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## Economic Opportunities of Space Enterprise in the Next Decades

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ECONOMIC OPPORTUNITIES OF SPACE ENTERPRISE  
IN THE NEXT DECADES

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ABSTRACT

At this juncture of the United States Space Program a major opportunity exists to give a new impetus to space applications (and space sciences) for the next two decades. It involves a redirection of the U.S. Space Program from an emphasis of means to one emphasizing scientific and economic application goals of space technology. This opportunity comes about with the successful deployment of the Space Shuttle System in the early 1980s. Four topics are emphasized: 1) The Development of Global Information Systems; 2) Large Space Structures Applications; 3) Space as an Energy Base for Mankind; and 4) Likely Phases of Space Application Development.

1. Global Information Systems

Space applications in the sixties and seventies were nearly exclusively one of data gathering, transmission, and data processing and evaluation to provide information. This is the case in the areas of national security as well as civilian space applications. This substantial thrust of the United States as well as worldwide space programs will be continued in the 1980s and 1990s, and well into the twenty first century. One has to realize that a substantial part of today's economic activities in the United States as well as worldwide have to do with the collection of information, the transmission of information and the evaluation of information. Dr. Fritz Machlup has estimated as early as 1960 that up to twenty, possibly thirty percent of all economic activities in the U.S. economy have to do with the collection, storage and transfer of information: in addition to the obvious information activities Machlup also includes education, library functions, data evaluation, research activities, the postal service, and other less-obvious information related activities of the U.S. economy. The revolution that the space program has already brought to the information industry, both domestic as well as worldwide, is so deep, that we all too often forget entirely about it. For just one example, a famine due to drought in some developing country today affects the compassion of a worldwide community, where twenty years ago and certainly a hundred years ago such events may have gone totally unnoticed. Or, more recently, the exchange of views between Middle Eastern countries, while not possible across the immediate frontiers, somehow was triggered, for better or worse, through space telecommunications linkups with United States reporters.

In the national security area it may be close to impossible to estimate the magnitude of the contribution of having objective, strategic information

on adversaries, yet this mutual knowledge more than anything else had a greater effect on mutual defense expenditures, leading gradually to a process of negotiations and accommodations. On the other side, where such objective information may become once again not available (say due to sophisticated evasion) such developments could prove to be extremely destabilizing.

Despite these impressive developments of the early 60's and 70's the next two decades will see an order of magnitude larger expansion of the role of space systems in the information era: the gathering of worldwide resources information, environmental information, climate and weather will make it possible, for the first time, to establish a quantitative base on which to research and husband natural resources regionally and worldwide. To mention but one item of crucial importance: the shift of the United States, as well as other energy economies to the increased use of coal will have a significant impact on the generation of CO<sub>2</sub>(1). Already the uses of fossil fuels in this century has led to local measurements that seem to indicate a long term, secular trend of increased levels of CO<sub>2</sub> worldwide. However, to truly assess the potential magnitude of this CO<sub>2</sub> problem, information on agricultural activities, rain forest, and a multitude of other biological processes worldwide is needed: these measurements of CO<sub>2</sub> conversion activities and how they impinge human activities are today just simple guess work, rather than statements based on global measurements. The LANDSAT system and other supportive space systems will make the measurement of biological CO<sub>2</sub> conversion activities possible on a worldwide scale.

The pressure for directly measurable benefits to justify the expenditures of public funds is strong, and indeed I believe NASA and the national space program have nothing to fear from the insistence upon such accountability. In Table 1 a summary of but three areas contributing to the establishment of a global information system, (the ones that technologically are well into the development stage) are listed. Only benefits for which reasonable, sometimes rather complex, detailed estimates exist have been listed. In but two areas, Land Resources and Ocean Observations, information benefits of the type that LANDSAT/LACIE and SEASAT will be capable of by the early to mid 1980s are listed. The benefits for Land Resources information are estimated roughly from half a billion to one billion dollars a year. These are benefits accruing to the United States only, i.e., do not include benefits that

might accrue to other nations by access to these United States systems. For Ocean Observations (SEASAT) a joint cooperative venture between industry and government is coming about, where industry will finance economic experiments in cooperation with NASA. Similar economic verification experiments on the use of weather information using space systems are currently being constructed in a cooperative enterprise on frost warnings for citrus crops in Florida.

