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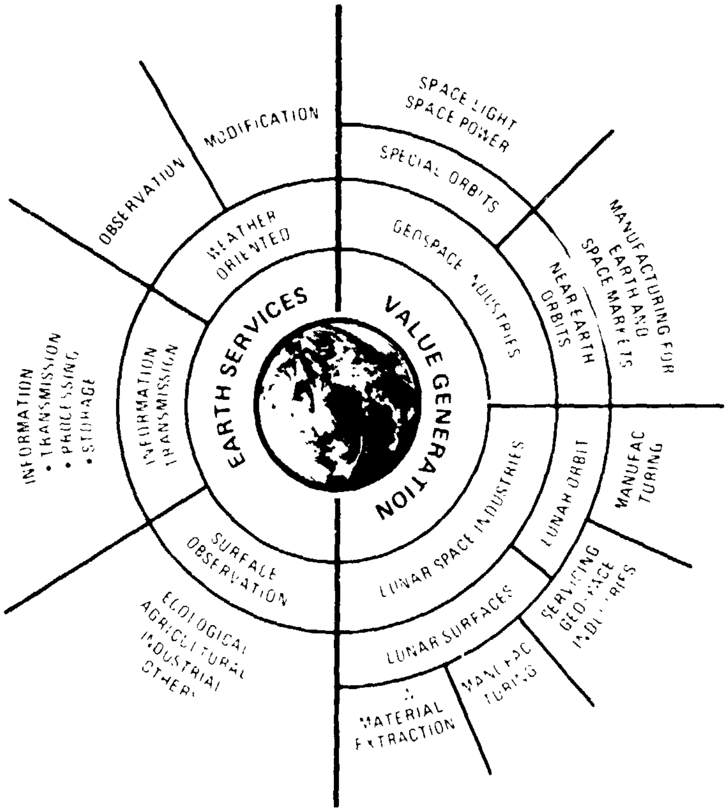
Space Industrialization



EXECUTIVE SUMMARY

FINAL REPORT

Rockwell International

Space Division

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FOREWORD

This $190,000 Space Industrialization Study was performed under NASA Contract NAS8-32198 for Marshall Space Flight Center from September 1976 through April 1978. The study was in two parts: Part 1 identified the potential goals for space industrialization and developed and assessed evolutionary program options for realization of those goals; Part 2 defined program support demands, evaluated and defined the leading program options, and developed recommendations for program implementation. The study results are documented in four volumes:

1. Executive Summary
2. Space Industrialization Background, Needs, and Opportunities
3. Space Industrialization Implementation Concepts
4. Appendixes

The Rockwell study manager was Mr. C.L. Gould. Other key Rockwell participants were A.D. Kazanowski and T.S. Logsdon. Additional support was provided by D.B. Anderson, C.R. Gerber, and T.A. Sackinger. Many others helped in various ways. They included the following key consultants:

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SPACE INDUSTRIALIZATION EXECUTIVE SUMMARY

ILLUSTRATIONS

TABLES

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INTRODUCTION

Space Industrialization can be defined as a new technology in which the special environmental properties of outer space are used for the social and economic benefit of the people on earth. These special properties include zero-g, hard vacuum, low vibration, wide-angle view, and a complete isolation from earth's biosphere. Design engineers have always been willing to go to great lengths to obtain those specific environmental conditions that fulfill their particular needs. For example, the Hale Observatory was constructed at the top of Mount Palomar so that it would be above a small portion of the earth's atmosphere. Eight million pounds of steel and cement were hauled up the side of a rugged mountain to achieve air density reductions of less than 20 percent. When industrial processes are transferred into space, the environmental conditions are typically modified to a far greater degree. In fact, in-space pressure levels of one-trillionth of an atmosphere are relatively easy to obtain.

Because so few experiments have been conducted in space, it is extremely difficult to envision all the benefits that might result from extremely low pressure levels there. But if the past is a reliable guide, pressures 12 orders of magnitude lower than those encountered at sea level should lead to previously unsuspected benefits. As Figure 1 shows, vacuum levels ranging from 10^{-2} to 10^{-10} atmospheres have already been used in a number of practical ways. These include food processing and preservation (including freeze-drying and refrigeration), metal distillation, x-ray devices, TV picture tubes, thin film deposition, and the manufacture of vacuum diodes and solid state electronic devices. Moreover, many orbiting satellites have already capitalized on the natural vacuum of outer space. For example, when the semi-rigidized Echo balloon was tested on the ground, more than 80,000 pounds of inflating gases were required to inflate it. When it was lofted into the vacuum of outer space, only 30 pounds of gases were needed.

The g-levels and the viewing areas achievable in space are also shown in Figure 1. In comparison with terrestrial conditions, these parameters are improved approximately six orders of magnitude. Precise g-level control is important in medical and chemical centrifuges, in crystal growth, electrophoretic separation, solidification and purification processes, and in the construction of extremely lightweight orbiting structures such as large-scale solar arrays and multibeam antennas. A wide-angle earth-oriented view can be extremely beneficial to meteorology, cartography, reconnaissance, communications, earth sensing, and wide-area navigation—all of these have already brought important benefits to the people on earth.

Thus, it is not hard to see why the aerospace engineer is so keenly interested in the beneficial environmental properties of outer space. But these properties can form the basis of a meaningful Space Industrialization program only if they can be exploited in practical ways. Businessmen are keenly interested in environmental properties, but they are much more concerned with profit-making opportunities to fill real human needs. The first task in our 18-month Space Industrialization study was thus quite clear: To match the needs of humanity with the opportunities for filling these needs through modern space technology.

As they look to the turn of the century and beyond, many people see increasingly bleak prospects for the future. The pressures of population growth continue, particularly in the less-developed countries. The people in these underdeveloped regions are surprisingly young with an average age of about 15, and (hopefully) they will live to see several generations of offspring. By contrast, in the developed countries like our own, the average age is about 29 and steadily increasing. The developed world has nearly reached that magic time when each couple replaces itself

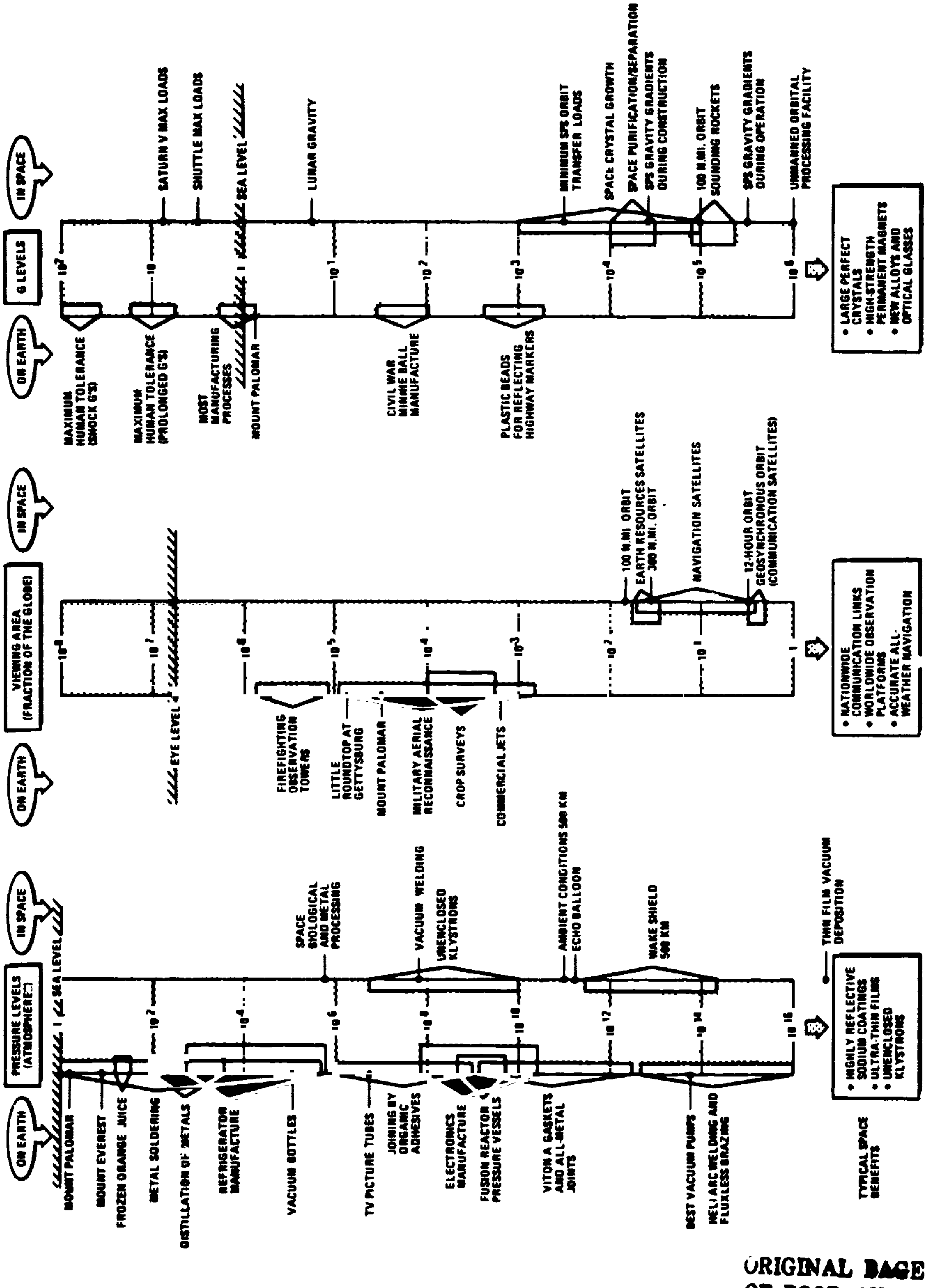

Figure 1. Environmental Properties in Space

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with only two offspring. Worldwide, however, that is not the case, and it is not likely to be in the near future. As Figure 2 shows, the overwhelming majority of the world's population is in the underdeveloped countries; and within 100 years, their fractional share of world population will nearly double. Of course, their populations will also increase in absolute terms. The birth rates in many areas have recently undergone encouraging declines, but so many of the people in the world are below the critical childbearing ages that the earth is committed to supporting at least double, more likely triple, its present population. Most experts are convinced that the best way to cut population growth rates is to develop a healthy worldwide economy. Emerging affluence has always been accompanied by reductions in population growth rates.

One key to a healthy worldwide economy is expanded trade—especially trade that results in a reasonable balance between imports and exports. The United States and other industrialized countries sell large quantities of goods to the developing countries, but today only a discouraging trickle of trade flows in the opposite direction. This negative balance of trade endangers the economies of the underdeveloped countries; it also deprives us of a market that could be provided by the 2 billion people living in the underdeveloped regions. If United States investments (public and private) in the productive use of space could contribute to the economic growth and purchasing power of these proverty-stricken areas, this could have an important positive effect on the economy of our own country and on the rest of the world. Specifically, if we could develop two-way markets of only $17 for each world citizen, 2.7 million new American jobs would be created—enough to reduce our unemployment level to 4 percent of our work force. This would not be a difficult level of trade to attain if underdeveloped regions could be edged toward slightly higher socioeconomic conditions. In fact, as Figure 3 shows, it is only 20 percent of the per capita trade we are already achieving with West Germany and the United Kingdom.

