SPACE TECHNOLOGY

LIFE SUPPORT SYSTEMS

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Interdisciplinary Conference
“Sustainable Development of Hot Deserts”

Columbia University

October 31, 2009

WHAT IS A SPACE TECHNOLOGY LIFE SUPPORT SYSTEM?

Life support system is a group of devices that allow a human being to survive in outer space.

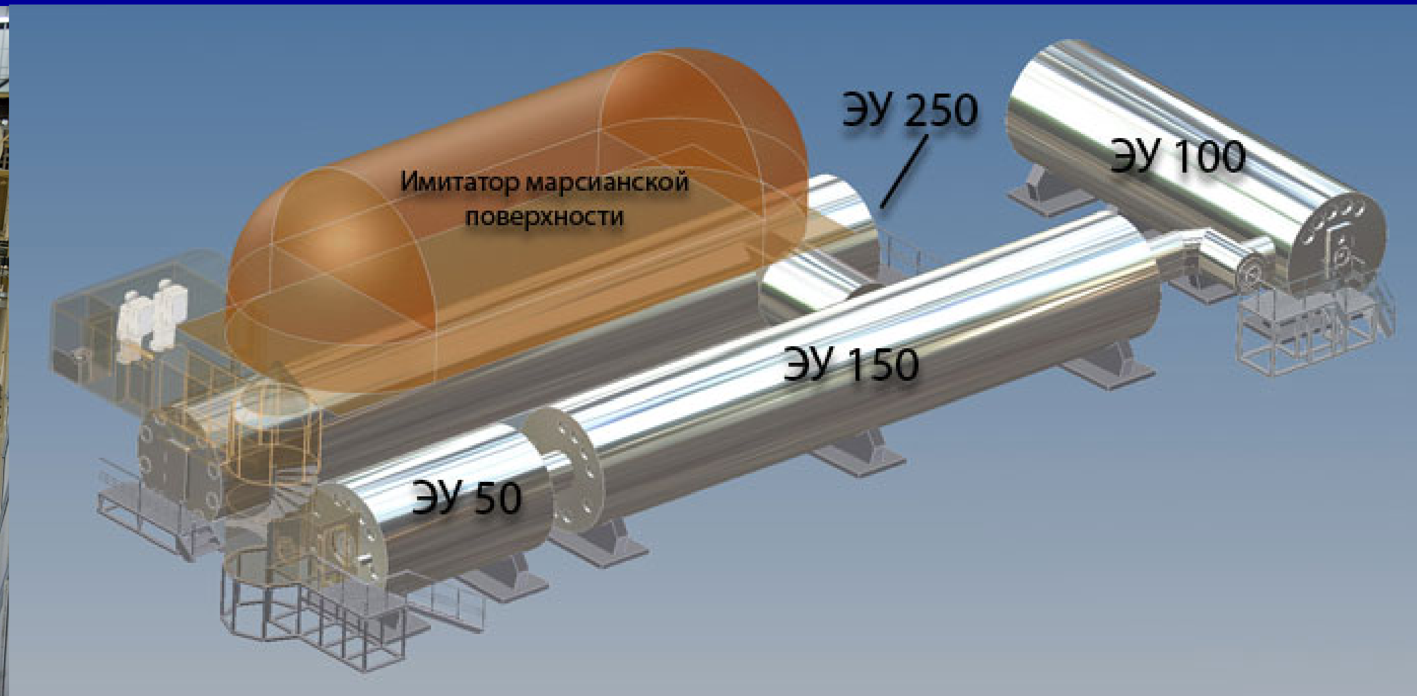
Main goals:

- Supply air, water, and food to crew members
- Remove and recycle human gaseous, liquid, and solid wastes
- Control the climate (temperature, air pressure, etc.)
- Monitor and maintain the health of crew members

Daily human needs: 0.84 kg oxygen, 0.62 kg food, and 3.52 kg water. Daily human wastes: 0.11 kg solid, 3.87 kg liquid, and 1.00 kg carbon dioxide.

Reliable operation of life support systems is critical for the success of space missions, especially long-term, and survival of humans in settlements on other planets.