For civilian space communications worldwide investment numbers are listed. Total market investments made into civilian space communications are estimated by us to be about one billion dollars as of 1976, with total annual systems revenues of about \$500 million. For the mid-1980s, even without the establishment of large structure antenna, we estimate this investment to increase to about \$500 billion, with annual revenues of between \$1.5 to \$2 billion. The investment listed under civilian space communications include total worldwide investments, excluding communist countries.

The listed programs are first stepping stones to the establishment of truly global information systems, involving the active collection of worldwide information as well as the transmission and the processing of that information.

Most of the information benefits gathered by observation satellites are public information benefits. The best analogy is the information services currently provided by the Department of Agriculture on domestic as well as worldwide crop information. It would be self-defeating -- if not discriminatory -- to restrict such global information to just a few users who might be able to afford to pay for the full costs of such information systems. Total system cost recovery in pricing such services would be inefficient as well. The public good aspect of information of the type gathered on earth resources, the environment, and ocean observations has long been recognized by knowledgeable economists. Kenneth Arrow made sweeping statements about the relationship between information and the public good as early as 1962. Yet, in the case of space observation systems the Office of Management and Budget seems to have somewhat ambivalent ideas along the lines that if indeed these benefits exist the private market should be able to bring these about ("capture them"). Combined with this seems to be the notion that the single role of the federal government is to "safeguard" -- i.e., obstruct -- the exploitation of space based information by private interests, which invariably would happen if a consortium for example of major grain trading companies were to put up such information systems for their exclusive use. The Space Act of 1958 gives rise to an additional fault: it excludes by statute NASA to be an operationally useful agency in space applications by excluding that agency from implementing or operating such systems. This contrasts sharply with the situation in the Departments of Agriculture and Defense, to mention but two other institutions.

What I am trying to say is that the bottlenecks to a full development of global space information systems is not the lack of benefits to the nation from such

systems -- if well managed -- but a serious lack of institutional and entrepreneurial spirit that needs new, inspired initiatives by government and private enterprises.

The establishment of such global information gathering systems and the worldwide distribution of this information to all participating countries will be a singular significant achievement, possibly equal in scope to the role of space information in the national security area.

## 2. The Large Structures Capability

The Space Shuttle system will make possible the deployment of "large structures" in space. Large structures would comprise all space applications or space science payloads that in dimension (length, width, volume) or mass clearly exceed capabilities of existing rocket launch systems. Some such structures ultimately envision the deployment of tens of square miles of antennae and solar arrays late this century or early next century. The assembly of such structures will occur in low earth orbit. The Space Shuttle being a reusable space transportation system to that orbit will open up to the United States the capability to deploy such structures in the 80's and 90's.

The in-orbit check out capability, the revisit and repair functions, as well as the ability to refurbish large structures (power, fuel, instrument packages, degraded subsystems) for the first time allows the achievement of reliability levels of operational space systems that are necessary before large investments can be made either by the government or by industry. Today reliability of operational space systems still is only in the neighborhood of 95 percent in terms of assured in-orbit functioning of spacecraft. With revisit capabilities in earth orbit the United States will not have to risk a whole program like Skylab due to the malfunctioning of one or two minor items. Similarly, one cannot expect significant industry investment in space applications where single mode failures during launch could destroy investments and payloads worth several hundreds of millions of dollars. If reliability levels can be raised to 99 percent or more, space application systems will be competitive with investments in technical systems on the ground at reasonable, competitive costs.

Large space structures will first bring about a further significant revolution in information related space activities: the collection, the in-orbit processing and the distribution of information back to earth. While today the uses of space communications are limited to performing subsidiary functions in an extensive ground communication system, in the 1980s and 1990s a gradual shift to space investments will occur, right down to household to household communications for a diffuse, wide variety of communication and information needs. Large scale antennas, deployed for scientific uses looking outwards, will promise order of magnitude expansions of our understanding in astronomy and of the universe.

