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Historical Overview of the Biosphere 2 Project

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In late 1969, as the moon landing commenced, the Institute of Ecotechnics also started, at first on a very small scale, to work on ecological projects which laid the conceptual foundation for the current Biosphere 2 project. These projects were designed to bring together ecological and scientific knowledge with appropriate technics to design economically viable and ecologically-upgraded total systems in a spectrum of challenging biomes around the world. The Institute of Ecotechnics was motivated to begin this line of research and development because, as Tom Paine noted, we could see that biospherics is one of the key scientific fields we have to master for life to succeed both on and off the planet.

Of course, the space program was an important ingredient in giving a new impetus to biospherics. The Russian scientific tradition is quite interesting in the equal emphasis it gives to Konstantin Tsiolkovsky, a founder of astronautics, and Vladimir Vernadsky, who laid the scientific basis for understanding the biosphere. Tsiolkovsky developed, along with Goddard in our country, the practical foundations of the idea of rocketing into space. Vernadsky pointed out that life itself is a tremendously powerful geological force, far more than the common perception of it as a thin shell surrounding a small planet. He saw life and the biosphere as a cosmic phenomenon, both because it fundamentally depended on cosmic energy coming in — solar radiation — and because it was an immensely powerful force that could transform the surfaces of planets. Vernadsky came to the same conclusion as Tsiolkovsky, namely that biospheres were destined to go into space, outgrowing their planetary cradle here on Earth. By 1969 the famous photographs of the blue planet seen from space had begun to change the way all of us thought and felt about the Earth, leading to a flowering of studies of planetary ecology. G.E. Hutchinson of Yale, who was a great American student of Vernadsky, edited the influential Scientific American volume *The Biosphere* published in 1970. But still many questions remained. How, actually, could you put a conceptual model of Earth's biosphere together, containing and regulating as it does such vast, marvelous and evolving complex systems?

About that same time, in 1968, Clair Folsome, who had consulted to NASA on the origins of life and was Director of the Exobiology Laboratory, University of Hawaii at Manoa, took a complete functional suite of microbes together with their associated aquatic element and an air volume and put them inside a closed laboratory flask in which he could measure the oxygen and carbon dioxide levels, study energy flows and visually observe changes. For the first time there was a closed ecological system object for scientific study. These closed laboratory ecospheres prove to be indefinitely viable and regenerating given an energy input as long as a sufficiently diverse functional complement of microbes is enclosed. The 1968 flask with its living ecosphere is among the collection of Clair's laboratory systems maintained for their historical and continuing research interest in the Space Biospheres Ventures Analytical Laboratory building. Clair, who had served on the Biosphere 2 Project Review Committee since its beginning, died unexpectedly last year. His work and vision continues at our Biospheric Research and Development Center and at many laboratories which continue working on the dynamics of closed ecological systems. Clair's research showed that each of these "worlds" establishes its own gas/water balance and metabolism. This fundamental discovery, reinforced by the findings of Lynn Margulis and other microbiologists, was that the key factor that makes the biosphere work are the microbes. With this discovery in 1968 which was continued by Folsome and other researchers during the 1970s, a vital element in the science now called biospherics was revealed. The work that the Institute of Ecotechnics did during the next decade focussed on the elements of how to make such a created biospheric system. One approach taken was to consider the biological/atmospheric component of man-made biospheres as an apparatus. Biospheric systems increase free energy inside a materially closed apparatus if you have a throughput of energy from outside, as do both the Earth and Biosphere 2. The Second Law of Thermodynamics is not violated because biospheres are not closed systems. Conversely, for analytic purposes, the technospheric unit as a behavioral region, is treated as an "engine" or, fundamentally, an entropy-producing component. If the increase in free energy of the life systems is greater than the entropy of the supporting technics, then basically we would have a biosphere that can continue indefinitely in harmony with its technosphere.

I formulated as a theoretical basis for biospheric systems the following three laws of biospherics, which can be tested in Biosphere 2 and subsequent biospheric systems. They are:

1. The energy passing through the system increases the free energy in the system relative to the entropy during the passage of time.