"MARS 500" GROUND-BASED EXPERIMENTAL FACILITY AT INSTITUTE OF BIOMEDICAL PROBLEMS, MOSCOW, RUSSIA



"Martian surface simulator"
EU-50: Martian landing module
EU-100: Medical and psychological experimental module
EU-150: Human habitat
EU-250: Greenhouse and storage

APPROACHES TO THE DESIGN OF LIFE SUPPORT SYSTEMS

Stocks only

Water, oxygen, and food stocks brought from Earth. Air revitalized by removing carbon dioxide. Additional oxygen produced by electrolysis of humidity condensate.

Stocks along with physicochemical regenerative systems

Oxygen and food stocks brought from Earth. Much reduced water stocks due to water recovery from shower, wash, and kitchen liquid wastes by their physicochemical treatment.

Closed bioregenerative life support systems

Initially, small stocks of water, oxygen, and food stocks brought from Earth. Then, water, oxygen, and food are recycled/produced by biorgenerative systems based on plant/algae growth and biomass composting.

PHYSICOCHEMICAL REGENERATIVE SYSTEMS

Key principles

- Recover water from liquid wastes by adsorption, membrane separation, filtration, evaporation, and other physicochemical methods
- Remove carbon dioxide and trace gases and add oxygen produced by electrolysis of “technical” water

Limitations

- No food and water production
- Relatively high energy consumption
- Service and maintenance difficulties
- No self-restoration