While today's space communications involve annual industrial budgets of at most a few hundred million dollars per year, the investment for conventional telecommunications on the ground is orders of magnitude larger: the gross asset value of a single company, AT&T, exceeds \$100 billion, with a further requirement by the same company to make a similar magnitude of additional investments over the next decade for communication needs in the 80's; i.e., about \$10 billion a year. By comparison space communications, however important and significant with regard to improving worldwide and domestic communications today, are only a fraction of that amount (2): the total world's investment in communications satellites and Earth stations exceeds \$1 billion and annual revenues exceed \$550 million as of early 1977. However, with the advent of large space structures some of the functions now performed tediously on the ground can be shifted to space-based operations, but only if maintainability, assured operation, inspection and repair capabilities indeed exist for such expensive ventures and investments. With large structures this breakthrough indeed will come in the 1980s, with a considerable push needed by the federal government to indeed "drag along" a highly regulated, oligopolistic (if not monopolistic) ground-based telecommunications industry. These large space-based systems may significantly enlarge the competitive character in telecommunications industry, possibly leading to a total revolution of this industry. Space communications efforts to date indeed have been highly competitive when compared to the structure and regulation of ground-based communications industry.

Similar order of magnitude advances can be expected in the gathering of information on such items as world crops, water flows and resources, uses of environmental and natural resources, and global impacts of fossil fuel users, e.g., CO<sub>2</sub> effects mentioned in an earlier section.

Two spinoffs, or side products, of the large structures phase in space applications and space sciences will be (a) the disappearance of the juxtaposition of manned versus unmanned space activities that characterize so many of the discussions of the fifties and sixties. The assembly and maintenance of large structures will involve some degree of manned operations in space; the exact level of such activities will be determined case by case and program by program based on considerations of efficiency and cost effectiveness.

(b) The experience gained in the assembly and maintenance of large structures in earth orbit through the 80's and 90's will be an important stepping stone to the establishment of space power systems, an experience which is necessary, although not sufficient, to establish the economic viability of space as an energy source for mankind.

### 3. Space As An Energy Base

In the remainder of this century and certainly in the years of the 21st century the viability of space as an efficient, clean and close to inexhaustible energy source for mankind will have been established.

It is too early to tell whether remaining environmental, and technical problems can be resolved, at economic costs, to make such investments feasible. The fact, however, is that compared to all known fossil fuel resources on earth, the latter represent about 10 times the daily solar energy that impacts earth: Earth's daily receipt of solar energy is about  $1.49 \times 10^{22}$  Joules (i.e., a large number), the total estimated world fossil fuel resources, accumulated over millions of years, are about 10 times that ( $8 \times 10^{12}$  metric tons of coal equivalent). Any area of similar size located at 1 AU (orbit of the Earth around the sun) has a similar energy collection potential.

It is very difficult to project over time spans even as long as five years. When one conjectures about economic matters, as well as technology, over several decades toward the year 2000 matters become even less amenable to confident analysis. On the other side, particularly in the energy field and in space applications the "gestation" period of major projects is anywhere from eight to ten years: to affect major space applications programs in the mid 1980s decisions have to be made now on research, development, testing and evaluation programs. In energy matters major utility plants take anywhere from six to ten years for achieving full operational capability. Thus one is confronted with an intrinsic dilemma: some of the most interesting and promising technologies need about a decade to be deployed even where the technology is known to be feasible. Where major engineering or technology uncertainties exist, such as with solar power satellites, another five to ten years in experimentation, research, and prototype developments are added. Yet, our capabilities to project economic conditions to make investments with comfort and certainty is, at best, limited to a few years. What is required in space applications is a willingness to incur risks for uncertain -- but potentially large gains. The novelty, as well as the scale of space energy projects has to be seen in the context of the particular economic sector in which these innovative activities will take place. In communications we quoted some figures above. In the energy sector I have summarized some very "aggregate" numbers in Table 2. The Edison Electric Institute recently estimated the total sunk investments for electric energy production in the United States to be \$161 billion (plant and equipment, historical dollars). We have estimated a similar number, in constant 1975 dollars, for that same plant and equipment of around \$200 billion. This plant and equipment to date produces 17 quads of electric energy. The American Gas Association estimates the incremental cost for adding another 10 quads in generating capacity in the neighborhood of \$476 billion. These numbers reflect the increasing cost of capital as well as the complexity and regulatory constraints imposed on new electric energy generation capacity. This estimate, coming from the Edison Electric Institute, may be taken as a reasonable, unbiased estimate of the true incremental cost for 10 quads.

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These numbers have to be compared to current conjectures about the cost of solar power satellites. ECOR, Inc. has been deeply involved with three other corporations, Arthur D. Little, Grumman

Aerospace Corporation, and Raytheon, in estimating the cost and performance of one particular solar power satellite of about 5 gigawatt capacity (output on the ground). Based on such units the estimated cost of generating 17 quads of electric energy through such technology will be about \$500 billion. This cost estimate allows for substantial cost uncertainties. Within these uncertainties one certainly may conclude that solar power satellite systems compare in the neighborhood, if not favorably, with conventional power generating capacity on the ground: for the same amount of total investment of \$500 billion the nation would get 17 quads (i.e., 70 percent more) of electric generating capacity than by investing the same funds in conventional additions to such capacity.