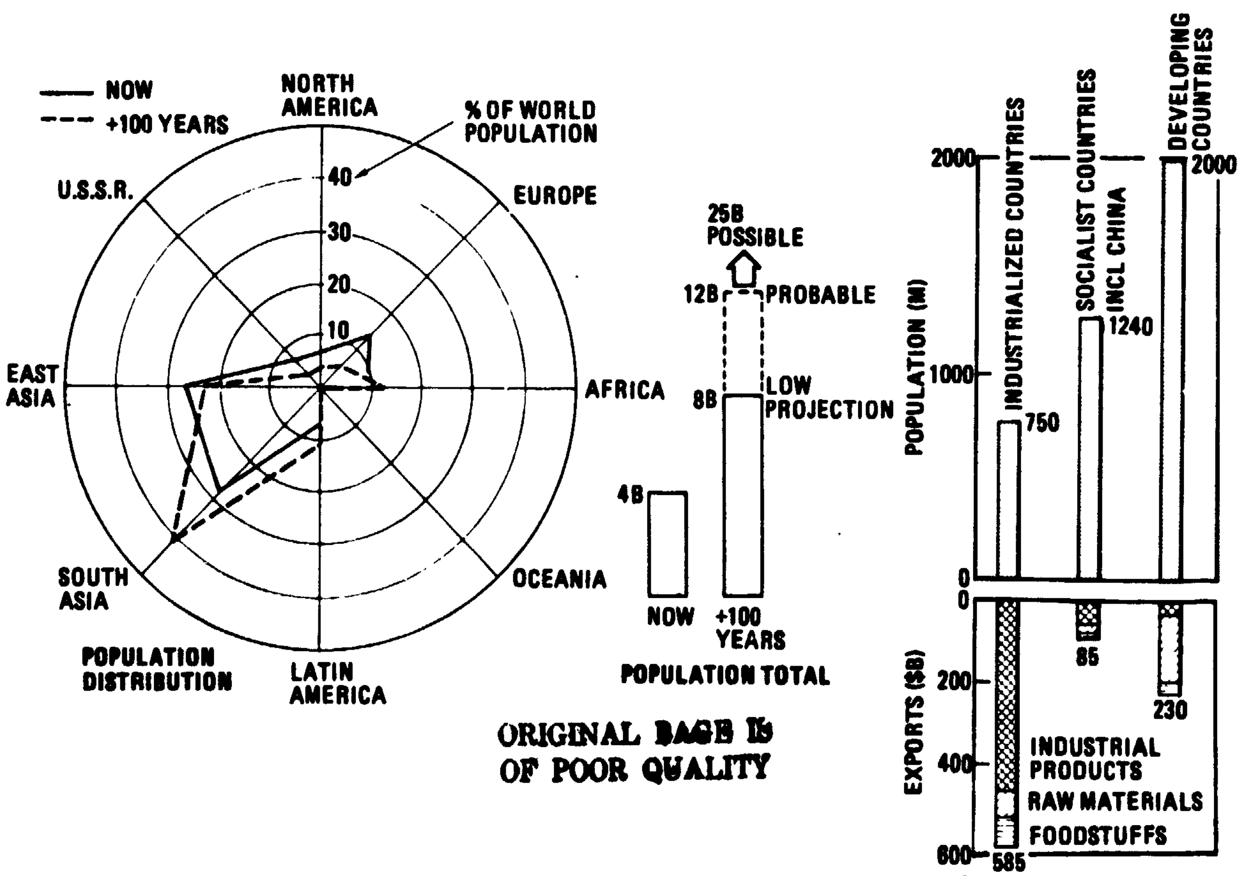


Figure 2. World Population Shifts and Trade Levels

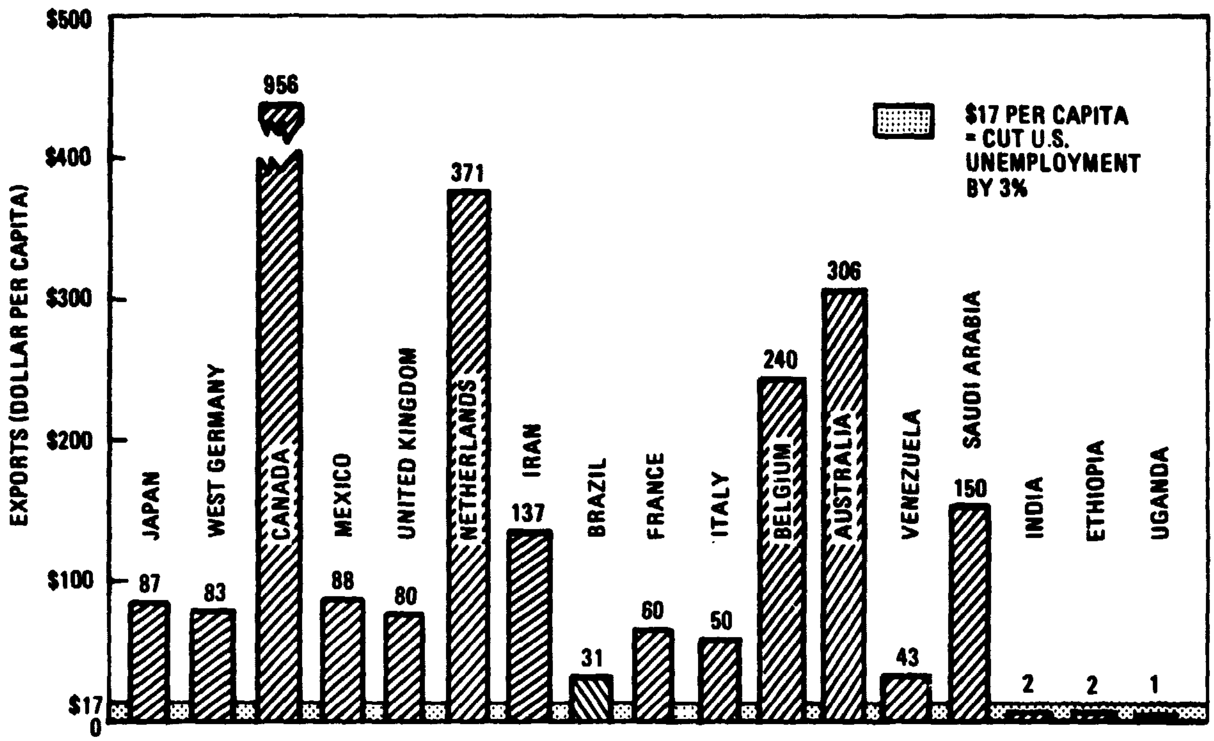


Figure 3. U.S. Exports per Capita to Various Countries

Healthy worldwide trade would also help assure us of uninterrupted supplies of needed raw materials. As indicated in the bar charts of Figure 4, we are spending more than $46 billion each year for imported petroleum products, and we currently import more than 50 percent of 14 important minerals, including platinum, tungsten, and magnesium. Without adequate exports to pay for these crucial substances, our country would quickly slip into a declining economic position. Over the long run, our trade balance has been quite favorable; however, in three of the last five years, our balance of payments has been negative, and in 1977 alone, we almost exceeded the deficits of all previous years combined.

Because of our high labor rates, high-technology items are essentially the only thing we, as a country, can export at competitive prices. Manufactured goods constitute about 61 percent of our exports, and agricultural products make up another 19 percent.* Unfortunately, other countries of the world have recently been making unusually heavy investments in research so that many high-technology items that were once solid American exports are now becoming common imports. Television sets, steel ingots, precision optics, and automobiles are a few obvious examples. Thus, the only way we can maintain a positive balance of trade is to increase worker productivity or to stay in the forefront of advanced technology. As will be shown in the remainder of this report, space industrialization offers us many possibilities for exercising both of these important options.

In 1973, when the OPEC oil cartel successfully raised the price of petroleum, it was widely feared that other fuels and minerals might also experience substantial price hikes. So far, however, this has not occurred. Prices have remained reasonably stable because of the widespread distribution of most minerals, the tacit threat of substitutions, and the economies of large-scale mining operations. In many cases, however, the quality of ore has significantly declined. In particular, the copper ores now being mined are not nearly as rich as they once were. As Phillip Morrison pointed

*Agricultural products are, in effect, high technology items: our farmers use the highest technology farming methods in the world.

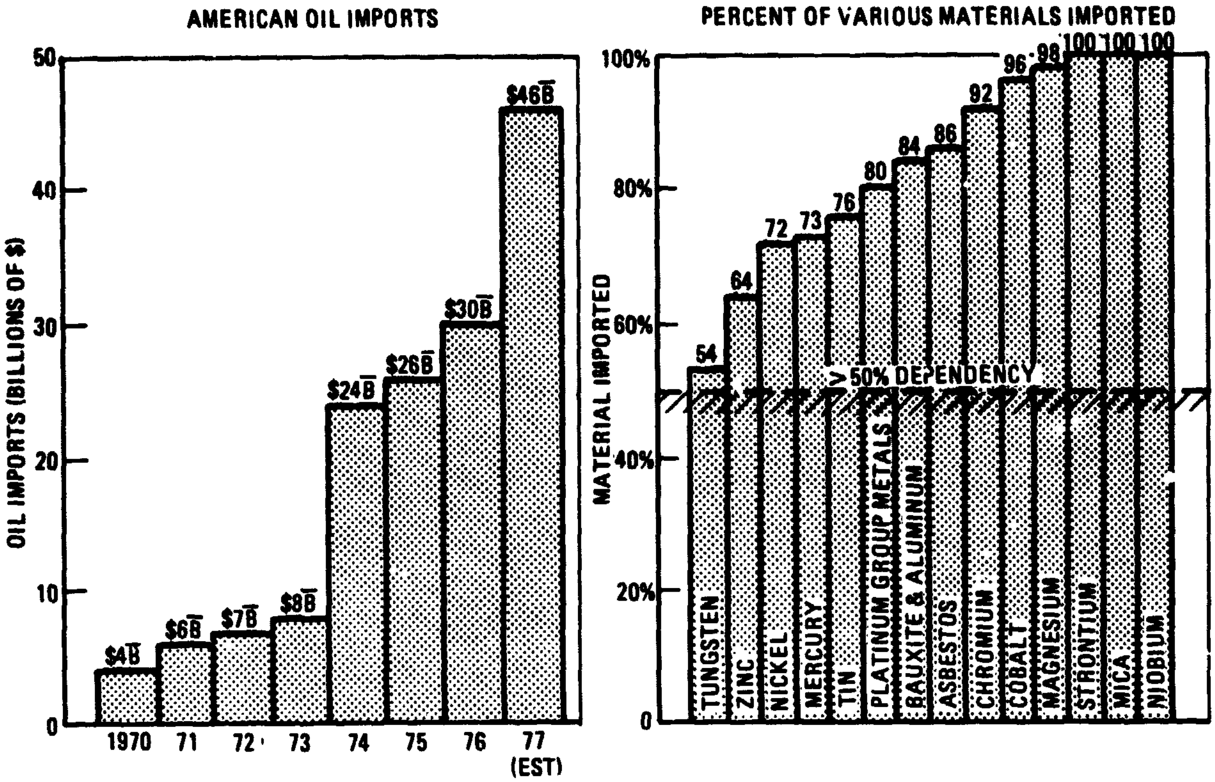


Figure 4. America's Dependency on Oil and Minerals

out in a recent *Scientific American* article, "The ancient miners looked for showy minerals with a copper content of 15 percent. The grade has steadily declined; it was 8 percent in Europe by the time of the Renaissance, and today most copper is won from low-grade ores, the U.S. average grade being about 0.65 percent."**

The recent book *The Limits to Growth* provides an alternate evaluation of the status of the world's future mineral supplies. Figure 5, taken from this popularized book, indicates that at least eight crucial minerals will be exhausted within the next fifty years at the present rates of increased usage. The assumptions made in this study on available reserves and recovery technology have been seriously challenged, and the projections are now widely regarded by most experts as needlessly pessimistic. For this reason and others, the Rockwell analysis team does not believe that these minerals will actually be exhausted in the indicated time frames. When supplies begin to run short, mankind will expend whatever energy and exploration efforts are required to locate and obtain needed supplies. Substitutions will also occur. Nevertheless, Figure 5 highlights a crucial problem: Our known mineral reserves are not infinite; large new supplies will be needed by future generations.

Fortunately, as is shown on the right-hand column of the chart, many techniques are available for expanding our recoverable supplies. These include intensified exploitation, the extraction of minerals from sea water, and the exploitation of ocean-floor reserves. These techniques could expand our mineral supplies to an essentially unlimited extent; however, a careful study of the list will reveal that each available technique requires larger inputs of energy than we are now expending. Thus, adequate energy supplies are again a key to a prosperous future for the United States and, indeed, for all mankind. As we shall see, space technology can help ensure that the needed energy will be available through conservation and through the production of abundant new supplies.

**Scientific American, March 1978, p. 41.

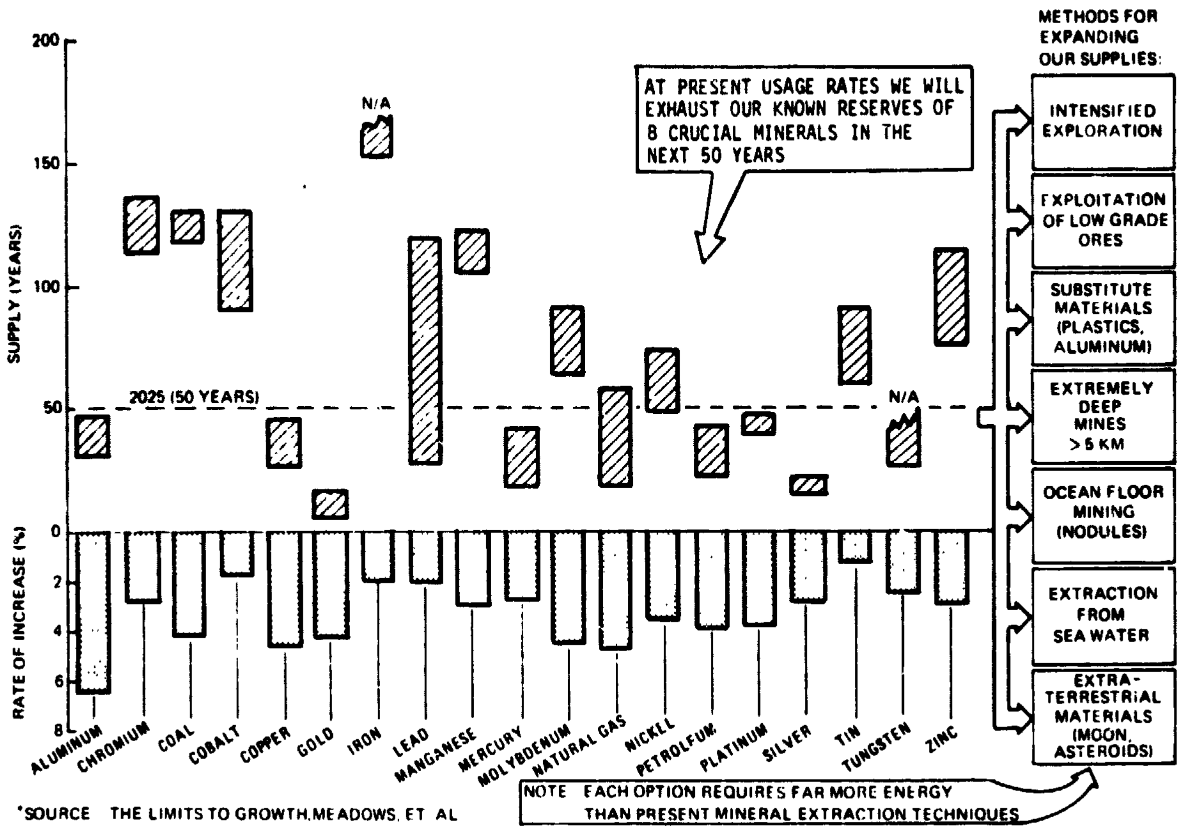


Figure 5. Potential Exhaustion of Selected Minerals

In addition to their physical needs, human beings also have psychological needs. These are basically similar for people everywhere. We need to be productive and feel useful (i.e., to have a job). We need an acceptable standard of living that improves each year and a quality of life compatible with our individual heritage. We think the United States must play the role of leader in this worldwide enterprise. The key direction of this leadership should not merely be good stewardship of what we have, but the continued creation of wealth for ourselves and for the people throughout the rest of the world. In the face of population growth, a more just and equitable distribution of scarcity is not enough. For prolonged scarcity makes the future look bleak and disappointing for the average world citizen. What is necessary, therefore, is new ways to create wealth—wealth that will make the world a healthier, more stable place to live.