BIOREGENERATIVE LIFE SUPPORT SYSTEMS

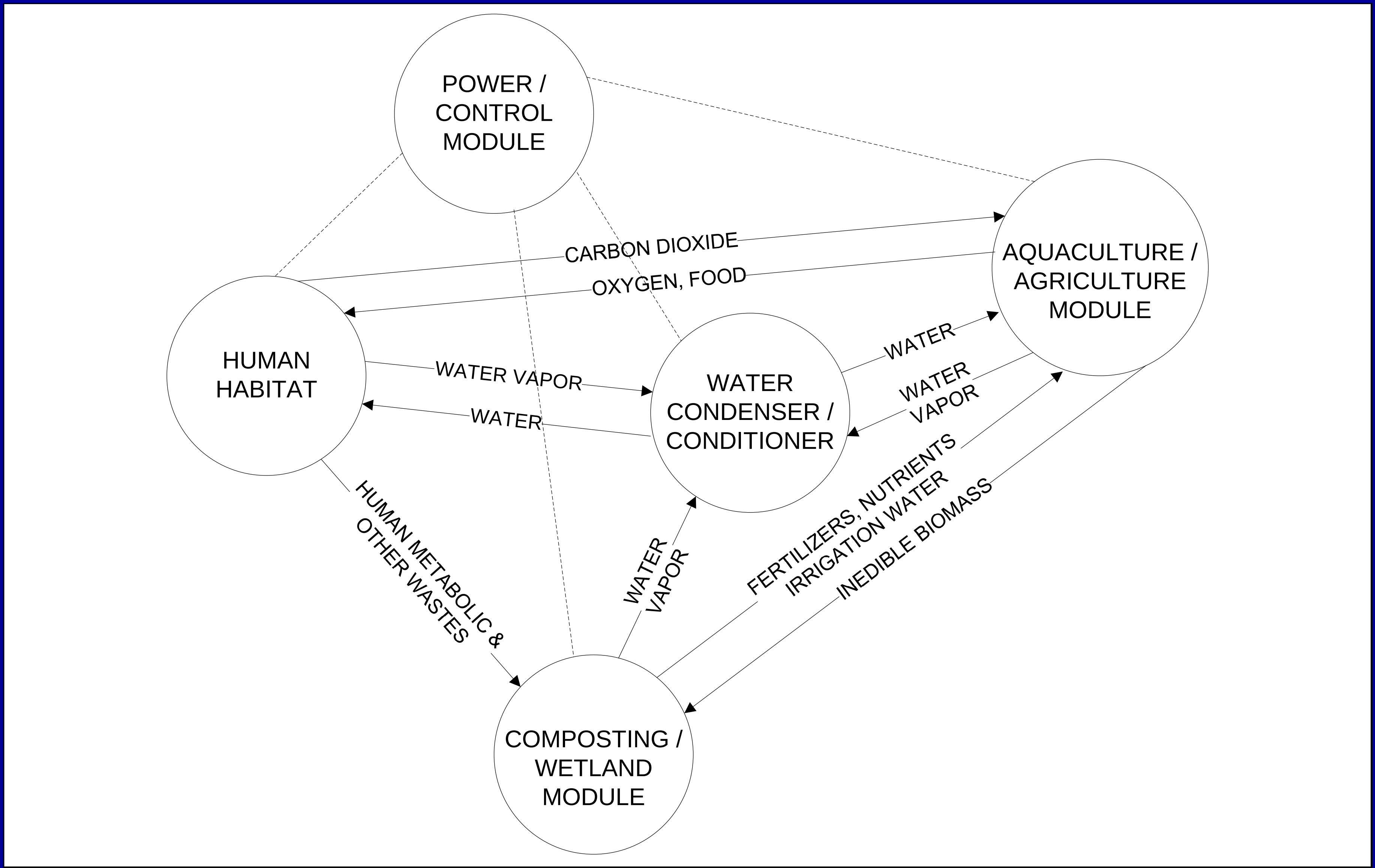
Key principles

- Closed loop for water, oxygen, carbon, and biogenic elements mimicking matter cycles in nature
- Enhanced food and water production due to accelerated carbon cycle with sufficient supply of nutrients
- Self-restoration ability
- Systems approach to production and consumption of water, air, food, and energy

Limitations

- High energy consumption in the absence of direct sunlight
- High surface and volume requirements
- Low adaptability to weightlessness
- Relatively narrow temperature range

