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CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEM

BREADBOARD PROJECT - 1988

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ABSTRACT

The goal of the first phase of the Controlled Ecological Life Support System (CELSS) Breadboard Project is to develop, build, and test a ground based CELSS at a one-person scale. The successful integration and operation of such a system should establish the feasibility of developing a CELSS that will meet life support requirements for crews during long duration space flights. Over the past two years, personnel of the Breadboard Project have concentrated on the construction and initial testing of a large biomass production chamber, the primary module for the plant growth and atmospheric revitalization for this CELSS. This large plant growth chamber is now functional and the first full biological test of the facility was completed in January 1989 using wheat as the test specimen. Associated laboratory research during the past year has concentrated on production studies with other crop species, microbiological characterization of hydroponic solutions, enzyme conversion of cellulose to sugar, aquaculture techniques, recovery of inorganic elements from plant waste through water leachate, and the development of a nutrient delivery system for microgravity. This paper will summarize this work and present future plans; especially those that are important to establishing modules or a complete CELSS, including food processing and waste management.

INTRODUCTION

A plan for the Controlled Ecological Life Support System (CELSS) Breadboard Project was written and approved in 1986. This project was initiated primarily because research results on some crops suggested that productivity was sufficiently high to allow a CELSS to be economically feasible. But these productivity estimates based on scaling upward small laboratory level studies, as history indicates, can not always be relied upon to yield operational level data. The Breadboard Project was initiated to empirically demonstrate the feasibility of a functioning CELSS.

Project Description

During the first phase of the project (five years), we plan to construct and operate NASA's first ground based CELSS. Currently, the working concept of this activity is as depicted in Figure 1. The development of this CELSS will depend on available proven technology and will therefore establish what we are capable of doing today with little attention to innovation or required new technology. Crop production trials on a functional level will be the primary focus during the initial period. Activities centered in the biomass production chamber (BPC), involve the growth of crops under environmentally controlled conditions including thin film hydroponics, a sealed atmosphere, and artificial lighting systems. Biomass produced in this chamber will be removed and transported to laboratories adjacent to the BPC for processing. Biomass processing will include the production of food and/or meals from edible plant material and the conversion of inedible biomass into edible products or usable raw materials. In these adjacent laboratories, wastes will be converted to plant nutrients, inorganic elements to plant fertilizer and organic material to CO_2 and water. Total mass will be carefully measured through all these laboratory activities. Three major modules of a CELSS: biomass production, biomass processing, and waste conversion will be integrated and validated during this first phase of the Breadboard Project.

Table 1 summarizes the major activities that are planned in the CELSS Breadboard Project over the next five years. At least three crops will be tested in the BPC; wheat, soybean, and potato; including multicroping studies and continuous production trials. Condensate water will be recycled through the nutrient delivery system and a trace atmospheric gas contaminant control system will be added to the BPC as required to control trace organics.

Food processing and waste management activities will concentrate on measuring and analyzing the biomass, condensate water, and atmospheric contamination produced within the BPC. Processing of edible biomass into food at a kitchen level will occur later in the project at which time meals will be prepared and tested. Reactors and subsystems to produce alternate food sources by utilizing the inedible biomass will be integrated with the BPC. These reactors will include enzymatic conversion of cellulose to sugar and the production of single cell organisms. Another one of the subsystems will probably be based on aquaculture.

The waste conversion module will first consist of a soluble mineral reactor that will remove elements from stem and leaves for use as a fertilizer. Combustion and biological reactors will be added to the Breadboard Project as it matures. Integrated tests of the completed Phase I Breadboard are scheduled to occur in 1993 and 1994.

The primary output from the Breadboard Project will be data on energy use and rates of mass flux through the CELSS. The copious amounts of data generated by the Breadboard tests will be reduced and analyzed through multivariate statistics. Appropriate models which will establish the utility of a CELSS in space will be selected and validated. These models will be useful in developing design requirements for more complex Breadboard facilities, including ones that involve humans as active participants.

Project Status

Over the last year, the BPC became operational and tests of wheat as a single crop are nearing completion. The environmental control subsystems have been programmed, thoroughly tested, and mated with a computerized monitoring subsystem and a data display software package. The atmospheric leak rate for the BPC was established to be < 5% of its volume per day. Extensive microbial sampling and analysis during the wheat studies baselined the microbiological characteristics of the chamber, the atmosphere, and the hydroponic nutrient solutions.

Crop research in the laboratories during the last year has concentrated on the preparation of soybean and potato for inclusion in the BPC. Most of the research on soybean involved tests of two cultivars at various CO_2 levels and studies of irradiance intensities on internode elongation. Our knowledge of soybean growth is almost at a point where this crop is ready for testing in the BPC. Methods to monitor the microbial populations present with these crops were also established during these tests.

In anticipation of the time when a CELSS will be functional in microgravity, a membrane nutrient delivery system was tested with several crops. This system will deliver water and nutrients to the roots of plants in a manner that will prevent loss of the nutrient solution to the surrounding atmosphere in microgravity.

Biomass processing research has thus far concentrated on enzymatic conversion of cellulose to sugar. Some success in this conversion using fungal species as a source of the enzyme was obtained. An integrated aquaculture system with lettuce as the plant component and Tilapia as the fish was operated for over six months. The flow of nitrogen through this system was well documented. Feeding trials with Tilapia were also conducted so that the feeding requirements of this species could be established in hopes that inedible plant biomass could be used.

Food preparation activities included the identification of at least 25 meals that could be generated from six crops. Food processing equipment required for the six primary CELSS crops was also identified.

Waste management research involved a few studies that used water leachate of wheat straw as a fertilizer for growing plants hydroponically. Results suggest that such leachate may supply much of the inorganic elements required for plant growth.