THE OPPORTUNITIES FOR SPACE INDUSTRIALIZATION

During the course of this study, we attempted to look 50 years into the future and correlate real human needs with space opportunities. Our work proceeded down two parallel paths. Along one path, we looked into the future for meaningful trends in human needs; and along the other, we searched for practical and economically viable space opportunities. In general, these opportunities can be broken down into the following categories:

1. Services
   - Information transmission
   - Data acquisition
2. Products
   - Organic
   - Inorganic
3. Energy
   - Conservation
   - New energy sources
4. Human activities
   - Space careers
   - Frontier for mankind

As we proceeded into the study, we found that is was easier (and more fun) to think up new space projects than it was to reduce the list down to a more manageable number. We used the ideas that have been advanced by NASA (Outlook for Space), Ivan Bekey at the Aerospace Corporation, and many many others. We also added many new ideas of our own. The overall lists are presented in Tables 1, 2, and 3. It is not possible to discuss each one individually in any reasonably sized report, but it is reassuring to observe that the known opportunities are quite numerous. It is also encouraging that these opportunities respond to the needs of mankind to a major degree. This suggests that the space program should be considered as a mainstream activity rather than a matter of minor interest, benefiting only a few people.

In the next few paragraphs, we shall briefly discuss one or two opportunities from each of the four major categories: (1) services, (2) products, (3) energy, and (4) human activities. Once this has been done, an integrated plan will be revealed, showing what we believe to be the proper evolution for a relatively ambitious but entirely realistic program of Space Industrialization.

SERVICES

In a very real sense, the services area of space industrialization is already a reality. For several years, space platforms have been providing valuable communication, navigation, observation, and weather services for people worldwide. Some of these services have been earning comfortable profits for corporate shareholders. Today, communication satellites are owned and operated by more than a dozen countries, and more than 100 have their own Intelsat ground terminals. These terminals transmit messages and data to and from such unlikely places as Niger, Bangladesh, Cameroon, and French Guiana.

The utilization of satellite technology in these primitive locations is based on simple economics. The cost of the hardware necessary to handle a satellite voice circuit (see Figure 6) has been declining by a factor of 100 every 12 years. In 1966, an Early Bird voice circuit cost more than $20,000 per year. Today Westar provides equivalent voice circuits for a little over $200. Moreover, large-scale Antenna Farms launched by the Space Shuttle may soon bring about further important cost reductions. Hardware investment costs as low as $14 per circuit-year seem entirely within the realm of possibility. With costs at this level, we will begin to see numerous new applications of advanced communications.

Complexity inversion (see Figure 7) is quietly fostering another revolution in our approach to space communications. Complexity inversion refers to the concept of putting large and complicated hardware in space so that the units on the ground can be small and simple. This philosophy contrasts sharply with the approach that was adopted in the early days of the space program when every effort was made to keep the space segment of the system small and light. In order to do this, the corresponding ground segments had to be massive and complex. For example, the Telstar communication satellite weighed only 150 pounds. This compact design held down launch costs and simplified the satellite, but as a result, it could relay high-quality signals only between such massive ground installations as the 85-foot Goldstone antenna, which weighs 600,000 pounds. Numerous other examples can be found in both civilian and military programs in which huge ground antennas and major computer installations painstakingly processed raw data to extract useful information from weak and diffuse signals radiated by small, compact satellites.

Because of recent advances in space technology and improved transportation capabilities, it is now possible to enlarge the orbiting satellites and, in turn, shrink the ground user sets. In particular, modern electronic devices and multibeam antennas allow the space segment to be vastly more capable and complex, but still stay within reasonable launch cost limitations–especially considering the launch economics of the Space Shuttle.

Table 1. Attractive Opportunities in the Services Area

Communications

Information Relay
- Direct TV broadcast
- Electronic mail
- Education broadcast
- Rural TV
- Meteorological information dissemination
- Interagency data exchange
- Electronic cottage industries
- World medical advice center
- Centralized "distributed" printing systems
- Environmental information distribution
- Time and frequency distribution

Personal Communications
- National information services
- Personal communications wrist radio
- Voting/polling wrist set
- Diplomatic U.N. hot lines
- 3-D holographic teleconferencing
- Mobile communications relay
- Amateur radio relay
- "Telegraphing" personal communications systems
- Worldwide electronic ping pong tournaments
- Central computer service (for transmitting hand-held calculators)
- Urban/police wrist radio

Disaster Warning
- Disaster warning relay
- Pre-disaster data base (earthquake)
- Earthquake fault measurements
- Disaster communication set

Navigation, Tracking, and Control

Navigation
- Public navigation system
- Global position determination
- Coastal navigation control
- Global search and rescue locator

Tracking and Location
- Implanted sensor data collection
- Wild animal/waterfowl surveillance
- Marine animal migrations
- Vehicular speed limit control
- Rail anti-collision system
- Nuclear fuel locator
- Vehicle/package locator

Traffic Control
- Multinational air traffic control radar
- Surface ship tracking

Border Surveillance
- U.N. truce observation satellite
- Border surveillance
- Coastal anti-collision passive radar

Table 1. Attractive Opportunities in the Services Area (Cont)

Land Data

Agricultural Measurements
- Soil type classification
- Crop measurement
- Crop damage assessment
- Global wheat survey
- Crop identification/survey
- Agricultural land use patterns
- Crop harvest monitor
- Range land evaluation
- Crop stress detection
- Soil erosion measurement
- Agricultural acreage survey
- Soil moisture measurement
- Soil temperature monitor

Forest Management
- Timber site monitoring
- Logging residue inventory
- Forest stress detection
- Forest fire detection
- Rural/forest environment hazards
- Lightning contact prediction/detection

Hydrological Information System
- Snow moisture data collector
- Wet lands monitor
- Tidal patterns/flushing
- Water management surveillance
- Irrigation flow return
- Run-off forecasting
- Inland water/ice cover
- Subsurface water monitor
- Water resource mapping
- Soil moisture data collector
- Irrigation acreage measurement
- Aquatic vegetation monitoring
- Underwater vegetation survey
- Lake/river suspended solids
- Sediment measurements (rivers)
- Flooded area monitoring

Land Management
- Land capability inventory
- Land use mapping
- Wild land classification
- Range vegetation mapping
- Rangeland utilization/population
- Flood damage assessment
- Beach erosion

Pollution Data
- Advanced resources/pollution observatory
- Salt accumulations (irrigation)
- Agricultural pollutant monitoring
- Lake eutrophication monitor
- Great Lakes thermal mapping
- Effluent discharge patterns
- Toxic spill detector
- Air quality profilometer
- Air pollutant chem[illegible] (Freon)
- Pollution detection [illegible] distribution
- Mosquito control (wetlands flooding)

Resource Measurements
- Oil/mineral location
- Drilling/mining operations monitor

Geographic Mapping
- Urban/suburban density
- Recreation site planning
- High-resolution earth mapping radar
- Wildland vegetation mapping
- Offshore structure mapping

Weather Data
- Atmospheric temperature profile sounder
- Rain monitor

Ocean Data
- Ocean resources and dynamics system
- Marine environment monitor
- Oil spill
- Shoreline ocean current monitor
- Algae bloom measurement
- Saline intrusion

Global Environment
- Glacier movement
- Ozone layer replenishment/protection
- Highway/roadway environment impact
- Radiation budget observations
- Atmospheric composition
- Energy monitor, solar terrestrial observatory
- Tectonic plate observation

Table 2. Attractive Opportunities in the Products Area

Organic
- Isozymes
- Genetic engineering of hybrid plants
- Urokinase
- Insulin
- New antibiotics via rapid mutation

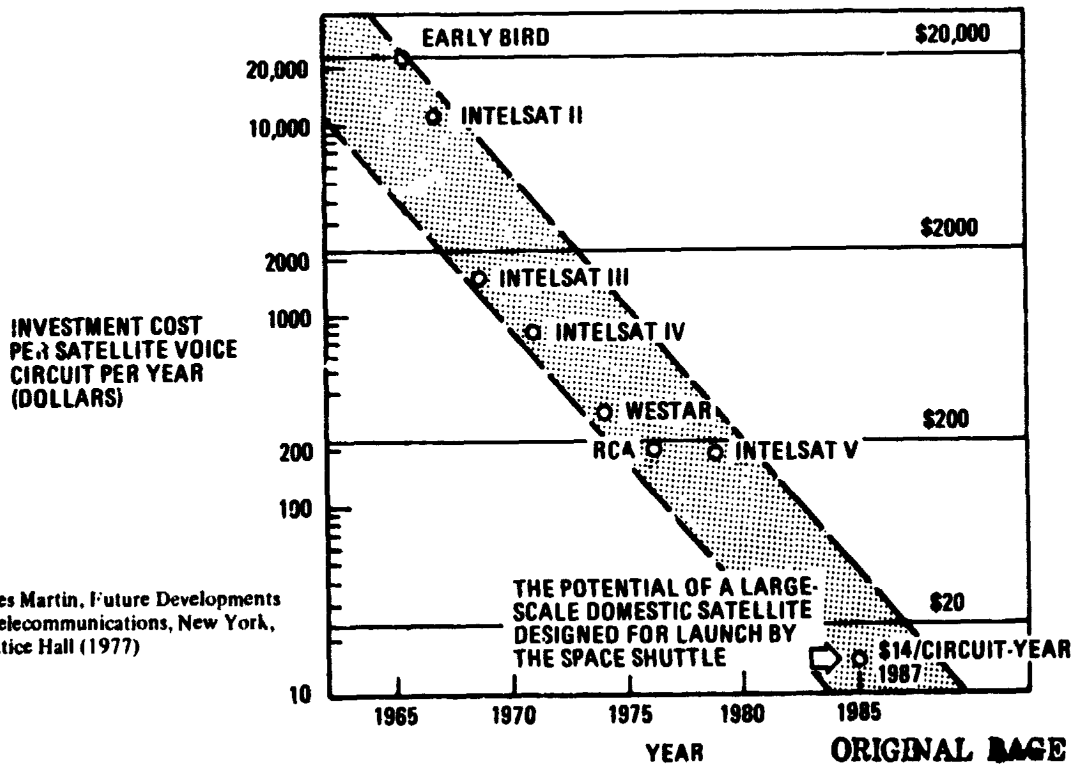
Inorganic
- Large crystals
- Super-large-scale integrated circuits
- Transparent oxide materials
- Surface acoustic wave devices
- New glasses (including fiber optics)
- Tungsten X-ray target material
- Hollow ball bearings
- High-temperature turbine blades
- Separation of radioisotopes
- High strength permanent magnets
- Magnetic bubble memory crystal film
- Thin film electronic devices
- Filaments for high-intensity lamps
- Aluminum-lead lubricated alloys
- Continuous ribbon crystal growth
- Cutting tools
- Fusion targets
- Microspheres

Table 3. Attractive Opportunities in the Energy Area

Lunetta
- Night illumination for urban areas
- Night illumination for argiculture and industrial operations
- Night illumination for disaster relief operations

Soletta
- Night frost damage protection
- Local climate manipulation
- Reflected light for ground electricity conversion
- Ocean cell warning for climate control
- Controlled snow-pack melting
- Stimulation of photosynthesis process

Other
- Satellite power system (solar)
- Fusion in space
- Nuclear waste disposal



James Martin, Future Developments in Telecommunications, New York, Prentice Hall (1977)

Figure 6. Investment in Satellite Voice Circuits

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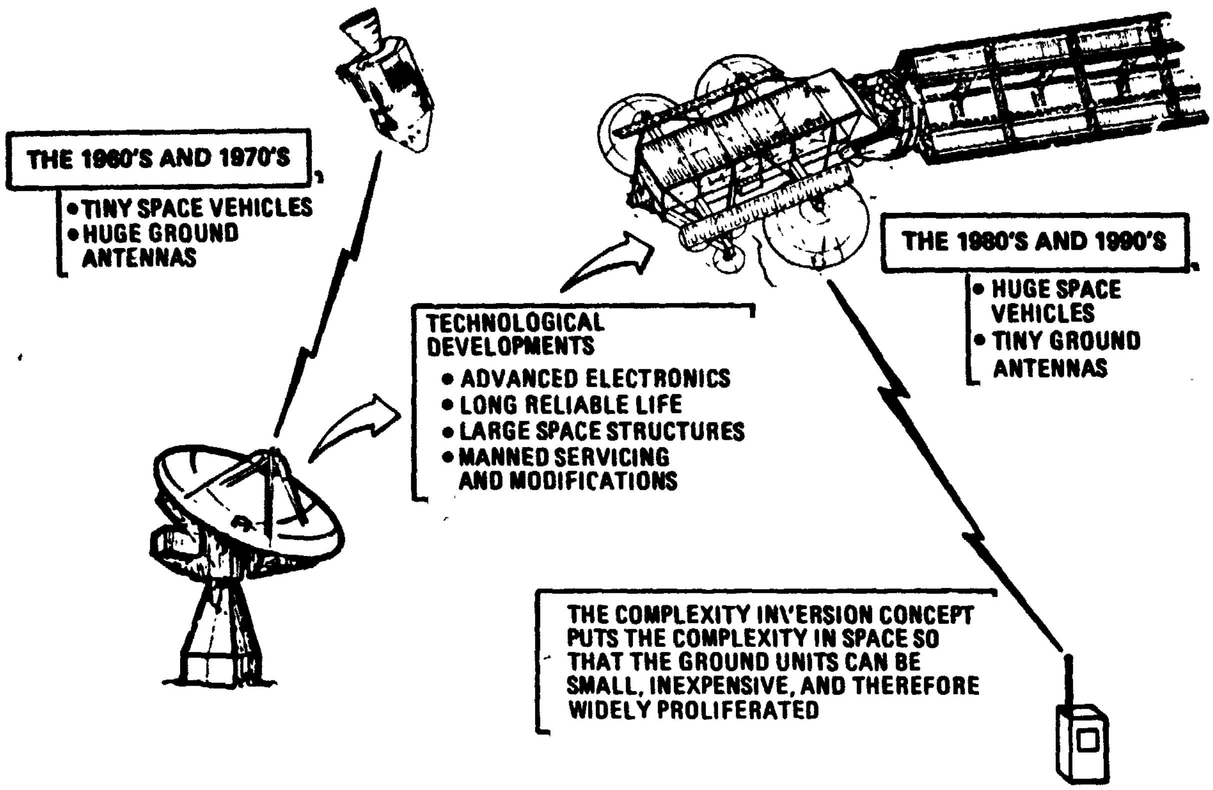

Figure 7. Complexity Inversion

The evolutionary trends in electronic technology are particularly noteworthy. In 1946, the world's most impressive electronic device, the ENIAC computer, reached operational status. It contained 16,000 electronic switches and was roughly the size of a five-room house. In 1977, the Mostek Corporation began to market the MK 4116, a solid-state chip which is about four times as complicated as the entire ENIAC computer, yet it measured only 1/5 of an inch on a side. The costs of solid-state electronic devices have also been dropping at a rapid rate. In recent years, costs have declined by a factor of 10 every 4.5 years.