PRINCIPAL FLOW DIAGRAM OF CLOSED BIOREGENERATIVE LIFE SUPPORT SYSTEM



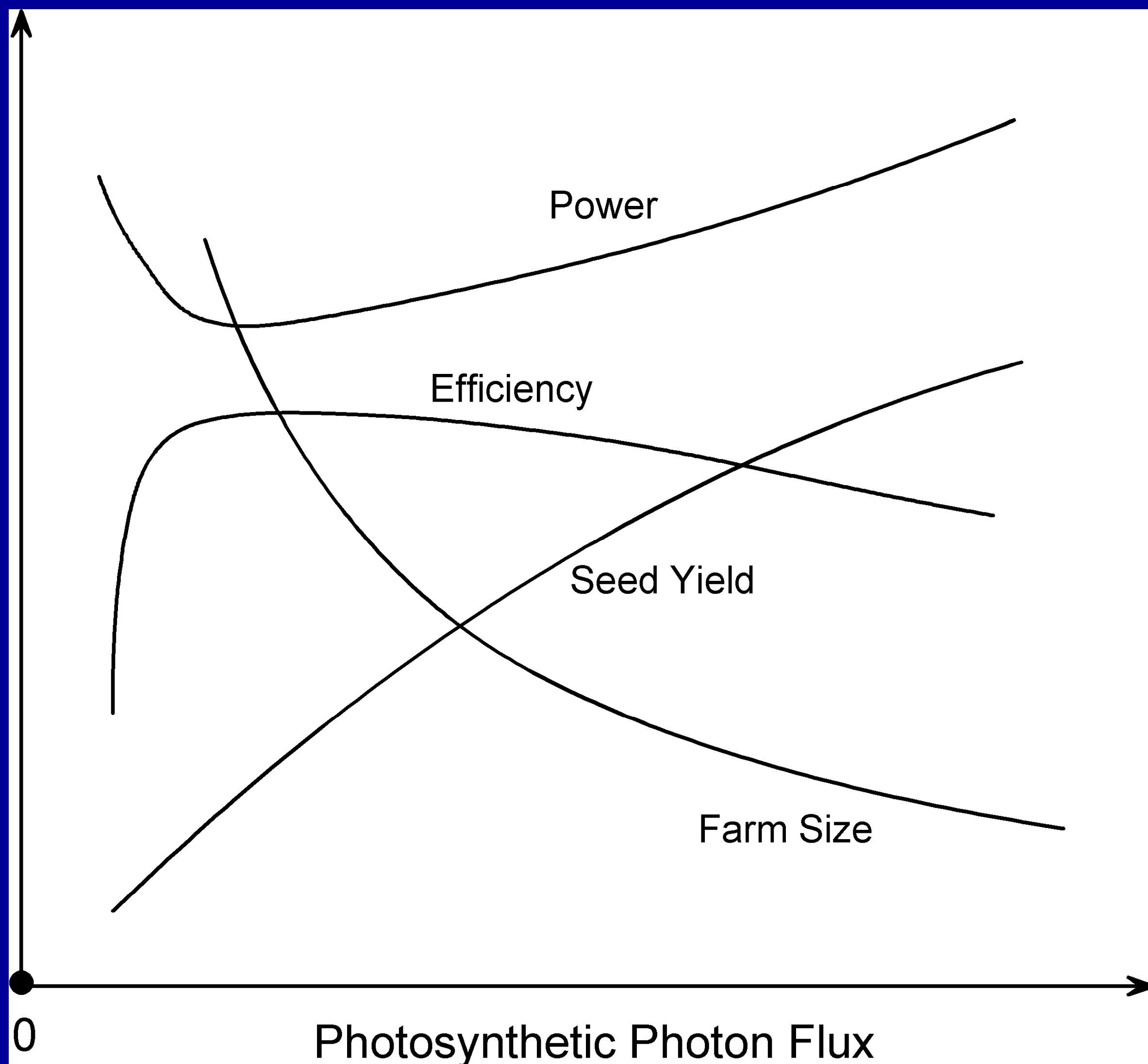
ENHANCED FOOD PRODUCTION BY ACCELERATING CARBON CYCLE

$$\left\{\begin{array}{l}\text{Sunlight}\\ \text{Carbon}\left(CO_2,\text{soil}\right)\\ \text{Nutrients}\left(N,P,S,\text{etc.}\right)\\ \text{Water}\end{array}\right\}\rightarrow\frac{\text{Plant}}{\text{growth}}\rightarrow\left\{\begin{array}{l}\text{Oxygen}\\ \text{Water}\\ \text{Edible biomass}\\ \text{Inedible biomass}\end{array}\right\}$$

Main parameters: light intensity, temperature, carbon dioxide, oxygen and nutrient concentrations, and air velocity over the plant canopy.

Higher plants: wheat, tomato, cucumber, potato, radish, lettuce, soybean, cowpeas, pinto bean, rice, strawberry, and duckweed.

Typical experimental dependence of crop production, efficiency of light usage, resulting farm area, and power on lighting intensity (Nelson et al., 2008)



Estimates of carbon ratios in biomass, soil and atmosphere in the Earth's atmosphere, Biosphere 2 and the Laboratory Biosphere facility and an estimate of carbon cycling time as a consequence (Nelson et al., 2003)

	Earth	Biosphere 2	Laboratory Biosphere
Ratio of biomass C: atmospheric C	1:1 (at 350 ppm CO_2)	100:1 (at 1500 ppm CO_2)	240-700:1 (mature crop to atmosphere at 1500 ppm CO_2)
Ratio of soil C: atmospheric C	2:1	5000:1	1500:1 (atmosphere at 1500 ppm CO_2)
Estimated carbon cycling time (residence in atmosphere)	3 years	1-4 days	0.5-2 days

Efficiency of different growing environments for converting incident photosynthetic photon flux (PPF) into edible food (Bugbee et al., 1989)

Situation	PPF absorption, % (absorbed/ incident)	Photo-synthetic efficiency, % (CO_2 fixed/ absorbed photons)	Respiration efficiency, % (carbon fixed in biomass/ carbon fixed in photosynthesis	Harvest index, % (edible biomass/ total biomass)	Integrated PPF efficiency, %
Theoretical Efficiency	100	33.5	82	100	27.5
Potentially-achievable efficiency	98	18	75	90	11.9
Utah State University CELSS project	90	16	70	44	4.4
World record in field	65	12	63	45	2.2
Typical field	50	8	55	40	0.9

ENHANCED ALGAE GROWTH. WATER PRODUCTION.