2. The system uses this free energy to increase its potential to extract a higher rate of free energy during the passage of time out of the incoming energy flux by a) increasing its mass by converting inorganic matter into organic matter, and b) by converting the inorganic matter

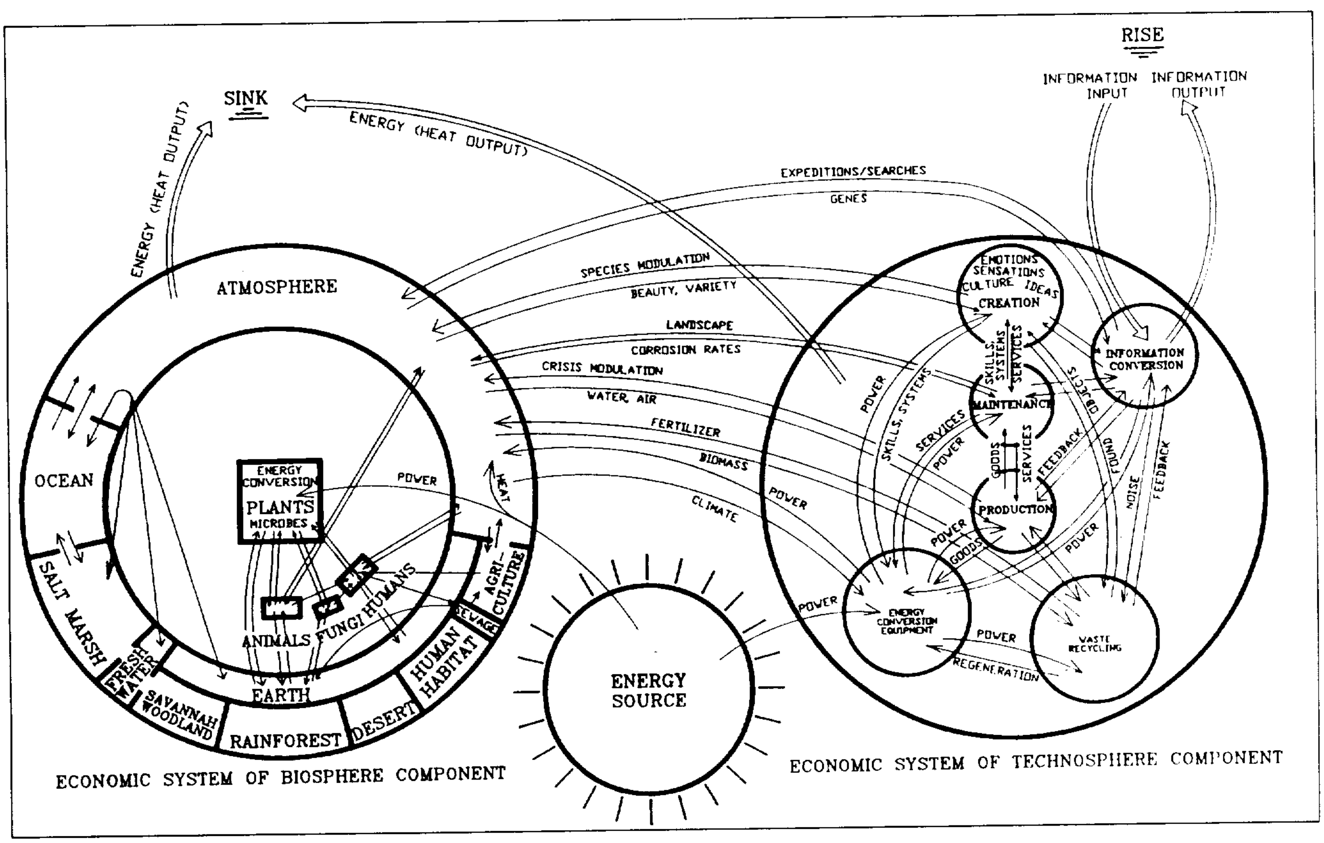

Figure 1. Biosphere/Technosphere Model for Biosphere 2. (Copyright 1986 by Space Biospheres Ventures)

into systems capable of storing more free energy.

3. Information passing through the system obeys the same laws of increasing free energy of the system during the passage of time, and of increasing the system's potential to extract a higher rate of free energy out of the incoming information flow during the passage of time.

Systems which do not obey these laws are inorganic systems or technical systems or failing biospheric systems; that is, the entropy is increased relative to the free energy during the passage of time upon the introduction of a flux of energy through the system.

