Paper Session III-B - Life Support Research & Development for the Department of Energy Space Exploration Initiative

Charles D. Scott
Oak Ridge National Laboratory

LaMar J. Johnson
Idaho National Engineering Laboratory

William W. Schertz
Argonne National Laboratory

James A. Wise
Pacific Northwest Laboratory

Charles E. Wyman
National Renewable Energy Laboratory

LIFE SUPPORT RESEARCH AND DEVELOPMENT FOR THE DEPARTMENT OF ENERGY SPACE EXPLORATION INITIATIVE

Charles D. Scott, Oak Ridge National Laboratory*
PO Box 2008, Oak Ridge, Tennessee 37831

LaMar J. Johnson, Idaho National Engineering Laboratory,
PO Box 1625, Idaho Falls, Idaho 83415

William W. Schertz, Argonne National Laboratory
9700 South Cass Avenue, Argonne, Illinois 60439

James A. Wise, Pacific Northwest Laboratory
PO Box 999, Richland, Washington 99352

Charles E. Wyman, National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401

ABSTRACT

Long-term, manned space missions of the future will require an approach to life support systems in which most of the waste materials must be processed and recycled and/or local resources are utilized. The requirement for a reliable life support system has been recognized as an important component of the Space Exploration Initiative, and the Department of Energy (DOE), in conjunction with the National Aeronautics and Space Agency, is organizing a program in support of the development of this type of technology. It is quite likely that bioprocesses will be important components of the integrated system, and this will be the primary area of research and development (R&D) within the DOE national laboratories. Microbial, enzymatic, and thermochemical processing of wastes will be investigated in the initial research studies. Other research areas of interest include water and air purification by plants, microbial detection systems, biophotochemical CO_2 recycle, tissue cultures for food, single-cell protein, bioadsorbents for pollutant removal, and several others. The resulting innovative technology developed for space exploration could also serve as the basis for new approaches for the processing and recycle of waste materials on Earth.

INTRODUCTION

The U.S. Space Exploration Initiative (SEI) includes participation of several government agencies, with the National Aeronautics and Space Administration (NASA) having the lead role and DOE and the Department of Defense having important

*Managed by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

support roles.[1] The DOE effort in the SEI will cover several areas including human health/life sciences. An important component of that area is R&D for life support systems. Oak Ridge National Laboratory has been given the lead, in conjunction with four other national laboratories (Argonne National Laboratory, Idaho National Engineering Laboratory, National Renewable Energy Laboratory, and Pacific Northwest Laboratory), to plan and organize an R&D program in support of this activity.

Long-term, manned space missions of the future will require an approach to a closed-loop life support system, sometimes called a Controlled Ecological Life Support System (CELSS), in order to reduce the need for consumables that must be transported from Earth.[2,3] For this concept, most of the waste materials would have to be processed and recycled and/or local resources would have to be utilized for facilities on planetary surfaces. Because this represents a relatively new approach for space applications, a significant research effort will be needed in order to develop the necessary technology. A CELSS can really be considered as a highly integrated physical/chemical/biological processing system that must be very reliable over long periods of time.

Since staff members of the DOE laboratories have a broad expertise in the processing of waste materials, much of the scientific and technical base established in that area would probably provide an important beginning for advanced systems useful for life support. It is quite likely that bioprocesses will be significant components of the integrated systems, and this will be one of the primary areas of R&D within the DOE. The resulting new technology developed for space exploration could also be the basis for exciting new approaches to the solution of terrestrial problems as well, particularly for processing and recycle of waste materials.

CELSS R&D AREAS

The life support system must have provisions for the necessary resources (food, oxygen, water), control of the habitat environment, and processing of the resulting wastes with recycle of as much of this material as possible (Figure 1). This should include purification and recycle of contaminated air and water, conversion and recycle of liquid, gaseous, and solid wastes, and necessary monitoring and control systems. Although technology is available for some of these needs, several required components are not adequately developed and a proven technology for recycling waste materials does not yet exist.

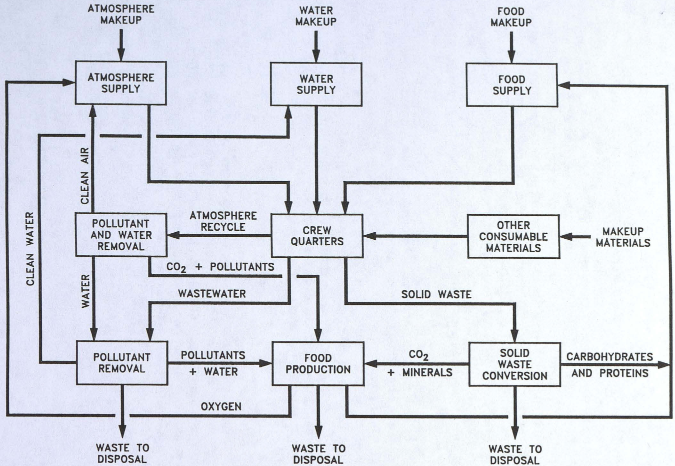

Figure 1. Life Support System with Waste Recycle

Pollutant Removal

Both molecular (CO_2, trace organic compounds, etc.) and particulate pollutants must be removed from the atmospheric gases and from wastewater so that they can be recycled for use. Sorption systems are prime candidates for the removal and recovery of molecular pollutants. Such systems may also serve as reservoirs or holdup for the isolated materials that would subsequently be used for food production. Filtration or centrifugation would probably be the most effective unit operations for particulate removal.