By developing the capability to build extremely large multibeam antennas in space and eventually adding the presence of man to operate, service, and (perhaps more importantly) update the system to incorporate ever-expanding technology, we can have systems in the 1980's and 1990's than can broadcast preprocessed information directly to the user. A multibeam antenna uses a sophisticated feed mechanism to send out several dozen high-intensity beams from a single antenna: each beam covers a different spot on the ground and each utilizes the entire surface of the antenna. With multibeam technology, pocket telephones, direct broadcast TV, and electronic teleconferencing–and dozens of other developments–will soon become practical and cost-effective. In addition, these multibeam antennas will allow extensive frequency reuse, thus conserving precious space in our increasingly crowded frequency spectrum.

Thus, we see that the trend of the future is to put the complexity into space rather than on the ground. This will allow the corresponding ground user sets to be small, simple, inexpensive, and therefore, widely proliferated.

In the past, cars, trains, boats, and especially aircraft have done much to conquer geographical barriers. Space can further accelerate this trend by providing easy, inexpensive access to distant data banks, computer power, specialized training, and other people. This conquest of geography can expand our personal options in areas such as education and job training. With space technology, thousands of stimulating courses of instruction could be brought into the home—or into remote areas in India. From an economic standpoint, the space segment would be only a small part of the overall system; the big worldwide market would be in the sales of the large number of inexpensive communications units to be used by millions of people.

One of our consultants (Dr. Kerry Joels) provided us with a detailed evaluation of the needs, benefits, and comparative costs of delivering educational information via various media. He also examined the effect that space-relayed information would have on job skills, increased productivity, and improved life styles. These studies showed that, in all cases, space-based relays would reduce delivery costs and increase productivity. The media he evaluated included:

- Television for lectures and demonstrations
- Library services for research and reference
- Computer-managed instruction for primary, secondary college, and trade schools
- Computer-aided instruction for correspondence courses for the handicapped and the disadvantaged

In the professional opinion of Dr. Joels, each of these could be commercialized on a large scale and each has enormous profit potentials.

Because they must be mass produced for use by unskilled participants, the user's terminals would have to be inexpensive and readily available and they must be designed so that they require little training to use. Educational instruction would be their primary purpose, but these same terminals would be also utilized for certain non-educational services such as electronic telecommuting or electronic cottage industry applications. Another novel and exciting use of the terminals would be to provide education and entertainment for the estimated 15 million Americans who suffer total or partial loss of hearing. Multimedia transmissions and programs with sign language or subtitles would greatly enrich the lives of these widely dispersed deaf citizens.

Electronic telecommuting is another service that could be carried out efficiently using space communication links. In an electronic telecommuting system, workers would be linked to their offices electronically. Rather than driving to work each day, the workers would operate from their homes or from a small satellite office where they could interact electronically with machinery located in a central office building. This procedure would save fuel, transportation costs, and commuting time. It could also allow a life-style whereby people could live, work, and play in small communities, but still perform jobs that are essentially urban.

Appreciable savings could be achieved by such an electronic telecommuting system. Forty percent of all the urban transportation in the United States is commuting by automobile. This commuting consumes about four percent of all the U.S. energy or about $6 billion per year in fuel costs alone. If commuting costs are calculated at ten cents per mile, it costs America's 86 million workers about $47 billion per year just to get to work. Moreover, if commuting time is figured at $5 per hour, there is an additional cost of about $90 billion in time lost by our work force. This lost time could otherwise have been used to make a contribution to our productive capacity and our quality of life.

Electronic telecommuting was recently tried experimentally by a Los Angeles insurance company (see Figure 8). Although this experiment did not utilize satellite technology, it did provide important information on the practicality and the economic viability of a satellite relay system

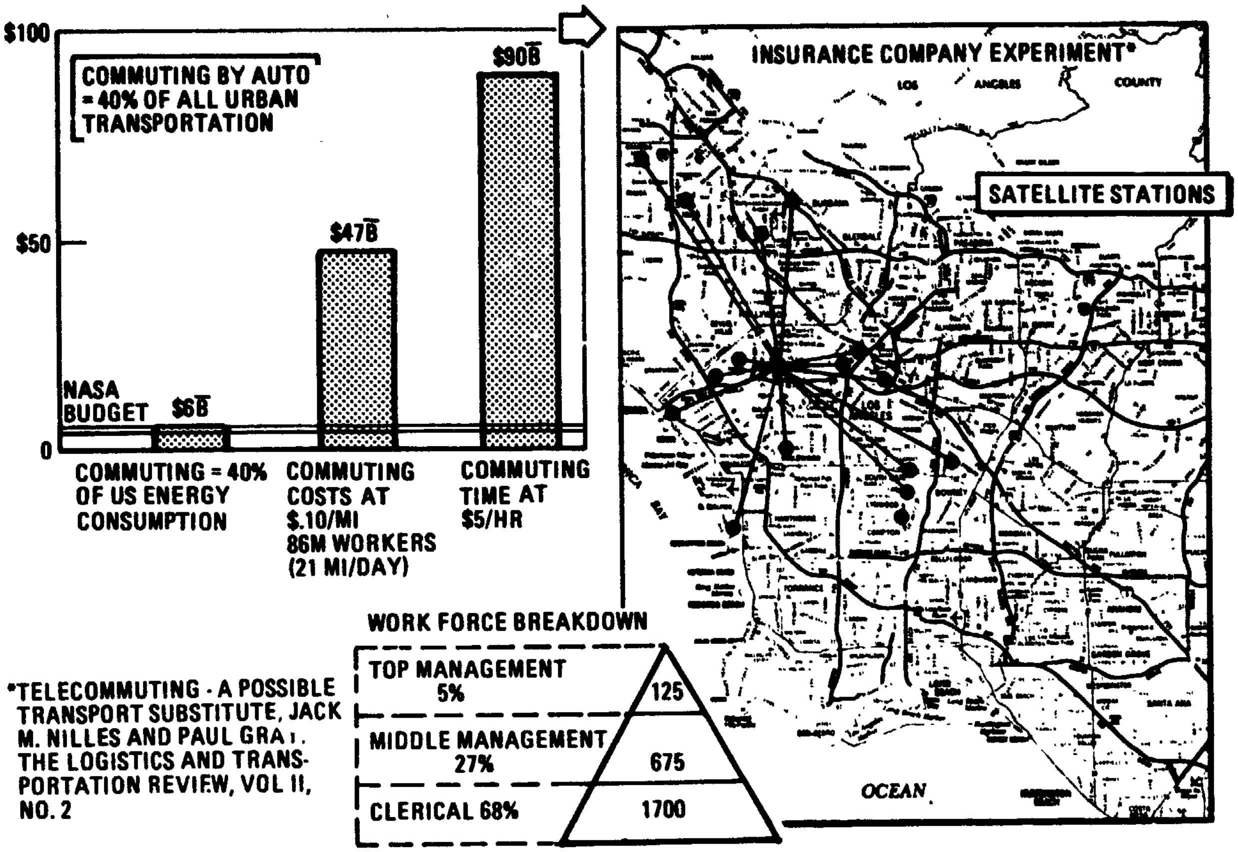

Figure 8. Electronic Telecommuting

The insurance company, with offices in downtown Los Angeles, employed 2500 workers, 1700 of whom did routine clerical work that did not require face-to-face contact. The primary job of these workers consisted of entering data into computer terminals. Because of high rental costs, the company officials decided to open two small offices in the San Fernando Valley. Then, rather than have all the workers report to the downtown headquarters, some of them (those who lived in the local area) were permitted to drive to the San Fernando Valley locations and operate electronic terminals whose impulses were transmitted to the downtown location. Because of the success of this operation, the company now plans to open two additional electronic offices in the Los Angeles area. Using this practical experience as a guide, they have employed special computer simulations to determine the savings that would result if they installed terminals in as many as 18 other locations.

This electronic telecommuting experiment produced surprisingly large benefits for the company. The major savings included reduced headquarters lease costs (because the satellite terminals were located in the lower-rent districts) and reduced salaries (premium salary rates were not necessary in the more desirable suburban areas). In addition, the employees saved about $1 million in reduced transportation costs. Altogether, the total savings amounted to about $5 million per year, spread over about 2500 employees, or about $2000 per employee.

If we would install a similar nationwide system, using satellite relay links, many workers could live anywhere they chose. Such a system could easily be instituted within the continental United States. An alternate use of the electronic telecommuting concept would be to export service jobs across international borders without actually moving people. This would help spread international work loads and provide satisfying job opportunities to those people who live in isolated areas.

The use of space technology for earth observations and information acquisition is as important as its use for information transmission, and it, too, can provide major benefits to the developing countries as well as our own. Perhaps the most commonplace examples are the weather maps that are shown on regular television weather forecasts. Among other tangible benefits, these observations have given us advanced hurricane warnings, thereby saving hundreds of people from injury or death. As these systematic observations help us to understand our weather and climate, we can respond more productively. It is not hard to see how accurate and reliable five-day weather forecasts could save billions of dollars for the agricultural, travel, and recreational industries alone. Moreover, accurate longer-range weather forecasts would make our lives more pleasant and convenient.

Space technology can also help researchers map the location and extent of the world's natural resources so that we can begin to use them more judiciously. Snowpack estimates and impounded water measurements can aid in the planning and production of hydroelectric power while minimizing the probability of unexpected flooding. And worldwide crop measurements using multispectral scanners can aid in production planning and famine relief.

PRODUCTS

Many production processes can greatly benefit from the low gravity levels, the hard vacuums, and the lack of vibration in the space environment. The possibilities of using these properties in making large perfect crystals, metals with special properties, new glasses, and many other beneficial products have been studied by many researchers. Those that have high enough value per kilogram to indicate an early payoff are currently being investigated both in the United States and in foreign countries—especially the Soviet Union, West Germany, and Japan.

Although scattered experiments have been performed, no attempts have yet been made to produce space-made products in useful quantities. In part, progress in this important area of research has been obstructed by the lack of an economical two-way transportation system. However, the Shuttle Transportation System will be available in about two years; and soon thereafter, broadranging experiments will be conducted, hopefully leading toward full-scale production efforts. A listing of some of the more attractive space products is presented in Table 2. At this time, it is extremely difficult to separate the winners from losers, but, once the Shuttle/Spacelab begins making regular flights, some winning combinations will surely be found that will spawn whole new industries and contribute to our economy and our quality of life.

One material—urokinase—provides an excellent example of how space processing could have important beneficial impacts on the general public. Urokinase is an enzyme (biological catalyst) which is produced within a small group of specialized cells located in the kidney. It is the only known natural biological substance that can dissolve blood clots in the human bloodstream. Free-floating blood clots are extremely hazardous; they cause phlebitis, coronory thrombosis, pulmonary embolisms, and crippling strokes.

Today the only available method for producing urokinase involves its separation from human urine. This process requires the collection and processing of more than 2000 pounds of urine to obtain enough for a single treatment. Consequently, urokinase is very expensive; a single dose currently costs about $1200. The separation procedures used in ground-based laboratories are hampered by the earth's gravity which induces sedimentation and harmful convection currents. Fortunately, recent experiments carried out onboard Apollo, ASTP, and Skylab have shown that urokinase cells can be separated much more efficiently in the weightlessness of space by using electrophoretic separation procedures. The electrophoresis equipment (see Figure 9) separates the cells by means of small differences in the electrical charge and molecular weight among the cells. Separate experiments indicate that the enzyme can be produced at a faster rate in a weightless spacecraft than is possible in the terrestrial environment.

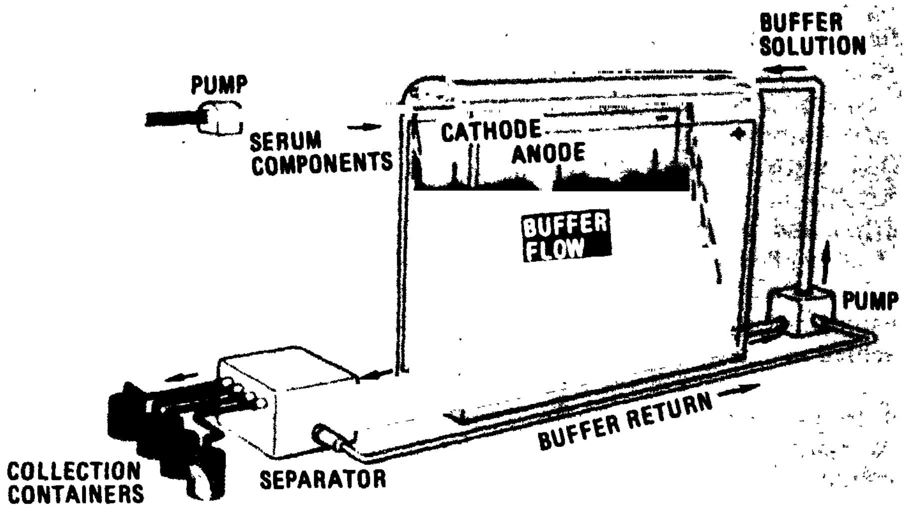

Figure 9. Electrophoresis Equipment

Since previous experiments involving urokinase (and similar materials) have indicated the possibility of high production rates of pure urokinase in space, it seems likely that large quantities can be made available by the mid-1980's. As space-based production rates increase in the mid-1980's, its cost should decline substantially, and its use become more widespread. Our studies indicate that the total world market for urokinase could be satisfied by 1995.

It also seems probable that large perfect crystals can be manufactured economically in space. Crystals of reasonable quality can be grown from a fluid mix under terrestrial conditions, but extremely pure and regular crystals–such as those needed by the electronics industry–can be produced only with great difficulty. Convection currents, gravitational distortions, and contact between the crystal and its supporting crucible create imperfections in the crystal lattice structure. In principle, the production of crystals in space would be extremely simple: a polycrystalline solid would be melted by using float-zone procedures, and upon solidifying, it would automatically develop a monocrystalline structure.

Several iterations were made on space processing concepts before coverging on a final design. One early concept called for a small free-flyer which would make large, perfect boules for the semiconductor industry. Two end products were envisioned: (1) large transistor devices for the rectification of high voltages and strong currents and (2) large perfect crystals to allow manufacturers to pack increasingly large numbers of circuits on a single LSI chip.