Perhaps it is fortuitous, but more probably synchronistic, that the information revolution was occurring at the same time that Biosphere 2 was designed. Certainly space exploration, global studies and the creation of a complex system like Biosphere 2 is almost inconceivable without the integration of global electronic communications and the varied powers accessible through computers and computer networks. Besides allowing for an energy sink outside Biosphere 2, we looked for not only an information rise in an artificial biosphere, but an information rise outside Biosphere 2 by making a network of information between researchers inside Biosphere 2 and those in Biosphere 1 (as we have termed the biosphere of Earth). The information sink or noise will be converted to waste heat (erased programs and data) and thus join the energy sink. Information rise produced by converting data and information to knowledge and by evolution of ecological organization in the life systems is another addition to the free energy component of the system (Figure 1).

When the Space Biospheres Ventures team in 1984-5 translated these approaches and the experience gained by the Institute of Ecotechnics and other consultants to the project into a model of Biosphere 2, we came up, via several iterations, with a plan for a seven biomic area, 3.15 acre airtight structure, with an volume of about seven million cubic feet (Figures 2, 3, and Tables 1, 2). To make the necessary calculations, SBV worked out a 12 level hierarchy scheme of ecology. This includes the levels of microbes, multicellular species, populations, food web niche guilds, functional systems, patches, phases, communities, ecosystems, bioregions, biomes and finally, the biosphere. For practical design of artificial biospheres it is especially important how you use the functional ecosystems landscaped or bio-regioned by biomes.

Each of the levels has a different spatial and temporal scale. For example, we know that biospheres can operate on a billion year scale. Biomes operate on a scale that ranges from tens to hundreds of million years. Landscapes are component parts of biomes, and the time/space scaling descends progressively, down to the microbes at the bottom level which can have doubling times as

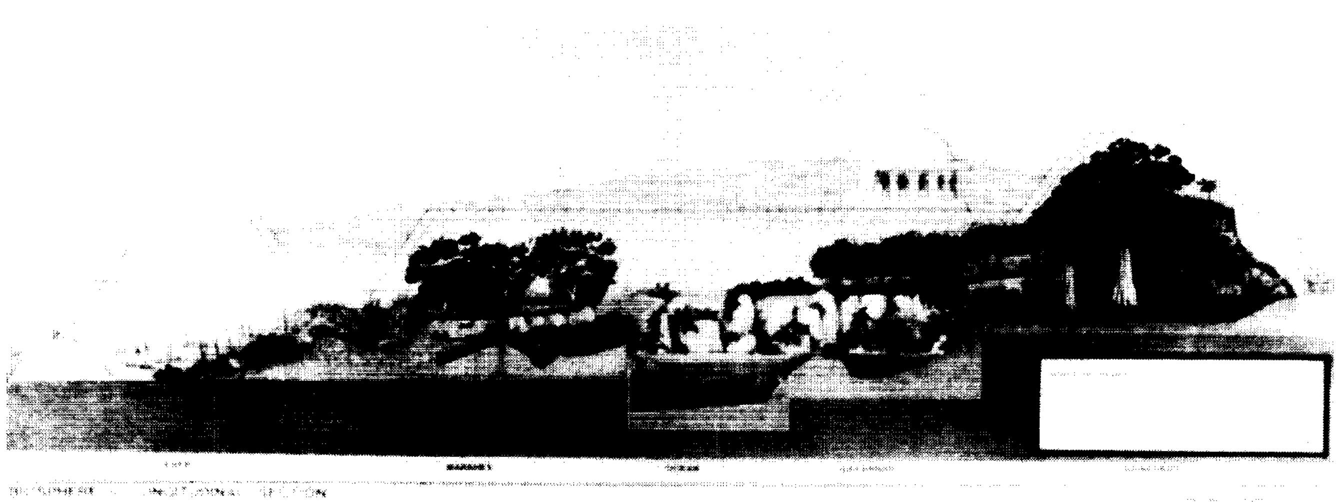

Figure 2. Biosphere 2 longitudinal section showing wilderness biomes, right to left: tropical rainforest, savannah (at top of rock cliffs), marine, marsh, and desert. Section measures 539 feet. (Copyright 1986 by Space Biospheres Ventures)

low as five minutes. In addition to this variety of time scales, there are differing spatial scales to keep in consideration. Biosphere 2 was designed for a minimum hundred year life span. Seven million cubic foot volume is the space scale that (according to our calculations based on mesocosm and Test Module work) is required to set up a situation which all the type phenomena associated with the biosphere might be produced and sustained.

