

B. Hybrid BLSS Architecture

A schematic of a hybrid BLSS architecture is shown in Figure 1. The crew requires food, oxygen, and potable water and produces CO_2, urine and feces. The plants and algae can utilize a portion of the CO_2 exhaled by the crew and require light, nutrients, and water to produce biomass and oxygen. The remaining CO_2 can be concentrated by the CDRA and reduced via Sabatier or Bosch reactors. The human feces could be ashed or composted to generate biogas and/or nutrients for algal and plant growth. In this architecture, the use of photosynthetic organisms is referred to the use of microbial bioreactors because they have higher growth rates and can utilize free solar energy that can be piped in using solar collectors when available[5], but microbial bioreactors can still play a role[7].

Algal reactors can be developed to mineralize the urea-N from urine into NH_4^+, which is readily adsorbed into algal biomass. Since the algal biomass is not used for food production in this scheme, the algal reactors can be sized for handling urine at higher light levels and the algal biomass is processed to produce oils, protein, fuel, nutrients, nitrogen-rich compounds, and fertilizer for plant growth.

Plants can be grown in gray water to produce fresh salad crops for supplementing crew diet. The inedible plant biomass can be recycled using pyrolysis into biochar and oil, or composted to produce biogas. The recycling of inedible wastes, as well as the production of biochars from algal biomass can help defray the need for resupplying fertilizers for plant growth. The biochar and compost can be used to amend regolith for creating growth media or soil for plant growth.

The biochar, as well as Bosch carbon, can be treated chemically and converted into activated carbon. The activated carbon would be used in the TCCS beds for air revitalization of crew cabin air. Once spent, the TCCS carbon beds loaded with VOCs can also be used as soil amendments for plant growth.

C. Benefits

The Hybrid BLSS architecture presented maintains the functionality of the existing PC ECLS architecture deployed on ISS, but it addresses some of its shortcomings:

1) Reduce resupply of activated carbons for trace contaminant control
2) Utilizes Bosch C and utilizes spent TCCS activated carbon beds
3) Reduces the need to produce brines from urine and reduces the NH_4+ load from the water loop
4) It provides for waste recycling of gray water, feces, and garbage (turned into biochar; not shown).
5) Provides for a source of oxygen when PC O_2 generation systems fail.
6) Plants and algae reduce the costs of CO_2 reduction and O_2 generation by using free solar energy.

This architecture also overcomes some of the shortcomings of the purely biological BLSS systems:

1) Avoids using algae as a food source and instead converts urine-derived algal biomass into useful byproducts.
2) Reduces the resupply of nutrients and fertilizer for food production.
3) Provides for fresh, nutrient-rich food that offsets the need for packaged foods.
4) Reduces the power cost of food production and nutrient provision by utilizing free solar energy.
5) Reduces risk to the crew should the biological organisms become contaminated.

III. Conclusion

Hybrid BLSS arcitectures combining PC and biological technologies are needed to support larger crew sizes than those found on ISS for enabling the development of a cislunar economy. They are expected to be more robust and reliable than BLSS systems composed of purely biological components. The role of plants and algae are to help close the gaps in the carbon loop left open in regenerative ECLS architectures.

The implementation of a hybrid BLSS may be accelerated by prioritizing the biological technologies that will make the current PC architecture more efficient. Since the demand for plant growth systems is probably going to remain small in the near term, that is, until a large lunar habitat is developed, then algal systems could be developed first. Ground studies employing small algal reactors illuminated with solar collectors demonstrating nutrient recovery from urine and the provision of fertilizers for plant growth would generate data for integrating these reactors into PC architectures. Similarly, simple PC methods to convert indedible plant materials and food wastes into biochars and activated carbons for trace contaminant control could be demonstrated in parallel. Finally, plant growth tests utilizing algal biomass, biochar and used activated carbons as nutrient sources should be carried out to determine if these fertilizers are comparable in supporting sustainable food production, that is, with minimal resupply of fertilizers from Earth. Once demonstrated and integrated in ground studies, these technologies should be tested in the spaceflight environment. Hybrid BLSS systems will remain harder to integrate and test than current ECLS systems but they are a necessary evolution for the colonization of space.

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