In the case of large transistor devices, our goal was to make enough large solid-state crystal rectifiers in sufficient quantities to allow efficient ac-to-dc conversion. Large crystals can be made under terrestrial conditions, but their imperfections create undesirable hot spots which severely limit their current-carrying capacities. If dislocation-free versions of these devices were available, existing ac lines could be used to carry enough dc power over long distances to partially alleviate periodic peak load problems. (The use of dc transmissions would cut line losses to a substantial degree and eliminate the need for synchronizing the two ac networks.) With two or more such substations, we could interconnect electrical power grids across time zones and weather patterns thus dramatically affecting the lives of millions of people. With increasing fuel shortages, it seems highly probable that brownouts will be common occurrences in the late 1980's, and a space-made product would be gratefully acknowledged if it decreased these problems by sharing power from, say, Houston to New York.

As we progressed in the study, we became increasingly aware of the difficulty of providing power in sufficient quantities to run large-scale factories in space. Naturally these factories would be designed to be more energy-efficient than their current terrestrial equivalents, but even under the best possible assumptions, their power demands turned out to be extremely high compared with anything we have launched into orbit to date. However, in considering the power levels of the SPS program, 500 kilowatts in a low-altitude orbit seems like a reasonable intermediate step toward 5,000,000 kilowatts in a geosynchronous orbit. In view of the desire to utilize the SPS as a technology driver and to get immediate and useful benefits from its development program, we designed the facility shown in Figure 10. This design utilizes the Shuttle external tank as the basic structure attached to an SPS-type solar array constructed by using the "beam machine" continuous process. A demonstration of the beam machine in operation linked to a power-augmented Shuttle orbiter is presented in Figure 11.

A natural evolutionary process leading to large-scale space processing operations is laid out in Figure 12. The Space Shuttle orbiter, upgraded with additional power for extended on-orbit stay time, will facilitate the early operations necessary to prove out the processing concepts. These operations should also result in some marketable products and materials. The next steps consist of small, Shuttle-tended free-flyers and a special space processing section of a manned space base which permit us to make large quantities of high-value products for earth markets. Recent studies, particularly those conducted by Science Applications Incorporated, indicate that thousands of tons of crystals, glasses, and metal items will probably be processed in space by the turn of the century. These large-scale operations will require major, dedicated factories that utilize hundreds of kilowatts of electrical power. In the concept shown in Figure 10, this power is supplied by a collector similar to, but several orders of magnitude smaller than, an SPS solar array.

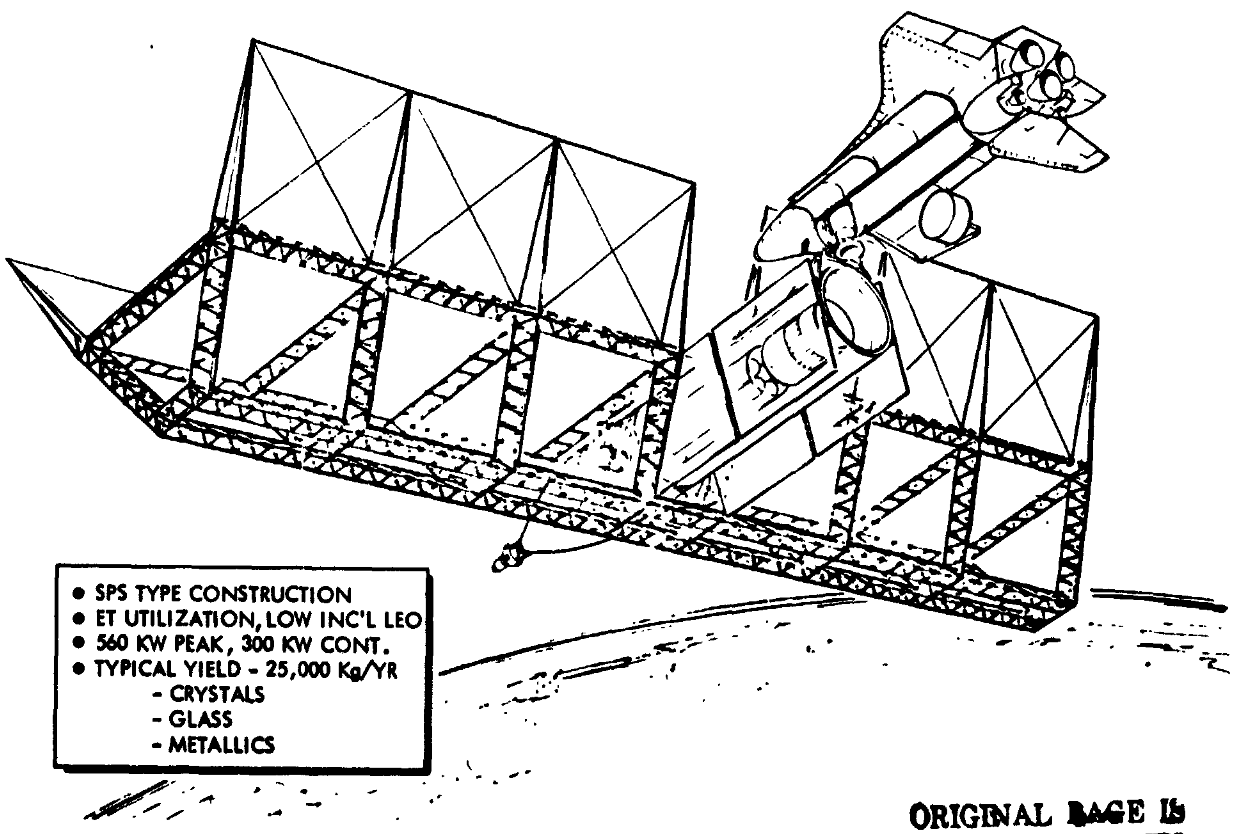

Figure 10. In-Space Factory

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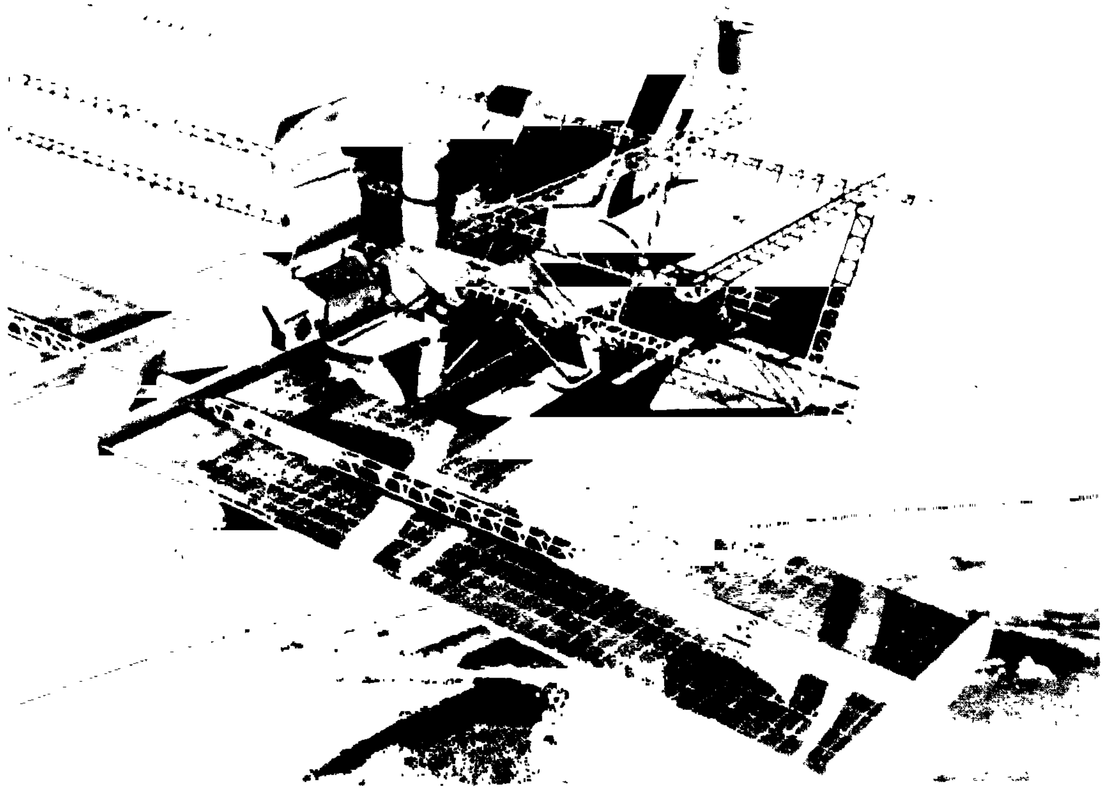

Figure 11. Large Space Structure Fabrication Process

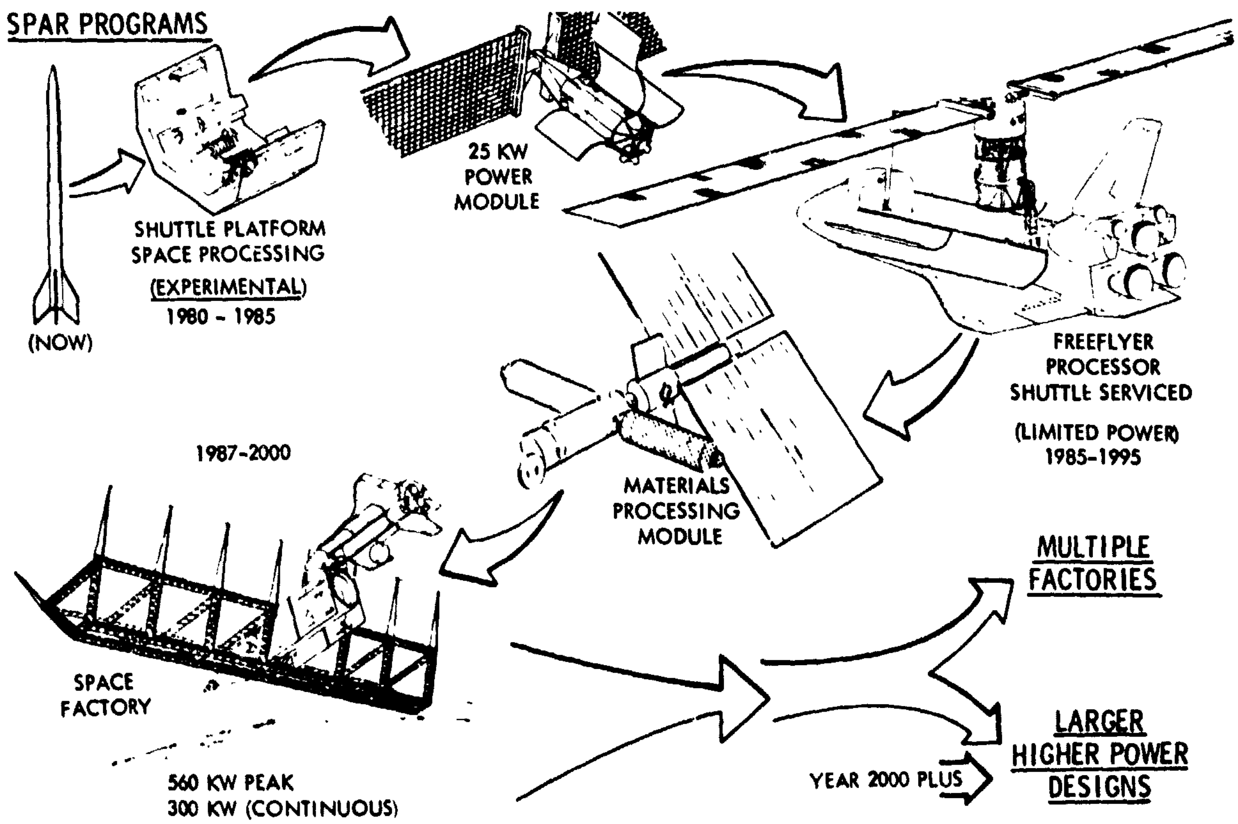

Figure 12. Space Processing Evolution (20-Year Span)

Numerous other products have been proposed for production in space. These include vaccines, special optical glasses, high-strength permanent magnets, high-temperature turbine blades, and contact lenses. As has been mentioned, it is not clear at this time which products will actually turn out to be winners. What does seem clear is that some high-value products will be manufactured in space in large quantities, and they will be economically competitive with similar products manufactured on the ground.

ENERGY

Space industrialization offers many methods for conserving and augmenting energy supplies. Electronic telecommuting and electronic teleconferencing are two examples that could help curb fuel consumption. In addition, energy could be saved by more accurate weather forecasting, and better snow pack measurements would permit more realistic water impounding to increase our production of hydroelectric power. The large dc rectifiers mentioned above would reduce the use of fuel-inefficient, peak-load turbine power plants. Higher temperature turbine blades, made in space, would also help us conserve our energy supplies. Even a 10-percent increase in operating temperatures would result in annual savings of millions of tons of coal and millions of gallons of aviation gasoline.

Space industrialization technology can also benefit us via the large-scale exploitation of new energy sources. The SPS is perhaps the best known example. As we see the situation with regard to the SPS, we are now in a stage of technology development that will help us find out whether we do, indeed, have the option of obtaining power from space that is economical, continuously renewable, and environmentally safe. It is our belief we should check out this option; and if it is not open to us, we should take appropriate steps in other energy directions.

The energy that can be intercepted in space exceeds the energy that can be intercepted by a similar facility located on the ground by about one order of magnitude. Moreover, the energy provided by the SPS is available 99 percent of the time—thus alleviating the storage problems associated with ground-based energy collection systems. For its size, the SPS can be remarkably lightweight. It can be constructed from extremely thin materials because of the virtual lack of gravitational forces in space and because of a seldom mentioned space-environmental property—no winds. An earth-based collector array of comparable average power levels would have to be hundreds of times heavier because it would have to be strong enough to support its own weight and resist the forces of high winds. In addition, it would have to be larger to compensate for losses due to the atmosphere, clouds, nightfall, and off-normal sun orientation.