Of course when we start out creating a biosphere today, it is quite different than the origins of our planetary biosphere some 3.8 billion years ago. There are many biologists who contend that the biosphere and the biotic cycle came before specific life forms, that perhaps clay molecules were recycling and building free energy as much as 200 million years before the origin of life. Using the clay as a template, the organic molecules could begin their reproductive processes.

In designing Biosphere 2, the SBV team had to include humankind and technics, besides the naturally occurring biomes. Thus, the work with Biosphere 2 can address the serious issues facing humanity in its relations with the Earth's biosphere, as well as providing valuable baseline data on how such systems operate as a preliminary to their design and creation for space habitation.

SBV had the challenge of developing two forms of intelligence to operate this biosphere/technosphere system. One was using the artificial form of intelligence. For this SBV's Computer Team, headed by Norberto Alvarez-Romo, developed a five level system hierarchy. The five functional levels identified are: 1) point sensing and activation, 2)

Figure 3. Biosphere 2 Floor Plan, showing wilderness biomes at top, human habitat and intensive agriculture biomes at bottom. (Copyright 1986 by Space Biospheres Ventures)

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local data acquisition and control, 3) system supervisory monitoring and control, 4) global monitoring and historical archive, and 5) telecommunications.

In addition, to prepare for Biosphere 2 operations, unique computer software has been developed for the following areas:

a. Atmospheric Carbon Dioxide Modeling and Real-Time Monitoring of Bioregenerative Life Support Systems. This model has been used to simulate and predict carbon dioxide levels for experimentation (including manned closures) in the SBV Test Module and to assist design and engineering calculations for Biosphere 2.

b. Thermodynamic Modeling, Simulation and Real-Time Control in Bioregenerative Life Support Systems. Biospheric systems are open to information and energy exchange with the outer environment. Energy inputs for photosynthesis, electrical power, communications, and heating are required. There is a need to offset external fluctuations and dispose of waste heat. Internal relative humidity and energy efficiency must also be managed. Machinery for heating and cooling air tends to be complex enough to typically require a dedicated human staff for operations, monitoring and maintenance. SBV has developed BIOSYS (a thermodynamic simulation model for closed bioregenerative life support systems) and Real-Time Expert System Applications to reduce the labor required for such functions by integrating simulation and control of internal environmental parameters with computer-driven programs.

c. Global Monitoring of Closed Bioregenerative Life Support Systems. SBV has developed automated monitoring and diagnosis of overall life system status. In addition, an historical archive database combines diverse data sets: environmental, analytical and biological. SBV has created a Bioaccessions Database to inventory and keep a history of all biological introductions into Biosphere 2. Atmospheric and water quality must be monitored not only for real time levels but also for trends and expected behavior. The Global Monitor and Advisor also serves as a repository in which models of bioregenerative and technical processes can be tested in real-time simulations.

BIOSPHERE 2 AREAS	square feet	square meters	acres	hectare
Glass Surface	170,000	15,794	3.90	1.58
Footprints				
Intensive Agriculture	24,020	2,232	.55	.22
Habitat	11,592	1,077	.27	.11
Rainforest	20,449	1,900	.47	.19
Savannah/ocean	27,500	2,555	.63	.26
Desert	14,641	1,360	.34	.14
West Lung (airtight portion)	19,607	1,822	.45	.18
South Lung (airtight portion)	19,607	1,822	.45	.18
TOTAL Airtight Footprint	**137,416**	**12,766**	**3.15**	**1.28**
Energy Center	30,000	2,787	.69	.28
West Lung (weathercover dome)	25,447	2,364	.58	.24
South Lung (weathercover dome)	25,447	2,364	.58	.24
Ocean Water Surface Area	7,345	682	.17	.07
Marsh Surface Area	4,303	400	.10	.04

BIOSPHERE 2 VOLUMES	cubic feet	cubic meters
Intensive Agriculture	1,336,012	37,832
Habitat	377,055	10,677
Rainforest	1,225,053	34,690
Savannah/Marsh/Marine	1,718,672	48,668
Desert	778,399	22,042
Lungs (at Maximum)	1,770,546	50,137
TOTAL	**7,205,737**	**204,045**

Table 1. Areas and Volumes of Biosphere 2.

d. Nutrition Diet Planning and Crop Production Scheduling. Within a closed ecological system, space and facilities for providing adequate nutrients for humans is limited. The aim of the system is to provide a schedule for planting crops so that each harvest yields an appropriate quantity and combination of foods for optimal daily nutrition.