There are unresolved issues and problems with solar power satellites: the estimates assume a further substantial decrease in space transportation costs; but these are clearly in hand with the successful completion of space shuttle systems technology. The estimates assume a substantial decrease in the cost of solar cell production, assembly and deployment in space; but the cost uncertainties allowed for cover these uncertainties. And, last but not least, there do exist serious questions of environmental effects: radio frequency interference, possible ionospheric effects of such large energy transmission (on the other side, solar energy output fluctuates by order of magnitude larger amounts each day and season), and local microwave radiation zones.

Yet "conventional" additions to electric generating capacity (or replacement of that capacity) has at least equally serious environmental problems: for nuclear fission technology the problems are myriad and may seriously conflict with other national interests; fusion technology remains an economic promise of the future, with potentially serious contamination problems (tritium), and technically unresolved issues of being able to sustain a net energy output from such enterprises. For fossil plant systems, even existing uses of fossil energy do seem to have a noticeable CO<sub>2</sub> effect, with potentially dangerous climatic long term implications; in addition, an equal use of world energy resources by developing countries at some future time clearly conflicts with the available resource base for fossil fuels, whatever those resources may be: a per capita energy equivalent consumption by developing countries, using United States 1970 energy consumption data, would have implied for 1970 a total worldwide fossil fuel production equivalent of 40 billion metric tons of coal, an irrationally high and economically unfeasible goal as of today.

While the energy problem is getting serious attention at local, federal and international levels, a major energy option using space as an energy source seems to whittle away unnoticed or neglected. At the same time millions, if not billions will be spent in inefficient or unreliable solar ground systems. I consider this a serious imbalance in the context of long term inexhaustible energy technologies available to the United States. The potential of solar power satellites and technology ranks at least at the same level as that promised by fusion or other "inexhaustible" energy options

beyond the year 2000, yet the funding is practically nonexistent.

While space may not be an energy source for mankind on Earth (for example due to ionospheric effects or microwave radio frequency interferences) space may yet become a natural "energy sea" for mankind to expand into with space-based industrial and habitat establishments, given the singular importance of energy in any economic system, the one resource for which no substitutes exist in the long run. While these ideas today seem somewhat "out of reach" these concepts have been shown to be within the technical capabilities of the United States.

#### 4. An Evolutionary Path: Likely Phases of Space Industrialization

Of course it is totally and completely unrealistic to expect today any commitment to investing \$500 billion of our resources to the establishment of even such a lofty goal as space habitation. This is not to say that social systems in the past, even in the very recent past, have not dedicated similar amounts of their annual resources to the pursuit of national security interests, religious interests or mere pleasures of architectural design: the building of the largest pyramid in Egypt was a project extending over hundreds of years, and employing a large portion of the total available labor force. The building of the Chinese Wall was an enterprise of similar magnitude, again extending over many hundreds of years, and equivalent to certainly much more than 10 million man-years needed for a solar energy base (i.e., \$500 billion) facility. In more recent times, up to 80 percent of the gross national product was dedicated by the United States in World Wars I and II to the pursuit of national security matters, adapting rapidly from a peacetime level of effort of between 10 to 20 percent of GNP. It is equally likely that any advanced society of the turn of the century (75 years ago) clearly would have committed tremendous resources to such a scheme -- if given the technical option to do so. However, no such dedication, even by the wildest imagination, can be expected in the pursuit of space colonization today.

But there is also no need for any such drastic acceleration of space expenditures to bring about space colonization over the next 100 years. Rather, many of the programs and activities in space will logically evolve some of the most important building blocks necessary for the accomplishment of space industrialization: using opportunities offered by the Space Shuttle and related technologies over the next decades, many of the technology components needed to commit to a full-scale space industrialization will come about by the utilitarian and scientific (is there any distinction?) uses of space. Table 3 indicates a rough outline of five phases of space industrialization that are likely over the next several decades:

##### 4.1 The Information Phase (1960s-1990)

This phase is geared toward using space and space sensing systems to gather, transmit and evaluate

information on a worldwide basis. This phase of space colonization began in the 1960s and will extend in the development and the initial deployment phase well into the 1980s and 1990s. It comprises programs such as communications, weather and climate, earth observation, sea and ocean measurements, as well as military surveillance. The space science program also is built around similar themes of information gathering, transmission and evaluation. The information technology in space will evolve substantially beyond the year 1990 and make important contributions to the organization, control and general feasibility of space habitation itself.