Waste Processing

Perhaps the most challenging tasks will be processing followed by recycle of the generated waste material. In this respect, the solid wastes will represent the most difficult problem.[2,3] Human wastes as well as other consumables and even plant waste, if plants are used for a food source, must be considered.[4] Various combustion methods can be considered for this processing step; however, valuable oxygen is consumed and the resulting products, primarily CO_2, must then be further treated before use. Some bioprocessing steps should also be considered for this application. Anaerobic digestion by mixed microbial cultures could operate without oxygen and produce CO_2 and CH_4. The latter could be a valuable fuel source.

The lignocellulosic fraction of the solid waste could more effectively be converted by the use of enzyme hydrolysis.[5] In that case, a considerable fraction of the product would be sugars that were either fermentable or consumable.

Food Production

Much of the isolated or converted waste material could be used as the feed for food-production processes. Most of the current research in this area is oriented toward the use of plants that utilize the waste material while producing edible fractions. Alternatives to this approach include the growth of single-cell protein by growing certain types of algae and perhaps the use of plant tissue culture, or even the culture of mammalian cells, for the high-density productivity of edible tissues.

Resource Recovery

Planetary surface habitats may be able to utilize sources of oxygen or other consumables that are constituents of rocks or soil. Extraction and recovery processes will be required to take advantage of these resources, but they may allow some of the recycle processes to be effectively used without the requirement of extremely high efficiency.

DEPARTMENT OF ENERGY RESEARCH AREAS

Initially, the major emphasis of the DOE research program at the national laboratories will be on the treatment of solid wastes for ultimate recycle. Ongoing work on the treatment of similar wastes for terrestrial applications will provide the basis for research that should have an early impact in the field. Three primary approaches encompassing a range of possible technologies will be taken: (1) thermochemical processing, (2) anaerobic digestion, and (3) enzymatic conversion.

The DOE laboratories have had extensive experience in the pyrolysis and gasification of biomass materials. Inorganic and hydrocarbon gases, as well as hydrocarbon liquids and a solid residue, are produced. Some of these products could be used as a fuel source, while others could serve as a feed material for plant or microbial processes. Oxidative processes will also be further studied, with the resulting CO_2 being the feed material for food production steps; however, oxygen will be required as a reagent. The previous work in these areas will be most relevant for use on solid waste from space habitats if plant residues make up an important fraction of the waste.

Anaerobic digestion of municipal wastes has been investigated at DOE laboratories for many years. This type of processing system utilizes a mixed culture of microorganisms to degrade carbonaceous wastes primarily into CO_2, CH_4, and H_2O with some solid residue. Much of the solid residue from space applications will be similar to that of municipal wastes. The products of this type of bioprocess would be useful for fuel and for feed materials for food production.

Enzymatic processes utilizing cellulases, hemicellulases, and ligninases have been shown to be effective in hydrolyzing many of the components of similar solid wastes. In this case, the resulting products include sugars that are directly usable as food or as feed material for microbial processes that can produce single-cell protein for food. Thus, much of the accumulated chemical energy in the waste can be directly used in the consumable carbohydrates without having to process it further for an alternative food source.

Other research areas of interest include purification of water and air by plant growth, microbial detection and monitoring systems, biophotochemical processes for CO_2 recycle, production of edible algae as a source of single-cell protein, investigation of plant and mammalian tissue cultures as potential sources of food, and use of inorganic adsorbents and bioadsorbents in fixed-bed contactors to remove trace pollutants from air and water.

The primary function of the DOE national laboratories in life support R&D within the SEI will be to establish a scientific and technical data base for advanced processing options. Thereafter, the national laboratory staffs will work closely with the

NASA staff that has the lead responsibility in this area to incorporate appropriate unit operations into the highly integrated system that will be required for an effective life support system.

REFERENCES

1. Stafford, T. P., Chairman of the Synthesis Group, "America at the Threshold: America's Space Exploration Initiative," Office of the President of the United States, Washington, D.C. (1991).

2. Jet Propulsion Laboratory, Workshop on Closed System Ecology, Summary Report, JPL Publication 82-64, Pasadena, California (1982).

3. Verostko, C. and Packham, N., "NASA Workshop on Resource Recovery from Wastes Generated in Lunar/Mars Controlled Ecological Lift Support Systems (CELSS)" (1991).

4. Wydeven, T. and Golub, M.A., **Waste Manag. Res. 9**, 91 (1991).

5. Petersen, G. R. and L. Baresi, "Advanced Environmental/Thermal Control and Life Support Systems," paper presented at 20th Intersociety Conference on Environmental Systems, Williamsburg, Virginia, July 9-12, 1990; and published as SP-831, p. 89 (1990).