A Rockwell International design of the SPS (which was developed under a separate contract) is shown in Figure 13. It covers a total area of about 82 km^2, weighs 36,000,000 kg, and generates 5,000,000 kW of useful electrical power. Gallium-aluminum-arsenide solar cells are used with a concentration ratio of 2 to 1. These advanced materials were selected because of their higher efficiency levels and because under the proper temperature conditions, these cells are self-annealing, a natural process which protects them to a degree against efficiency losses due to space radiation.

The energy collected in space would be beamed to the ground via the microwave array located at the center of the SPS (see Figure 14 for an artist's concept). Because of the vacuum of space, unenclosed klystrons can be used in generating the microwave beams. Although at ground level the beam contains less energy than ordinary sunlight, it reaches the ground continuously day and light, and it is in a form that can be converted into electricity at about 85-percent efficiency. This compares with the less than 15-percent efficiency that can be achieved in producing electricity directly from noonday sunlight using solar cells.

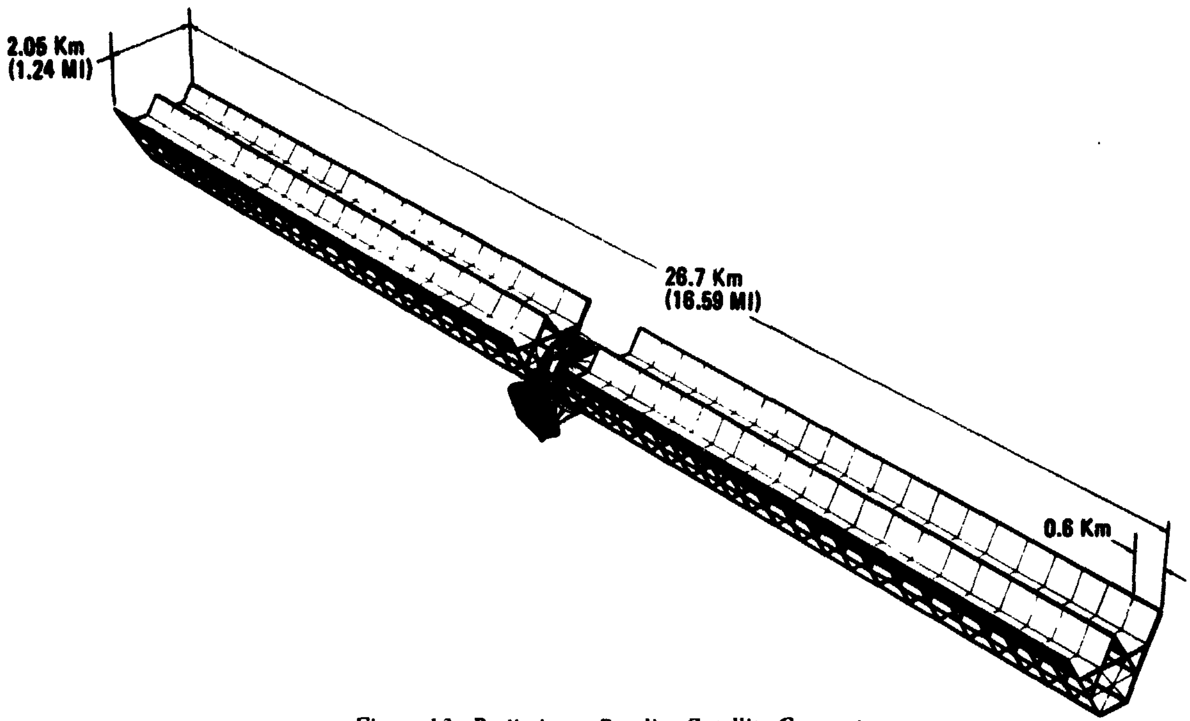

Figure 13. Preliminary Baseline Satellite Concept

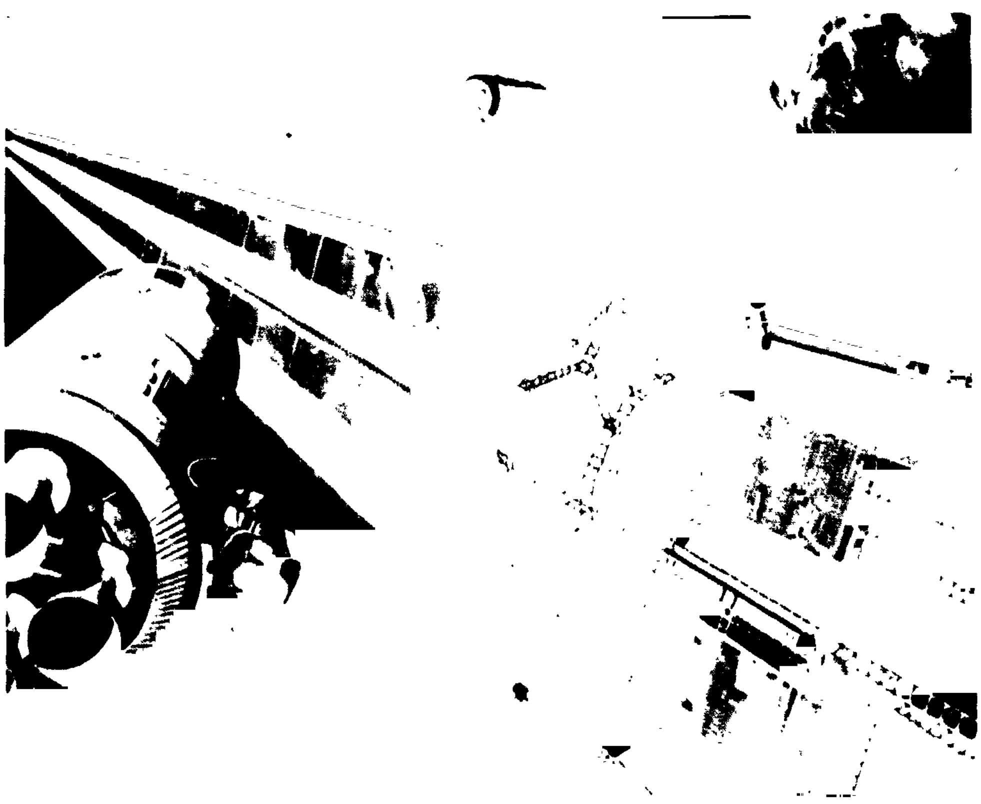

Figure 14. Five-Gigawatt Solar Power Satellite–Artist's Concept

Although its proponents correctly note that no new technological breakthroughs are necessary to construct the SPS, it does involve enormous engineering difficulties. It will be competitive with terrestrial power sources only if the cost of space-rated solar cells drops by about 2 or 3 orders of magnitude, and space transportation costs drop by a factor of about 25. Moreover, each SPS would be huge, but extremely light. To have an appreciable impact on our energy problems, and to capitalize on the economies of scale, it will be necessary to construct approximately 100 SPS units, which, all together, would be about half the size of Connecticut.

Still, these difficulties are not necessarily beyond the capabilities of modern technology. As we have seen, order-of-magnitude decreases in the cost of electronic devices and transportation systems have been taking place every few years, and large, lightweight structures in space seem to be particularly well suited to the environmental conditions in space. If it can be made to work, the SPS holds such promise for ensuring a new source of clean, safe, and abundant energy that we owe it to future generations to examine this option carefully to see if it is a genuine possibility. In the meantime, we should structure the program so that the hardware units pay handsome dividends in other key areas of space industrialization.

Other energy-producing opportunities in space include the Lunetta, which reflects sunlight to localities on the dark side of the earth, and the Soletta, which reflects substantial amounts of solar energy, typically providing one solar constant over limited regions of the earth, both day and night. The exploitation of new energy sources can also be aided through the manufacture of special deuterium-infused glass spheres for use in laser fusion reactors and by conducting fusion research in orbit. These reactors yield superior performance in the easy-to-obtain hard vacuum of space because the enclosing vessel can be significantly enlarged, thus keeping the high-energy neutrons from brutalizing the wall materials of the enclosing vessel and creating impurities which tend to quench the fusion reactions.

HUMAN ACTIVITIES

Human activities in space have excited man's imagination throughout the space program and they still make the headlines far more frequently than the many other facets of space. The human spirit needs the promise of a better future and the challenge of distant worlds. This era of the "high frontier" marks the first time mankind has ever had a frontier that is only 200 miles away from every person on earth. There is an emerging, uplifting spirit becoming widespread, especially among the young; and space (encompassing both pragmatic reality and fiction) is its focus. Space colonization, which claims its own devoted following, has many similarities to space industrialization, but its motives are fundamentally different. It is our opinion that a flourishing space industrialization program will do much to turn the dreams of colonization into hard reality; however, the time scale will be expanded more than most space colonization enthusiasts might desire. The large-scale operations envisioned within the space industrialization program will inevitably cause hundreds, perhaps thousands, of workers and technicians to pierce the high frontier. Thus in addition to providing real benefits to millions of people living and working on earth, space industrialization will give rise to numerous new earth-based specialties and space careers.

PROGRAMMATIC IMPLICATIONS

During the course of the study, parallel efforts were conducted to extrapolate both mankind's needs and technical opportunities into the future. The resulting lists of human needs were then used to trigger new ideas for space opportunities. This feedback process helped us uncover some 300 specific human needs (there could be many others) and some 200 promising space opportunities. By careful evaluation and judicious combination, the 200 opportunities were pared to about 100, each of which was then written up to a specific 12-point "merit-criteria" format for more detailed evaluation. It was intended to further reduce the list to some 25 outstanding opportunities upon which an evolutionary space program could be firmly anchored. However, as the evaluation proceeded, we found it surprisingly difficult to throw out very many of the apparent opportunities. Hence our list of so-called anchor opportunities still numbers about 50, each of which seems both worthwhile and cost-effective within a time frame extending to the year 2010.

As we looked at the options and the opportunities, we interviewed large numbers of people, within our own company and outside, and in and out of the aerospace industry. About 100 evaluators, young and old alike, and of various ethnic and technical backgrounds, helped us develop an overall program philosophy. It includes a specific set of attractive opportunities in the areas of services, products, energy, and human activities.

SERVICES

The service opportunities we recommend for implementation are listed in Table 4. Note that the time frames range from the year 1980 to the year 2010. Within these specific time frames, R stands for research, D for development, O for operational. An arrow following the O indicates a plateau of capability. An O' or O" indicates a step increase in capability each is essentially a Block II or quantum jump increase.

Prudent engineering will allow us to achieve many separate services with the same basic machinery. However, in our view, the most heavily publicized portions of the service program should be the anchor opportunities that are listed in Table 4. As can be seen, many of these opportunities relate directly to our desires to reduce fuel consumption and to improve the quality of urban life, to reduce the soaring costs of universal health care, to help feed a growing world population, and to understand and predict our weather and climate.

We believe that the acceleration of the opportunities indicated will pay big dividends, particularly in developing countries. In the long run, the creation of customers (with buying power) in the developing and heavily populated countries is the most important overall world contribution that industrial countries can make, both for their own well-being and for a better world. In addition, methods for achieving a fuller understanding of our climate and weather should be sharply accelerated on the reasonable chance that we might encounter major payoffs before the turn of the century.

PRODUCTS

As stated previously, the specific winners in the products area (Table 5) are hard to predict until at least some of the Shuttle/Spacelab experiments have been conducted. However, we are confident that space electrophoresis will work and that the cost of urokinase will be reduced to affordable

Table 4. Anchor Opportunities – Services

Anchor Opportunities	Time Frame 80-85	85-90	90-95	95-00	00-10
	Services				
Transmission					
Direct-broadcast education-U.S.	O	O′	O″	→	→
Direct-broadcast education-Developing countries	D	O	→	O′	O″
Business system data transfer	O	O′	O″	→	→
Electronic telecommuting	R	D	O	→	→
Electronic teleconferencing	D	O	→	→	O′
World medical advice center	D	O	O′	→	→
Time and navigation services	O	→	→	→	→
Implanted sensor data collector	D	O	O′	O″	→
National information services			D	O	→
Personal communications	D	O	O′	→	→
Electronic mail (excluding packages)	D	O	O′	O″	→
Medical aid and information - U.S.	D	O	→	→	→
Teleoperation from space			R	D	C
Observation					
Oil/mineral location	O	→	→	O′	→
Crop measurement	D	O	O′	→	→
Ocean resources and dynamic system	D	O	→	→	→
Water resource map and runoff forecast	O	→	→	→	→
Global effects monitoring (STO)	O	O	O′	O″	→
Landsat D	O	→	→	→	→
Topographic mapping	D	O	→	→	→
High-resolution resource survey	D	O	→	→	→
High-resolution radar mapping	R	D	O	→	→
Microwave radiometer		O	O	→	→

D = Development, O = Operational, R = Research
O′ or O″ = Step increase in capability
O——→ = Plateau of activity

Table 5. Anchor Opportunities – Products

Anchor Opportunities	Time Frame 80-85	85-90	90-95	95-00	00-10
	Products				
Organic					
Isozymes (also medical diagnostic)	R	O	→	→	→
Urokinase (anticoagulant)	D	O	→	→	→
Insulin (from human sources)	D	O	→	→	→
Inorganic					
Large crystals (size and perfection)	O	→	→	→	→
Super-large-scale integrated circuits	O	O′	→	O″	→
New glasses (including fiber optics)	D	O	O′	O″	→
High-temperature turbine blades		D	O	→	→
High-strength permanent magnets	O	→	→	→	→
Cutting tools	D	O	→	O′	→
Thin-film electronic devices	D	O	O′	→	→
Continuous ribbon crystal growth	D	O	→	→	→

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levels. Since urokinase is not actually a new drug, the lengthy process of approval for use can be cut short. Every adult in our country is probably acquainted with a stroke or heart attack victim that this drug could have saved from death or invalidism by quickly dissolving the offending blood clot. As more companies realize the economic potentials of space manufacturing, they will increasingly explore, develop, and implement many other beneficial made-in-space possibilities.

In addition, we believe that other health-related products, such as diagnostic kits using isozymes, should be emphasized. Continuous-ribbon crystal growth is also quite attractive because it has the potential for lowering the cost of solar cells for use in space and on the ground.

ENERGY

The anchor opportunities in the energy area are tabulated in Table 6. Solar energy from space is easily understood and sorely needed. Of course, at the present time, no one can be sure of the technical practicality, environmental acceptability, or economic competitiveness of either the SPS or the Soletta system, but we think the U.S. technological community has the obligation to put this option within reach or else determine that it is not a viable option.