In addition to this computer/technical system, we trained the biospherian crew in ecological/naturalist observation. This is colorfully phrased by E.O. Wilson of Harvard as "the naturalist trance". In this particular state of attention, the scientific observer can begin to take in the totality of the life events occurring around him, and receive insights into its mechanisms and patterns.

SBV works with this parallel structure during training of the Biosphere 2 crew so that they can work as naturalist observers as well as with the artificial intelligence system. The control system is designed where there could be a human intervention at each stage of the computer hierarchy. The analytic/computer system can sound alarms and intervene if it discerns dangerous trends or conditions before the human observers do. The data from Biosphere 2 will be networked in real-time with scientific institutions which consult to SBV and to others in related fields. This will be important for research purposes and to also help detect incipient problems. It is inevitable, of course, that both the human being and the computing systems can give the wrong data/or reach false conclusions. Building this "binocular vision" of naturalist observation and artificial intelligence into the operation of Biosphere 2 increases the likelihood that at least one eye, hopefully, is working properly to monitor and manage the system, or if both should fail, that recovery will be quicker.

	HIGH		LOW	
	Celsius	Fahr	Celsius	Fahr
Rainforest	35	95	13	55
Savannah	38	100	13	55
Desert	43	110	2	35
Intensive Agriculture	30	85	13	55

Table 2. Biosphere 2 Temperature Ranges

We had to revise our approach to the entire technosphere as we encounter it in the world today because the technosphere inherited from the Industrial Revolution, which began when the world had less than a billion people, is polluting the entire life environment in Biosphere 1. In Biosphere 1, though, the buffers or surge tanks or reserve capacities are so great that the time it takes for these impacts to reach the politically effective majority of human beings is quite long after they commence. In Biosphere 2 cycling times are faster and buffers much smaller. We cannot afford to have environmentally damaging technics in the system at all. (Neither can Biosphere I for much longer.) So SBV had to do quite a bit of work developing a technosphere which could give backup support to Biosphere 2 without polluting it. The challenge was to develop technical systems that would be adequate to the 21st century space exploration that Dr. Paine has described,while maintaining and helping better manage a healthy planet Earth biosphere.

The design of the cross-section of Biosphere 2 connecting Earth and Mars was the first logo of Space Biospheres Venture. *Logos*, I understand in its root meaning, denotes the structure of effective reason, and the structure of our effective reason was that biospheres constitute an essential component of living permanently in space. This is what our destiny, our adventure and our future in space requires.

Why did we pick Mars? Our conclusion came out of many of the same factors that persuade many other space scientists and thinkers who see the enormous potentiality of Mars. We discussed options with a number of people, the astrogeologists, astronauts, biologists and many other people with quite a profound interest in space. We could, of course, have started out and said let's first make a prototype for microgravity, let's use an opaque system and make, not a full biosphere, but a small ecosphere, with only an agricultural/atmosphere-regenerating life system. But we reasoned (and had many friends, astronauts, cosmonauts, astrogeologists, concur) that the objective, at once so doable that it would catch the imagination of humanity sufficiently to unlock the necessary resources, would be to set as a goal the settlement of Mars. SBV began the Biosphere 2 project with the idea that it would be directly sunlight-driven, modeled such that we would get valuable ecological knowledge for the Earth as well as developing further our conception of a well-developed Mars habitation base.

By 1987, Space Biospheres Ventures felt that we should have even broader scale discussions and interchange with the international community interested in closed ecological systems. We invited space life scientists from NASA, ESA, the Soviet space program, leading ecologists and scientists like Howard T. Odum, Ramon Margalef, Walter Orr Roberts, pioneers in the field like Clair Folsome, Ganna Meleshka (Institute of Biomedical Problems, Moscow) and Josef Gitelson (Bios-3 Project, Institute of Biophysics, Krasnoyarsk) to participate in an international workshop on closed ecological systems at the Royal Society in London. In September, 1989, the second international closed systems workshop was held in Krasnoyarsk, Siberia, co-sponsored by the Institute of Biophysics (IBP), Institute of Ecotechnics and SBV. Gitelson, the director of IBP had told us this meeting would coincide with a major new step in *glasnost* that was going to be opening up Krasnoyarsk to travel from the outside and to the international scientific community. Indeed there was an almost incredible openness in the workshop, remarkable not only because so many of the Soviet scientists had studied English so that it could be the official language of the meeting, but because a free and full examination of the Bios-3 closed system facility where the most advanced Soviet closed system work has been conducted was allowed. We had previously opened the Biosphere 2 site to our Russian colleagues.