Microalgae (chlorella) cultivator with a culture volume of 20 liters can successfully assimilate CO2 and supply water and clean air for one man (Gitelson et al., 2003; 2008).

BIOS-3: closed ecosystem at the Institute of Biophysics in Krasnoyarsk, Russia, 315 m^3 (11,124 cubic feet) with 3-person habitat.

Density of algae in a photo-bioreactor can increase at very high rate - from 0.174 to 4.064 g (dry weight)/L after 7 days growth (Ai et al., 2008).

ENHANCED WASTE AND WASTEWATER TREATMENT

Thermophilic aerobic bacteria composting

Processing temperature up to 100 ^{o}C. 1.5 kg of vegetable wastes can be processed in about 5 hours.

Subsurface flow wetlands

Primary requirements: warm temperatures and lighting. A 4 m^2 wetland area of subsurface flow can serve one full-time resident by removing 85-90% of organic compounds in the wastewater that tie up oxygen; 75-80% of nitrogen and phosphorus, with the coliform bacteria reduced by 99.8% without use of chemicals.

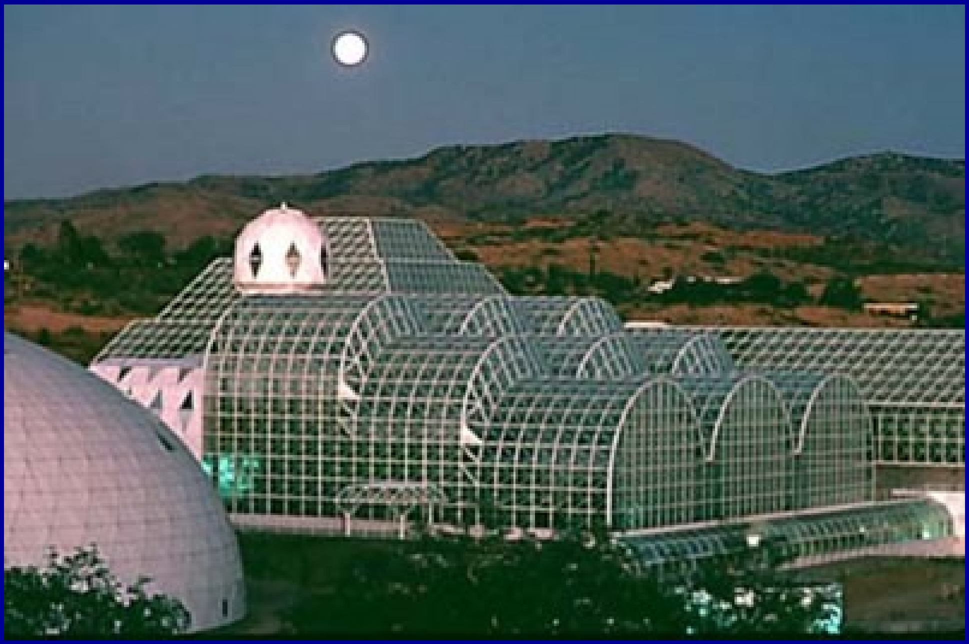
MONITORING AND OPTIMIZATION

Information acquisition, close monitoring, and continuous control are critical for the reliable operation of life support systems.

Key technologies:

- *Machine Vision* takes images and automatically analyzes them for monitoring the health and growth rate of plants
- *Biotronics* uses a hybrid absorption emission spectrometer for making chemical analysis of plant nutrients, on-line microbiological analyzer, ultrasonic microbiological control unit, and signal processing/pattern recognition
- three-dimensional adaptive optimization of crop photosynthetic characteristics

BIOSPHERE 2



Biosphere 2 is a 3.15-acre (12,700 m^2) structure originally built to be a man-made, materially-closed ecological system in Oracle, Arizona. 204,000 m^3 volume. Closed mission: September 26, 1991 to September 26, 1993, 8-men crew.

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