#### 4.2 Large Structures Phase (1980s-2010)

The area of large structures will be opened with the advent of the Space Shuttle. With an ability of repetitive flights, the ability to assemble larger structures in space operations, the capability to maintain, repair and refurbish large systems, the 1980s and 1990s will see the establishment of entirely new antenna systems, optical systems, initial prototypes of space power and space manufacturing systems. The space lab program, as currently envisioned for the 1980s, will include a variety of research important to answering some of the key questions with regard to any space habitation: how do organisms grow in low gravity; what is the effect of capillary forces; what is the ability and role of man in EVA; how long can man operate in space without adverse physiological effects; is there a high energy radiation problem; what will be the role of automated assembly and remote control through teleoperators?

#### 4.3 Industrial Prototype Phase (1990s-2025)

This phase, starting in the late 1990s or early decades of 2000, will see the deployment of economic prototype and operational SSPS systems, space processing systems, justified by economic uses on Earth and the establishment of biocultures, as well as a permanent space station and construction base. Most of these activities will be undertaken by governments, with substantial industry participation. Elements of a space construction base will evolve much earlier in the large structures phase, beginning in the mid-1980s.

#### 4.4 Industrialization Phase (2010s-2075)

In the following decades, industrial space activities, with or without financial participation by government, will develop and sustain themselves entirely, based on pursuits of economic interests. Once this point is reached, the space program will have become truly irreversible: economic self-interest, again and again, has proven to be the most lasting historical motivation to human activity. The most likely and obvious application will be space-based solar power systems -- of the SSPS type -- financed by utilities and industry. Another area of substantial economic activities may be waste disposal for extremely toxic chemical, biological and nuclear wastes, vaccine and enzyme production, cryogenic refrigeration, long-term storage, crystal growth, and possibly entirely novel space production processes. At the same time,

closed space agriculture and habitat systems may be established, including possibly a permanent Lunar base.

#### 4.5 Space Habitation (2075)

This phase of space industrialization will be the threshold phase of space colonization. It means achieving the levels of economic output (value added) with a labor force sustained in space sufficient to regenerate closed systems (i.e., without support from Earth), in economic, technical, environmental and social balance. After the crossing of this threshold, no physical resource limitations (energy, materials) seem likely to limit the growth of such communities from then on for thousands of years.

Beyond this threshold around the year 2075 little can be said as to dominant economic or technical considerations. The only limiting factors will be three principal determinants of economic systems:

##### (1) The Cost of Time (interest)

Even three percent a year -- the average rate of technological innovation over the past century in advanced societies -- this interest rate will severely limit any substantial expansion beyond the asteroid belt. Given the time preference of societies today -- and who are we to change these -- a 10 percent interest rate (in real terms) seems more realistic, thereby confirming the rate of space industrialization even further: the higher the interest rate placed on long term investments, the fewer of these can be undertaken. Since other advanced societies can be expected to be driven by similar utilitarian considerations -- a principle of nature -- it makes physical travel beyond any solar system a ruinous enterprise. Communication of information is much cheaper and faster.

##### (2) The Cost of Labor

In times of physical abundance -- and there have been several -- labor will become a severely limiting factor to space industrialization rates. An economic system has little incentives to expand faster than its population growth, once economic saturation levels are reached -- other than the rate of technological innovation. But with limited population, labor resources will limit the rate of space industrialization.

##### (3) The Rate of Technical Innovation

This rate has hovered about 3 percent over the past 100 years in the most advanced societies. Some decrease in this rate has been noticed for the U.S. economy over the past decade. At times, these rates of innovation have been truly explosive, leading to deep societal and economic changes and upheavals. Yet, historically, many advanced civilizations have stagnated at zero growth for centuries. Hence, little can be conjectured about the future development of the rate and willingness to innovate, venture and risk.



In many ways an explosive area of growth may develop, quite similar to the change from nomad economies to agriculture systems 4,000 to 5,000 years ago, or the change from agricultural (land based) systems to industrial societies 400 years ago (invention of printing, use of coal).