At the Krasnoyarsk meeting, the participants issued a resolution recommending that the name "Biospherics" be used for the scientific discipline which studies, creates and manages closed ecological systems. These include CELSS-type sys-

Figure 4. The SBV Biospheric Research and Development Center at the Biosphere 2 Project.

tems, "ecosphere" closed objects that have one ecosystem, and biospheric closed objects that have two or more ecosystems with ecotone interaction, both small man-made (Biosphere 2 and its successors on Earth and elsewhere) and large natural biospheres (the Earth's).

In 1986 SBV constructed the Biosphere 2 Test Module, designed for two purposes. One was to check out the sealing and structural engineering planned for Biosphere 2. The second was to be a testbed for research in the operation of closed ecological systems. We calculated that in its volume, and using mainly sunlight levels of energy, we could design life and technical systems to support one human being within an ecosystem. There has been closed life system research in the Test Module since the end of 1986, included three, five and 21 day human closure experiments.

One of the major problems in building Biosphere 2 was — and there were a number of problems! — there was no research facility that we could subcontract to conduct a lot of the preliminary investigations. So we had to build an entire research facility called the Biospheric Research and Design Center (BRDC) at the project site (Figure 4). This facility includes computer laboratory, plant tissue culture and analytical chemistry laboratories, insectary, and plant quarantine facilities in addition to the Test Module prototype and agricultural/ aquaculture greenhouses to develop cropping systems and techniques (Figures 5, 6). The work at BRDC accelerated the design and logistics of the Biosphere 2 project. In addition, research was conducted by the many research scientists, engineers and institutions consulting to Space Biospheres Ventures. Since there were not any existing research institutes focussed specifically on biospherics and the creation of closed ecological systems, SBV faced at least some of the problems that NASA faced in selecting an astronaut corps at the

Figure 5. Biosphere 2 prototype agricultural system.

beginning of the space age. The Institute of Ecotechnics' contributed in this regard, as a consultant to SBV, by recommending people and institutions whose work was known by the Institute of Ecotechnics through its conferences and field projects consultancies over a number of years. At present, SBV is moving ahead quite rapidly and simultaneously in research and development, systems design and architecture, construction and quality control, and biospheric training programs. Such biospheric systems and the mastery of closed life systems are needed to open the road along with astronautics to widen the horizons of life in space.

The Biosphere 2 time scale calls for completion and closure for the first two year experiment in the fall of 1990 (Figures 7, 8). At that time, we will begin work on opaque systems research using the biospherics expertise gained in the Test Module and Biosphere 2. These opaque life systems will be oriented towards space station, lunar base and extended planetary mission use; that is, towards