Table 6. Anchor Opportunities – Energy

Anchor Opportunities	Time Frame				
	80-85	85-90	90-95	95-00	00-10
Energy					
Reflected Solar Energy					
Night illumination for urban areas	R	D	O	O'	→
Night illumination for agricultural and industrial operations			O	→	→
Night frost damage protection			R	D	O
Reflected light for ground-electrical conversion		R	R/D	D	D
Microwave Transmission					
Satellite power system (solar)	R	R/D	D	O	O'
Fusion in space	R	R	D	D	O

Fusion is of such tremendous importance to the future of mankind that we should seriously pursue every breakthrough potential. Space seems to offer such an opportunity in that we can use its infinite vacuum to allow movement of the container walls farther away from the fusion reaction and also quickly restore the vacuum whenever impurities are introduced into the system

Also in the energy area, the use of the Lunetta to illuminate burgeoning cities on a worldwide basis could bring a benefit of space capability directly to more people than any of the other anchor opportunities. This can be accomplished fairly quickly and at a reasonable cost. We also recommend the use of the resulting large structures technology to help push us toward either reflected light for power (Powersoletta) or SPS; the decision as to which option should actually be pushed to operational status cannot be made at the present time. However, night frost damage protection as a byproduct of Powersoletta would be readily understood by the public and probably widely accepted.

HUMAN ACTIVITIES

The human activities, which are shown in Table 7, are actually support functions they support primarily the large-scale energy programs. Therefore, their timing and emphasis are based mostly on

Table 7 Anchor Opportunities – Human Activities

Anchor Opportunities	Time Frame 80-85	85-90	90-95	95-00	00-10
Human Activities					
Medical and genetic research	D	O	→	→	→
Space vacation cruises (Shuttle flights)			D	O	→
Orbital tourism (LEO Hotel)			R	D	O
Orbital Therapeutics				D	O
Entertainment and arts			O	→	→
Lunar					
Unmanned explorers	D	O	→	→	→
Lunar orbiter		D	O	→	→
Lunar base		R	D	O	→
Lunar industry			R	D	O

the crucial energy decisions. The earliest need is for the development of facilities to house in-space working personnel. Subsequently, these facilities might be expanded to allow ordinary people to go into space purely for pleasure purposes. Although this may sound as if it is only remotely related to space industrialization, the appeal of personally living, working, and playing in space is so strong and so universal, that there is little doubt that space tourism will become a reality (for some) during the lifetime of most of the people now dreaming about the possibility. We saw clear indications that these hopeful dreams were dominant in most of those individuals under 30 who participated in our program evaluation.

Man's presence on the moon will be of fundamental importance to mankind in the long run, partly because of its valuable resources and partly because of its relative accessibility to the geosynchronous orbit. Because of the moon's reduced gravity, it requires about 20 times less energy to carry a one-pound mass from the moon to geosynchronous orbit than it does to carry an identical one-pound mass from the surface of the earth to the same destination. Further lunar exploration and eventually new manned visits are recommended, but this is not the program driver and should not be the main point of public communication.

PROGRAM SUMMARY

Implementation of the anchor opportunities shown in Tables 4 through 7 would require the development of key supporting items such as

Shuttle/Spacelab	Polar platform
25-kW power module	Space base
Advanced teleoperator	Orbital transfer vehicles
Geosynchronous platform	Heavy lift launch vehicle

Their acquisition was included in the programmatics of space industrialization.

Figure 15 summarizes the thrust and direction of our proposed Space Industrialization program. As can be seen, the program is divided into three 10-year time frames starting in 1980. In the first decade, the center of activity will be in low earth orbit as we begin to use the Shuttle to its fullest possible extent. Early extensions of its capabilities should include the development of a 25-kilowatt power module that can be left permanently in earth orbit. Also in this early era we will establish a public service platform and a global weather and resources base, both of which will provide highly visible worldwide benefits. We will eventually construct a large multi-function facility in a low altitude orbit. This facility will include a construction base, a space factory, and space operations center. It will be used in helping us learn to build the large structures we need to make the 500-kilowatt power modules, SPS precursors, and operational Lunettas.

In the second 10-year interval, we will increase the capabilities of the space factory, public service platform, and global weather and resources facilities. We will also bring a satellite power system into initial operation. If this plan fails to work, possible alternatives will include fusion-in-space or the Powersoletta.

The necessary transportation elements are also sketched in Figure 15. In the 1980's, we will need only the Shuttle and its derivatives. A low-thrust interorbital transfer system will also be needed. In the late 1980's or 1990's, we will develop a large chemical upper stage capable of transporting man to the geosynchronous altitude but it will not be initially used in this mode. The research and development should start toward a new Shuttle derivative vehicle, in the size range capable of delivering components of the SPS into a low altitude orbit. Beyond the 1990's, this transportation system will become fully operational, and transportation units will also be needed to carry materials from the moon to various geosynchronous destinations.

Some of the major benefits to be derived from this program are listed near the top of each segment of Figure 15. Note that in the 1980's, most of the benefits will be in the services area, both informational and observational. The world will clearly benefit from new technologies in education, health, conservation of resources, and human productivity. Lunetta will begin to serve many cities and will be on call for special situations.

In the decade of the 1990's, we will move toward a long-term solution to the energy scarcity problem. Thus large numbers of productive workers must be stationed in space for extended periods. In this same era, the space factories will reach productive status and an operational Lunetta system will be installed in a set of five three-hour sun-synchronous orbits.

In the final time segment extending from 1990 to 2000 (and beyond), the power options will begin to come of age. We will construct additional Lunettas and utilize the moon to furnish oxygen and materials for massive energy-related projects at the geosynchronous altitude.

Beyond the year 2000, the energy produced in space will supply a major fraction of all the world's energy. Throughout the entire program, we will continue to expand services, make new products, and move toward full understanding, prediction, and localized control of the earth's weather and climate. Most importantly, people will become increasingly involved with space, first by receiving such direct benefits as information and light but later on by direct participation—even including space travel. Flourishing growth-oriented partnerships will begin to evolve between developing and industrialized countries, between the academic community and commercial interests, and between space and terrestrial activities. In terms of stimulation and excitement, these activities will impact man in much the same way as he was affected by the opening of the New World.

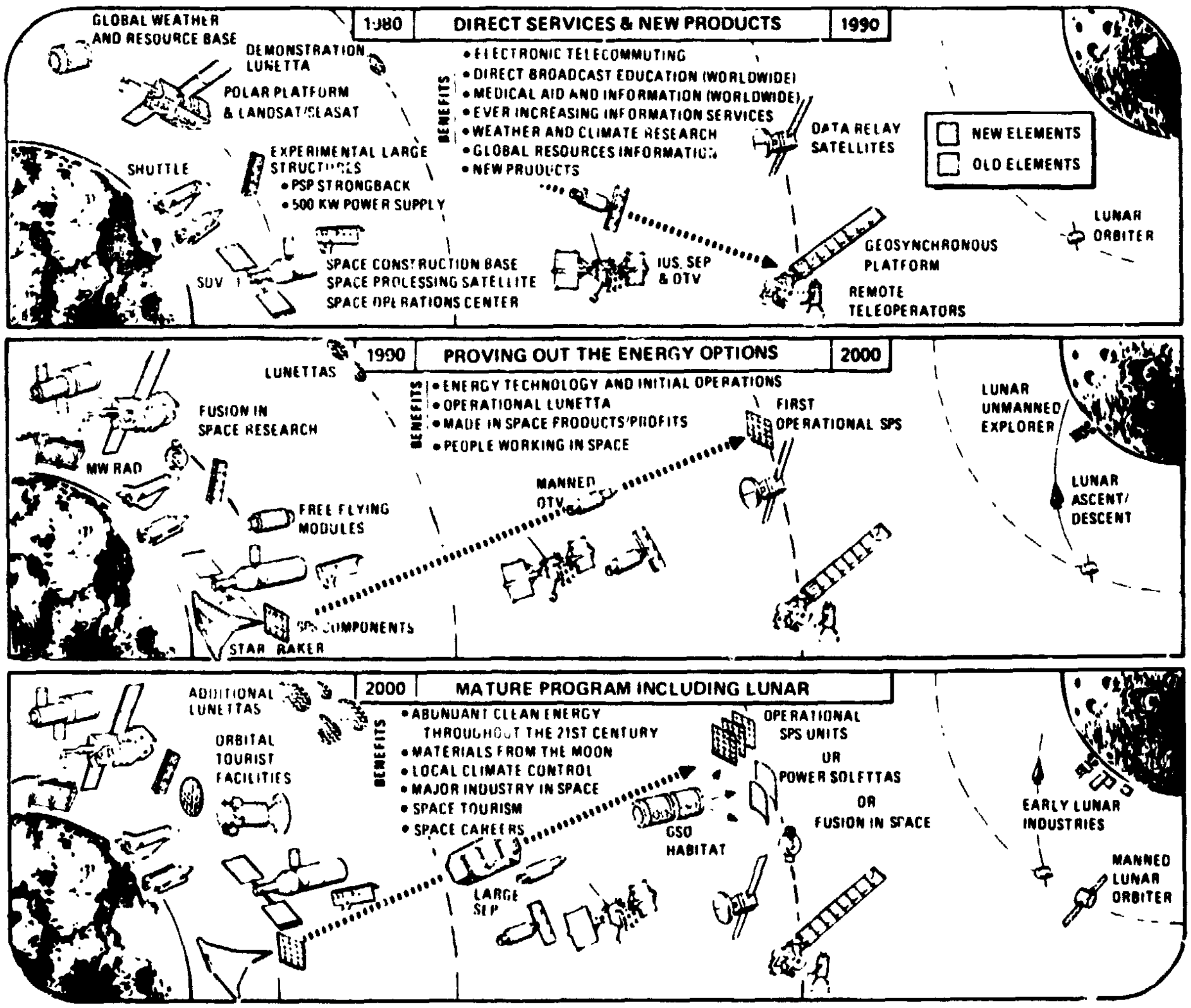

Figure 15. Thrust and Direction of Proposed Space Industrialization Program

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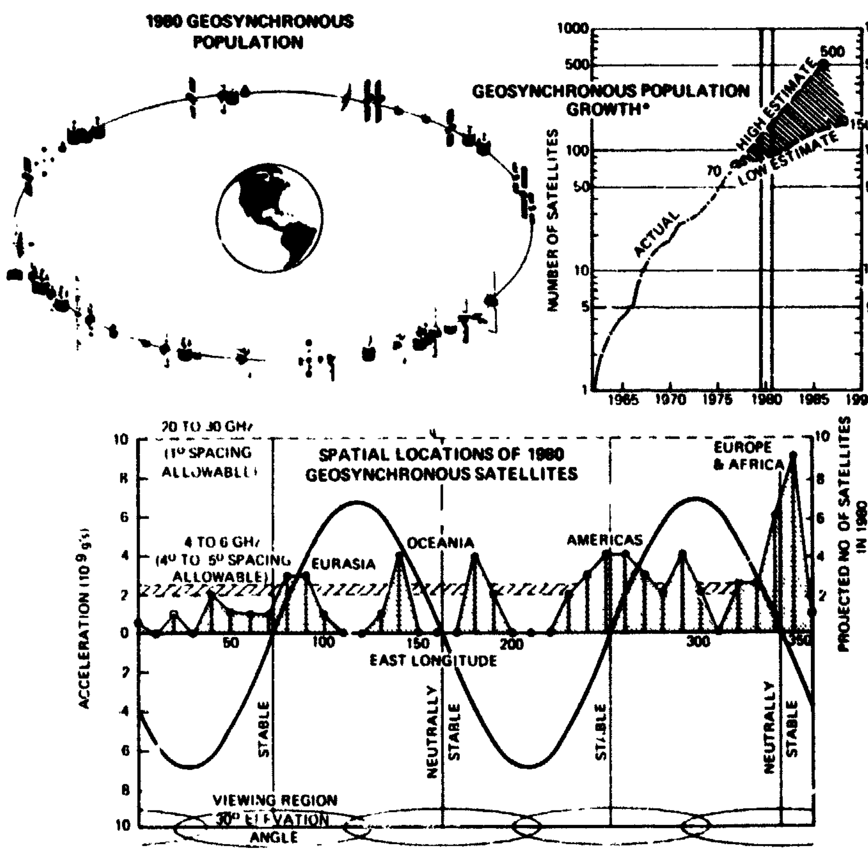
HARDWARE CONCEPTS

Most of the 65 anchor opportunities analyzed in the study had precursor systems or detailed studies on which our system costs could be based. However, several of the hardware concepts were unique. To cost these, it was necessary to develop preliminary designs. While it has not been our intent in this study to design optimized hardware systems, we did need relatively firm hardware concepts so that classical cost-estimating relationships could be applied. These relationships are primarily based on weight and complexity, although secondary factors were taken into account.

THE GEOSYNCHRONOUS PLATFORM

Our overall evaluations indicated that greatly expanded information transmission services from space were among the most beneficial activities that could be accomplished in the early time period Although there is some controversy in this area, we felt that the United States should take a bold step and design a multifunction platform of major capability with continuing reliable operation. In the interim, we foresee a proliferation of small separately owned-and-operated satellites at the geosynchronous altitude. Unfortunately, as the sketches and graphs in Figure 16 show, the thin rim of space vehicles around the earth at the geosynchronous altitude is already beginning to approach its saturation level. Today there are about 70 geosynchronous satellites, and projections indicate increased future crowding at this crucial location in space.



*DATA SOURCE ORBITAL ANTENNA FARMS, EDELSON AND MORGAN, ASTRONAUTICS & AERONAUTICS SEPT 1977

Figure 16. Geosynchronous Satellites

By installing a series of multifunction platforms, this orbital crowding can be partially alleviated. Of course, there will continue to be intense competition for the best frequencies and the best geosynchronous locations. As we negotiate with other international powers in this important arena, we should attempt to reserve the best frequencies for those services that can provide new benefits to millions of people. These frequencies are necessary to the success of the geosynchronous platform if everyone is to have his own inexpensive receiver. In those cases where the service by its nature requires only a few hundred ground stations, the frequency selection is not quite so critical to the success of the program. When only a few installations are needed, ground hardware costs are not so sensitive.