In conclusion, the above estimates and cost schedules may prove in time to be quite encouraging: while to some the cost estimates may seem exceedingly high, nevertheless, in rough outline form the feasibility of achieving these levels of investment and commitment over the next hundred years, in an evolutionary approach, seems assured, even with funding of space activities held at roughly current levels. The establishment of space habitation will be an evolutionary outcome of the current United States space program, with many intermediate steps already outlined. Several of the necessary steps will be self-supporting from an economic as well as technical-engineering viewpoint. With further innovation beyond the year 1995 (the technology and cost base assumed for the SSOS estimates), indeed a self-supporting community of 10,000 people seems possible a hundred years hence. However, for many of the reasons outlined above, this threshold is also not likely to be passed much sooner than that. In either case, mankind, through the efforts of the space program, will achieve in the next 100 years the most significant accomplishment yet: true Earth-independent, self-supporting systems which will invariably lead to the establishment of a multitude of new, different, varied and enterprising civilizations.

The information, large structures and energy themes will form the major phases of the United States or world-space program over the next decades. Many additional themes and uses will develop, some entirely unforeseen today. Yet these opportunities will only come about if we pursue them.

The emphasis given the space applications program over the next decades will have tremendous differential impact on when and whether these new, in some sense revolutionary developments, will come about for mankind in the early 21st century. This change is potentially so fundamental that it makes any speculation beyond the early decades of the 21st century somewhat futile and I will not attempt to do so. It suffices to say that enterprises and economies making use of the inexhaustible energy resources of space near the sun are so fundamental a step for mankind that it can only be compared in importance and magnitude to the change mankind made from nomad life to agriculture or from agriculture to the industrial society.

The German mathematician Hilbert was asked in 1905 what, in his opinion, the ultimate achievement for mankind would be. Clearly having in mind developments over the next several hundreds or thousands of years Hilbert replied, "The day man can catch a fly on the moon." While only 65 years later this was considered by some as "accomplished" (a truly incredible "collapse" of time) what Hilbert may have meant in a broader sense is the stage when mankind will achieve a technical, scientific and humanistic development to truly take possession of the space around earth, and the solar system. This

accomplishment, dictated and guided by possibly narrow economic needs indeed can be achieved by the United States over the next several decades. While in the 1960s such enterprises without government activity would have been inconceivable, the Space Shuttle will make this next important step possible, if not likely. This development will be guided as much by the pursuit of economic interests as by those of national prestige. No spectacular initiatives are needed by the nation to bring this about. What is needed is a firm, steady and constant support through the 80's of an inspired national space effort.

One last consideration: how best to integrate the space efforts of other allied nations with that of the United States. The best short term and long term interests of the United States are served by an open market policy, giving equal access to the means of space transportation to all allied nations, in open competition, in some cases successfully, with and against United States enterprises. Protectionism in space -- by utilizing the exclusive control the United States will have for a long time to come in reusable space transportation systems -- would be a most negative and dangerous development. An open market policy in space should be a cornerstone of United States space policy. Such a policy will help to bring about the most varied and dispersed uses of space applications and space sciences, while serving at the same time the best interests of the American people.

In conclusion, the United States today is offered a unique opportunity to pursue and bring about a vastly increased use of our investment in space with an inspired and sustained space applications policy. This, however, will only come about with inspired leadership, combining economic interests with those of technical and scientific enterprise. Such enterprise today is probably the weakest link of the U.S. space program.

#### NOMENCLATURE

1 quad =  $10^{18}$  British thermal units (Btu)

#### REFERENCES

- (1) Energy and Climate, report published by the National Academy of Sciences, Washington, D.C., 1977.
- (2) Worldwide Communications Satellite Systems Markets, ECON report no. 77-263-3, prepared for NASA, April 1977.

#### ILLUSTRATIONS

- Table 1. 1980s Global Information Systems Benefits and Costs (U.S. Benefits only).
- Table 2. Investment Costs in U.S. Electric Energy Production.
- Table 3. Phases of Space Industrialization.