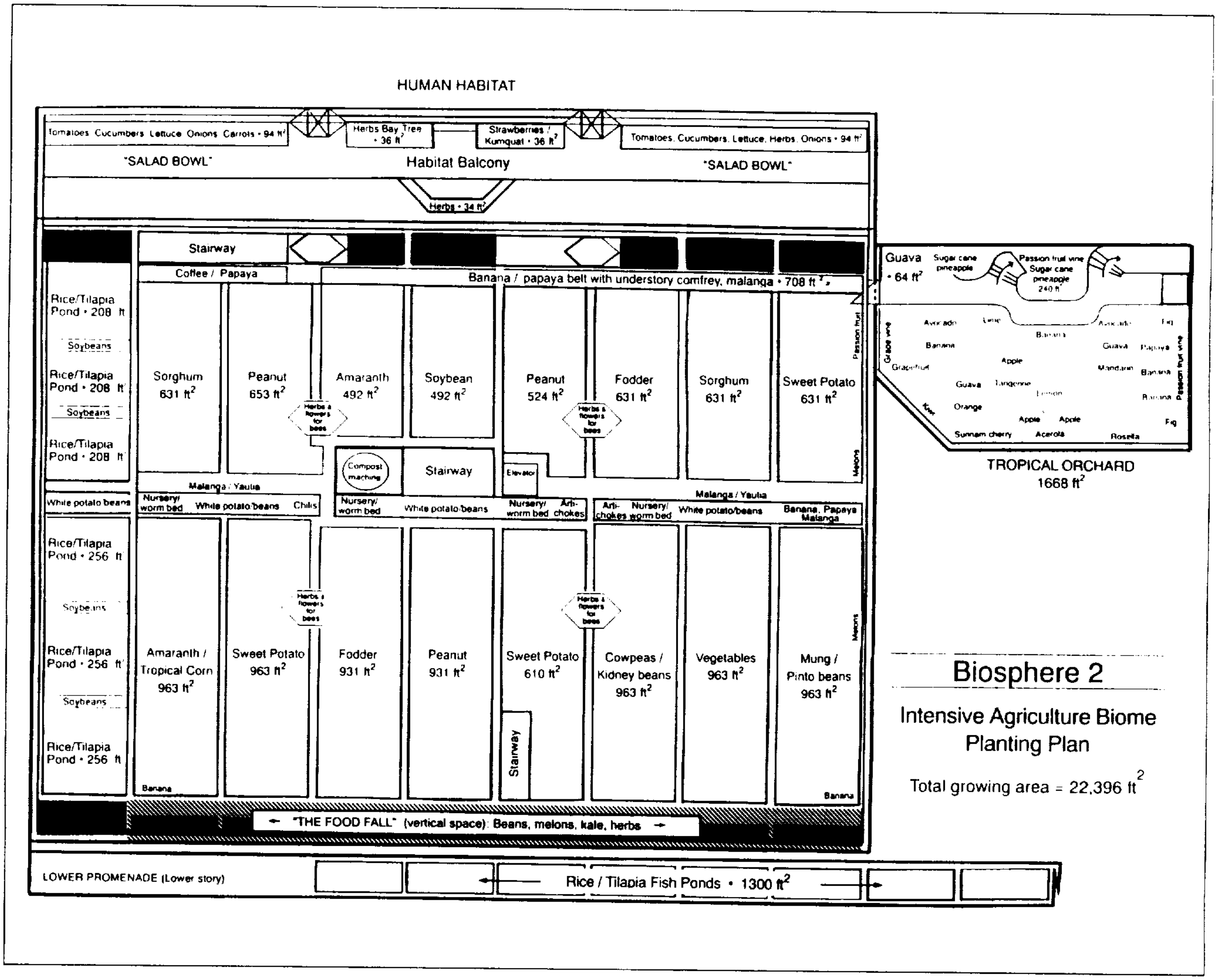

Figure 6. Biosphere 2 Intensive Agriculture Planting Plan. Plant growing area is increased by use of vertical surfaces which border on technospheric areas not requiring sunlight, and use of the portion of sloped lower story which receives full sunlight. A two-year plant cropping scheme designates harvest and planting schedules, rotation of crops, and recycling activities over the initial manned closure experiment to acheive human and domestic animal nutrient requirements and maintain soil fertility. Planting plans vary according to season of the year. (Copyright 1989 by Space Biospheres Ventures)

space applications that are relatively near-term. We would then look at the testing and deployment of such life systems in microgravity. Space Biospheres Ventures has a small investment in the External Tanks Corporation, and is negotiating joint ventures with several companies, American and foreign, who are working in these space application fields. Space Biospheres Ventures is also a founding corporate member of the International Space University, and has helped organize workshops on closed ecological systems at the last two conferences of the Space Studies Institute in Princeton. When we commenced the design and construction phase of SBV in December 1984 SBV targeted the early 1990's as when we wanted to be ready with closed systems because we considered the mid-1990's would see the operation of the microgravity space stations. By 1992 we think SBV will be ready to produce ecosystem modules for microgravity and initial lunar deployment.

The financing of Biosphere 2 may be of interest to NASA and others here from universities and private corporations. All space-related work to date has had tremendous commercial spinoff and so SBV decided to finance Biosphere 2 by venture capital. SBV anticipates the spinoff from commercial applications of biospherics on air, soil and water pollution control, environmental control, software systems for monitoring and management of complex systems in addition to the education and training programs that will come out of Biosphere 2 will provide very good returns on investment.