SUMMARY

If humans are to become settlers in space, then a recycling life support system is a prerequisite to the success of such a venture. Through its Life Sciences Division, the NASA continues to support research and development of a CELSS. The BPC is in operation and promises to allow us to evaluate atmospheric and liquid subsystems during plant growth in a sealed environment. When waste and food processing modules are integrated with the biomass production component, we will begin to better understand the mass and energy requirements of a functioning CELSS. A primary product from this project will be conceptual designs for future facilities that will be constructed in the next phase of the CELSS Breadboard Project. This will permit a logical progression in testing a bioregenerative life support system in a complete operating state on the ground, and ultimately in space.

Table 1. Major activities FY 89-93 of the CELSS Breadboard Project, Phase 1.

PROJECT MATRIX

TASK	ACCOMPLISHMENTS				
	FY89	FY90	FY91	FY92	FY93
CROP PRODUCTION	Wheat	Wheat, Soybean	Wheat, Soybean, Potato	Multiple Crops	Continuous Production
WATER RECYCLING	Design	Fabricate And Install	Operate	Modify	Operate
ATMOSPHERIC GAS CONTROL	Measure And Analyze	Design and Fabricate	Install	Operate	Operate
BIOMASS PRODUCTION CHAMBER					
SUPPORT LABORATORIES					
FOOD PROCESSING	Harvest, Store, Measure, Analyze	Establish Laboratory	Process Edible	Process Inedible	Evaluate
WASTE CONVERSION	Store, Measure Analyze	Establish Laboratory	Recycle minerals, Design Combustion System	Install	Evaluate
DATA MANAGEMENT	Environmental Nutrient Delivery, Atmospheric	Energy, Trace gas	Multivarient Analysis	Models	Validate

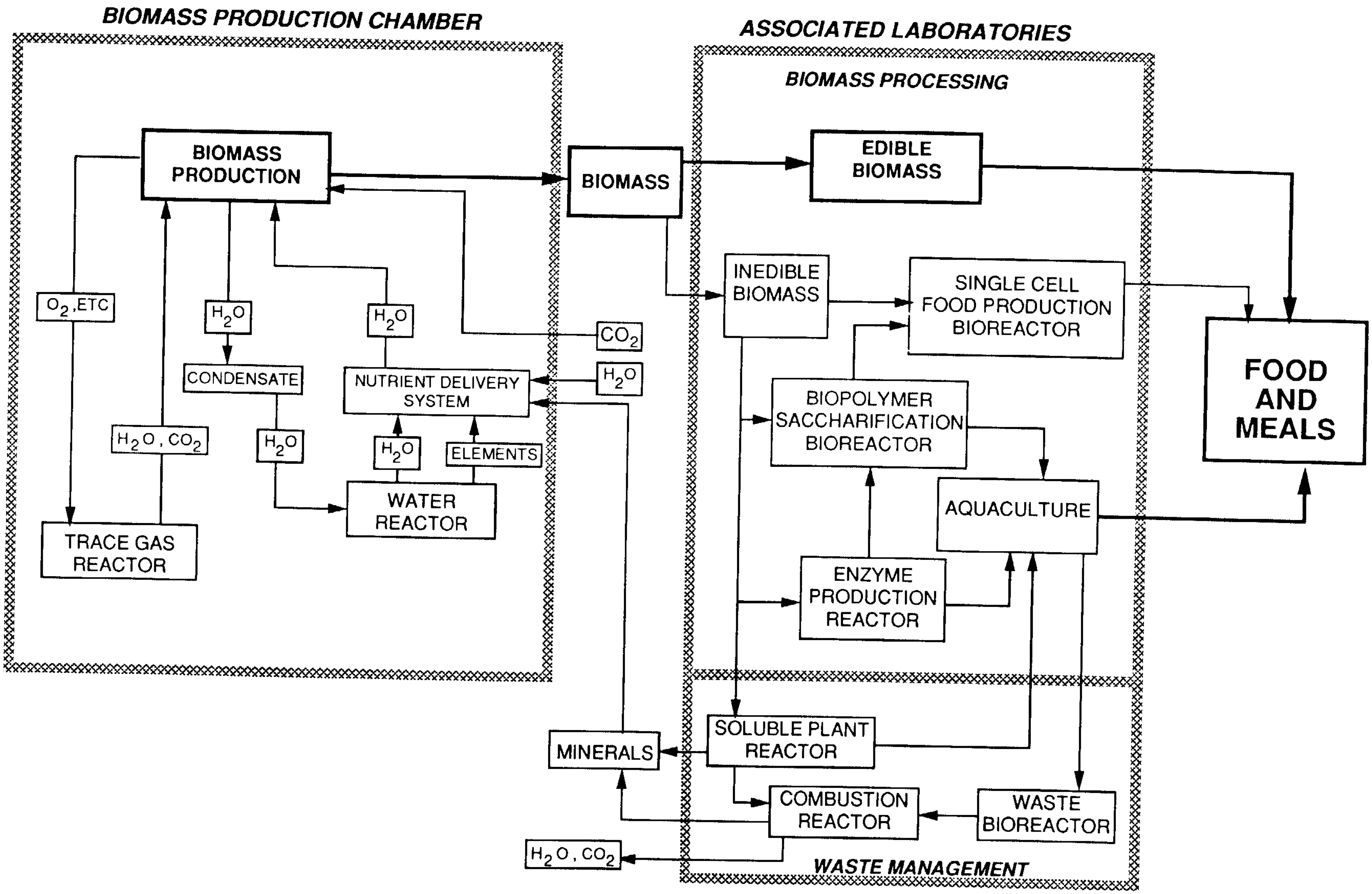

Figure 1. Schematic of the relationship between proposed components in CELSS Breadboard Project, Phase I.