Table 1 1980's Global Information Systems Benefits and Costs (U. S. Benefits only)			
LAND RESOURCES (LANDSAT/LACIE)		OCEAN OBSERVATIONS (SEASAT)	
Application Area	Annual Benefits	Application Area	Annual Benefits
Agricultural Crop Information	294 - 581	Arctic Operations	10 - 29
Petroleum-Mineral Exploration	64 - 260	Coastal Zones	.3 - .8
Hydrologic Land Use	22	Marine Transportation	22 - 53
Water Resources Management	13 - 41	Ocean Fishing	27 - 143
Forestry	7	Offshore Oil and Natural Gas	21 - 34
Land Use Planning and Monitoring	15 - 48		
Soil Management	5 - 9		
Annual Benefit Range	420 - 968	Annual Benefit Range	80 - 160
Annualized Systems Costs (at 10% interest rate)	60 - 80	Annualized Systems Costs (at 10% interest rate)	80 - 100
CIVILIAN SPACE COMMUNICATIONS			
Space Systems		For Comparison	
1976	Mid 1980's	ATT 1977	
Market System Investments	\$ 1 Billion	\$5 Billion (Est)	
Annual System Revenues	\$500 Million	\$100 Billion	
		\$1.5 - \$2.0 Billion (Est)	
		\$ 36 Billion	

Table 2 Investment Costs in U.S. Electric Energy Production			
	Today (1975) 17 Q	Earth Based Increment Δ 10 Q (additional)	Space Based Δ 17 Q (additional or replacement)
Edison Electric/ American Gas Assoc. Estimates	\$161 Billion (historical dollars)	\$476 Billion	\$500 Billion (1975 dollars) (First 50 Five gw SSPS units)
ECOM Estimates	\$200 Billion (constant, 1975 dollars)		\$200 Billion (SAI, Driggers) (First 20 Ten gw SSPS units)
Other Estimates			
<u>Key Uncertainties</u>			
Environmental	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> Effects</li> </ul>	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> Effects</li> </ul>	<ul style="list-style-type: none"> <li>• RF Interference</li> </ul>
Technical	<ul style="list-style-type: none"> <li>• Fossil Fuel Prices &amp; Resource Availability</li> </ul>	<ul style="list-style-type: none"> <li>• Nuclear Proliferation &amp; Contamination</li> </ul>	<ul style="list-style-type: none"> <li>• Ionospheric Effects</li> </ul>
Economic		<ul style="list-style-type: none"> <li>• Waste Disposal</li> <li>• Fossil Fuel Prices &amp; Resource Availability</li> <li>• Resources Access by Developing Nations</li> </ul>	<ul style="list-style-type: none"> <li>• Micro Wave Radiation Zones</li> <li>• Large Space Structures Technology</li> </ul>

Table 3 Phases of Space Applications Development

Phases	Information Phase	Large Structures Phase	Industrial Prototype Phase (with ground support)	Industrialization Phase	Space Habitation Phase
Main Tasks	Collection, Transmission	Assembly/Support Technologies	Testing/Coasting Open Systems	Closed Systems Designs/Tests	Economic Balance of Closed System (with Net Energy Output)
Initial Start up	1960s - 1990	1980s - 2010	1990s - 2025	2010s - 2075	2075 Islands I - III
Economic/ Technical Scientific Activities	INTELSATS	• Antennas	• SSPS Prototype	• Lunar Base	• 10,000 People
	DOMSATS	• Optical Systems	• Processing: LG Capillary Forces	• Closed Agriculture Systems	• \$50 Billion/Year Gross Product
	TIROS	• Spacelabs	• Cryogenic Refrigeration	• Environmental Balance	• Space Energy Base with 17' Grade Net Energy Output
	NIMBUS	• Information Processing	• Biocultures	• Net Energy Output of Closed Systems	• Autark Space Economics
	GEOS	• Space Power Support Systems	• Space Station/Base	• Large Scale Recycling Systems	• Climate Modification (Management)
	LANDSAT	• Reuse of Space Materials and Systems	• Recycling of Space Materials	• Helium 3 Prod. in Space (Fusion)	
	ATS	• Weather & Climate Res.	• Weather Modification		
Surveillance					
Space Transportation System Needs	Expendable Rocket Systems	• Space Shuttle • LVS, Tugs • Assembly Platforms	Chemical/Laser LLV Large Seps Mass Driver RDT&E Space Shuttle Derivatives	• Laser Fusion Propulsion • Modified "ORION" Systems • Lunar Mass Driver RDT&E	
Costs (1975 \$)	\$75 Billion	\$100 Billion	\$150 Billion	<\$200 to \$250 Billion	Total > \$500 Billion
Average Annual Funding			\$5 Billion per year, 1975 dollars		