On behalf of SBV, I want to welcome all of you to the Biosphere 2 Project. We hope that good relationships and interchange occur during the workshop which can continue into the future. We

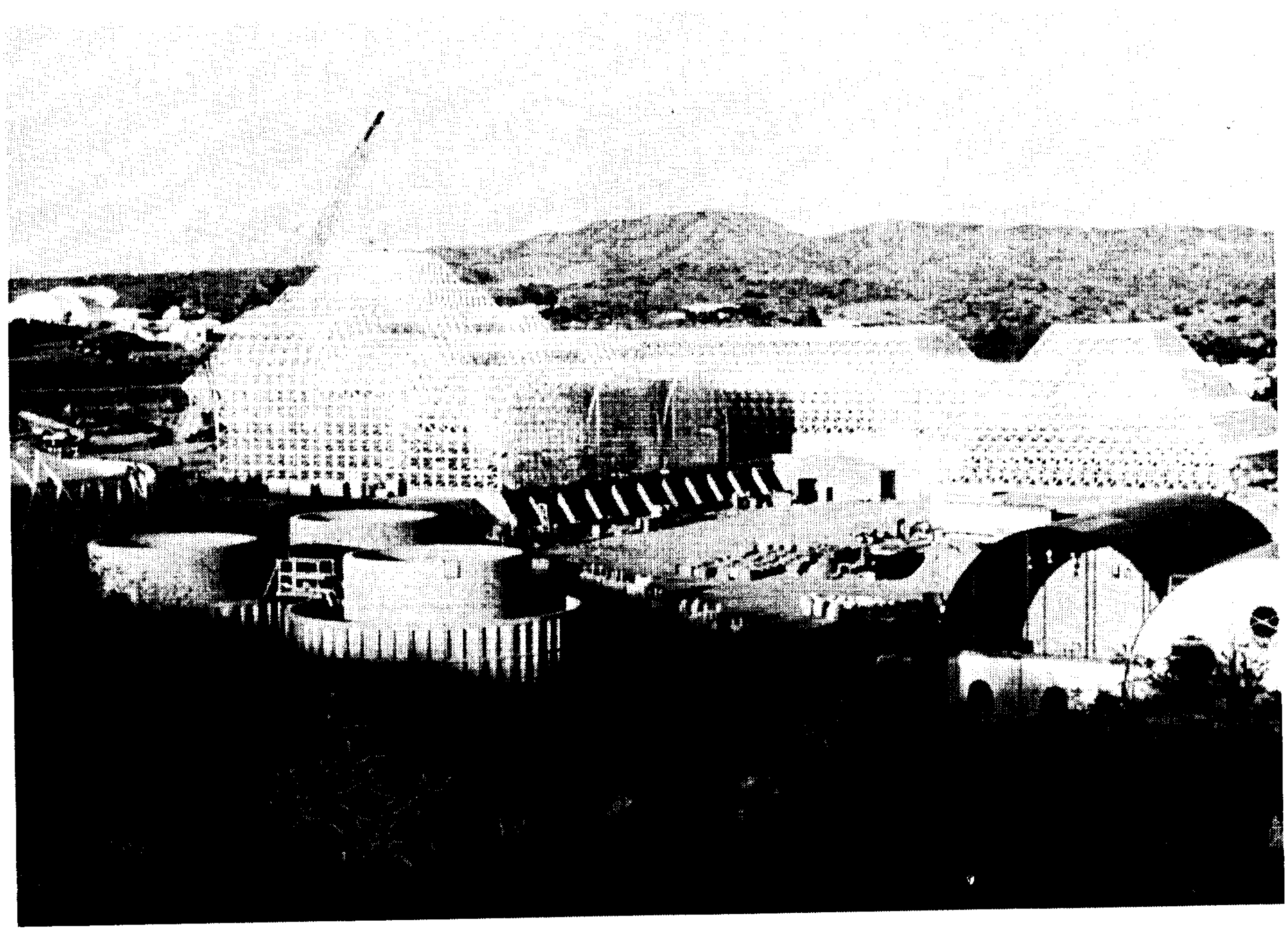

Figure 7. Biosphere 2 under construction, exterior view.

know that the action of everyone here is extremely important for the space and Earth objectives that are becoming possible. At this workshop are represented university, governmental and private industry research and application groups. We think that the cooperation of these different kinds of human institutions is going to be just as necessary as the working together of different peoples or scientific fields. An extraordinary range of efforts by individuals and institutions is needed to make this transition into our solar system home, humanity's first great step to the stellar world.

Figure 8. Biosphere 2 wilderness biomes under construction, interior view. Savannah at right; marsh biome upper left, marine biome lower left.