The baseline geosynchronous platform which was developed during the course of this study is sketched in Figure 17. It weighs 30,000 kilograms, is 240 meters long, and develops 500 kilowatts of RF energy. It would provide five new nationwide services to the American people:

1. Direct-Broadcast TV (five nationwide channels, 16 hours per day). In effect, the geosynchronous platform would add five new networks of broadcast capability; however, these networks would provide mostly educational and specialized programming rather than entertainment. The consumer would need to buy a one-meter rooftop antenna and a converter at a total cost of about $100. With sufficiently high-quality programming relevant to people's needs, we are convinced that virtually every American family would eventually make the required $100 investment to gain access to this material.

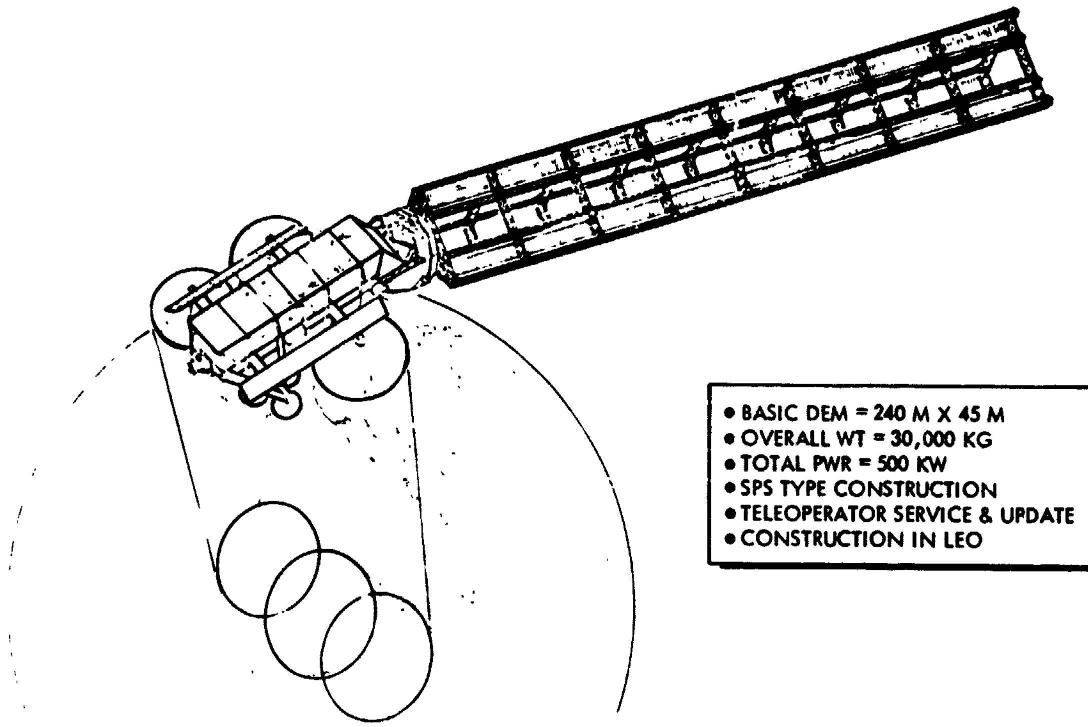
2. Pocket Telephones (45,000 private channels linked to our present telephone system). The user sets would be of the size and cost of a good pocket calculator and would allow direct calls to any person in the continental United States who owned a similar set, even if his exact location were unknown. Calls could also be made to and from conventional telephones. Each call would cost approximately 20 cents. Used on a routine basis for ordinary communications, the portable communicators would also have important safety and emergency uses.

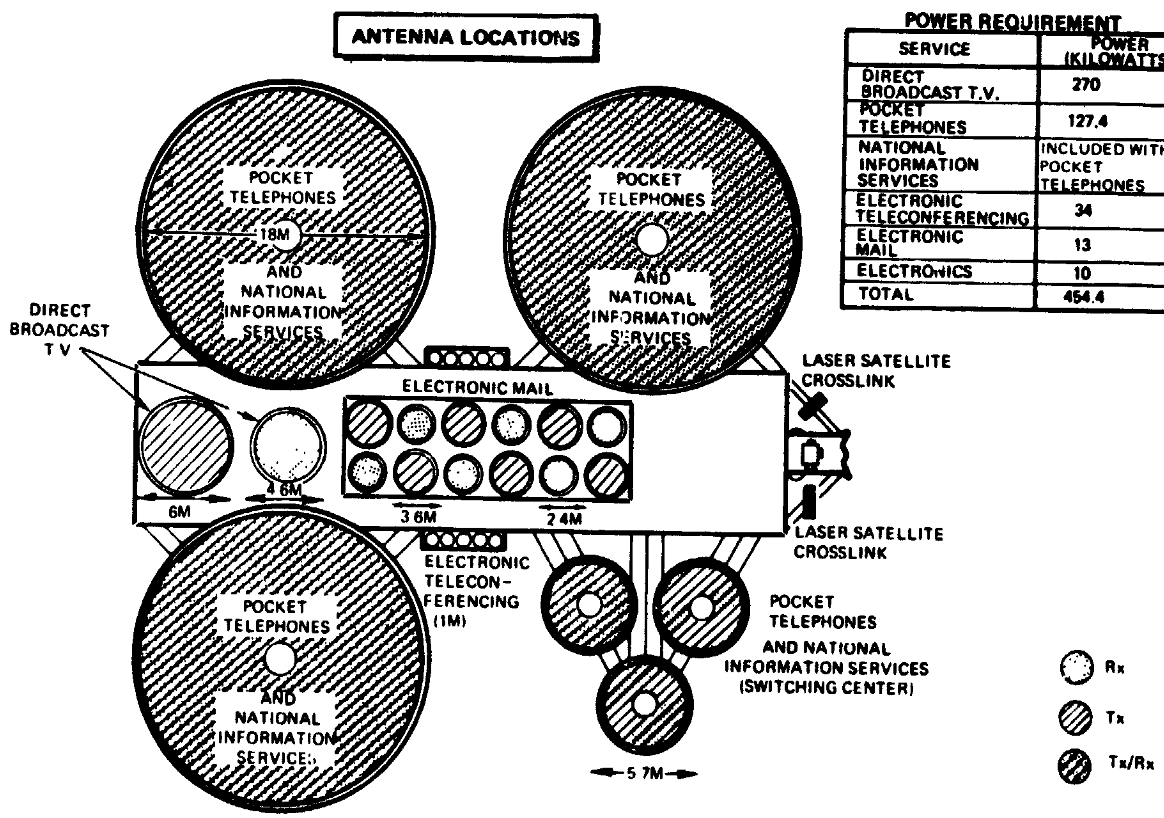
3. National Information Services. (This system would utilize the pocket telephone hardware.) With the cost of nationwide calls reduced to an affordable level, each American citizen would have access to national, rather than local data, people, calculating power, etc. Many small businesses could spring up and provide specialized national data banks or other imaginative services.

4. Electronic Teleconferencing (150 two-way video, voice, and facsimile channels). The electronic teleconferencing system would allow for as many as 150 simultaneous color video teleconferences between parties anywhere in the country. Multiple video conferences originating from three or more locations would also be possible. For clarity in communication, high-fidelity stereophonic sound systems would be included. Project Prelude, which utilized the joint Canadian-American CTS satellite, recently demonstrated the feasibility of this concept.

5. Electronic Mail (40 million pages transferred among 800 sorting centers overnight). The mail would be sorted automatically by zip code or even by mail route, plant location, etc. Major companies would probably have fiber optics or microwave relays connected to the nearest electronics sorting center.

Note that the key services provided by the geosynchronous platform (educational TV and pocket telephones) could be even more important to developing countries than they would be to the U.S. (because many underdeveloped countries lack competing terrestrial infrastructures). Therefore, nearly identical copies of the geosynchronous platform could be built to provide service to other parts of the world.





POWER REQUIREMENT

SERVICE	POWER (KILOWATTS)
DIRECT BROADCAST T.V.	270
POCKET TELEPHONES	127.4
NATIONAL INFORMATION SERVICES	INCLUDED WITHIN POCKET TELEPHONES
ELECTRONIC TELECONFERENCING	34
ELECTRONIC MAIL	13
ELECTRONICS	10
TOTAL	454.4

Figure 17. Geosynchronous Platform

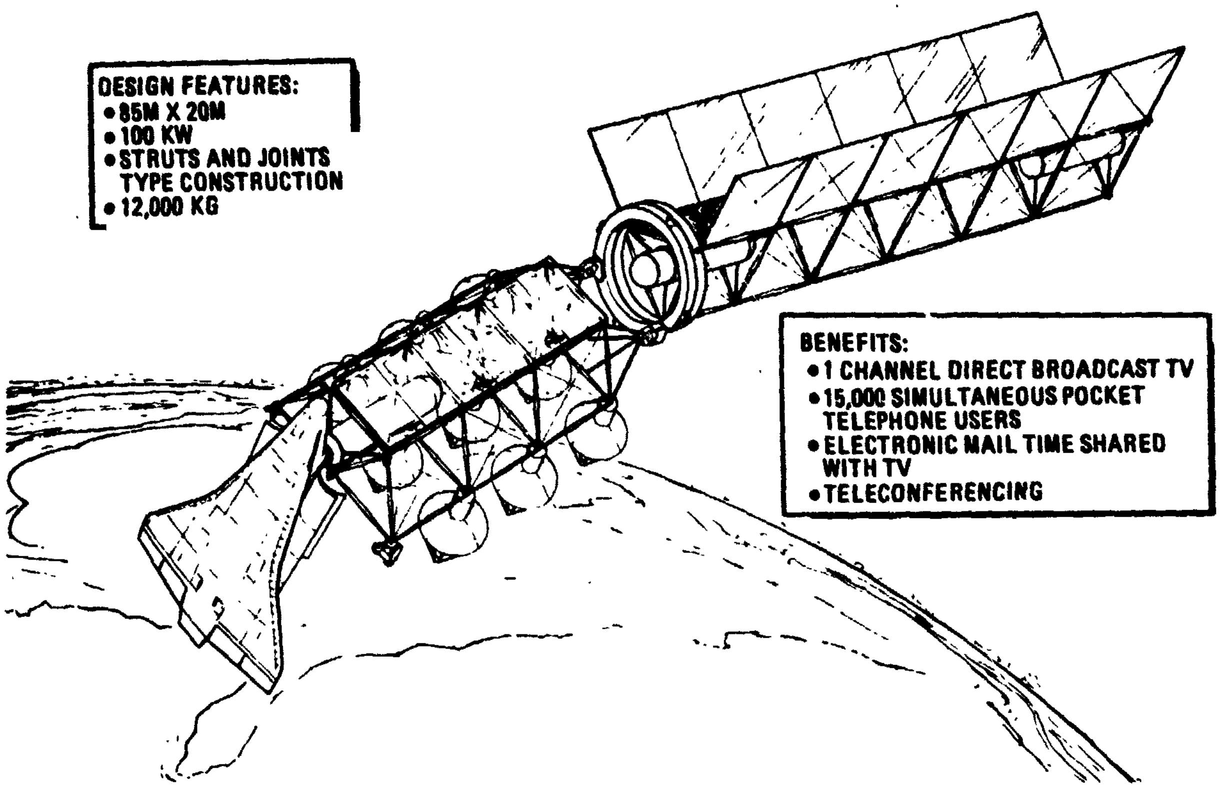


Figure 18. 100-Kilowatt Geosynchronous Platf... ı

The initial development funds for the geosynchronous platform and the first hardware item would come from public funds (shared between NASA and other benefiting government agencies). In addition to the services just described, the industrial firms could lease locations or "pads" and install their own mission-peculiar equipment. For an annual fee, the geosynchronous platform would provide the user with abundant electrical power, heat rejection, attitude control, orbit maintenance propulsions, and (perhaps most importantly) repair and updating capability.

In our designs, we utilized remote man-operated teleoperators which we think could initially be more productive and cost-effective than periodic manned missions to the geosynchronous orbital location. This is true, in part, because the teleoperator would be always available, have more eyes, hands, legs, strength, reach, mobility, etc., than a suited astronaut, and would be more radiation hardened. Eventually, as we move toward the construction of large SPS units at the geosynchronous altitude, the amount of activity in that orbit would inevitably pull man there also. Thus we believe that any intermediate hardware designs should take this natural and inevitable evolution into account.

The baseline 500-kilowatt geosynchronous platform previously discussed, provides an impressive array of services for the people of the world. But an alternate approach could be to develop a smaller, less powerful platform that might eventually be duplicated several dozen times. A smaller version of the geosynchronous platform is sketched in Figure 18. Its power level is only 100 kilowatts, it does not need the technology of SPS, and its services are also restricted t ı significant degree. For example, rather than providing five channels of direct broadcast television, it provides only one, and rather than handling 45,000 simultaneous pocket telephone conversations, it handles only 15,000. In addition, its electronic mail services are restricted to off-peak hours when the other services need less electrical power.

The resulting 100-kilowatt platform is smaller, less complex, and considerably lighter than the 500-kilowatt version. However, in view of its reduced services, it is not as light as we might expect. Although it provides only a third to a fifth of the services of the 500-kilowatt version, it weighs almost half as much. Moreover, it puts stronger demands on some of the ground equipment, thus raising overall costs. However, despite the fact that it loses some of the economies of scale, the smaller 100-kilowatt version is still a viable possibility, particularly in a situation in which the SPS technology and tooling are not available.

THE EARTH OBSERVATION PLATFORM

The hardware systems associated with several of the recommended services opportunities need to be placed into a sun-synchronous orbit for proper earth-observational conditions. The payloads associated with these anchor opportunities would be combined into a general-purpose platform, such as that shown in Figure 19. This approach entails two significant advantages: (1) a cost saving estimated to be on the order of 25 percent and (2) synergistic benefits resulting from having various important earth features sensed simultaneously by multiple sensors, thus permitting a large variety of comparisons so as to obtain cross-correlated resource data.

The sketch near the bottom of Figure 19 shows the Earth Observation Platform packaged and mounted within the Shuttle cargo bay. Two solar panels, each containing two arrays, are folded, rotated, and mounted along the two lower sides of the triangular configuration. All of the earth sensors are shown mounted on the upper surface, along with the 0.6-meter direct-access antenna for platform command and control. Depending on the final orbital altitude and inclination selected, either one or two OMS kits would be required. As the figure shows, there would be ample room for either combination of OMS kits.

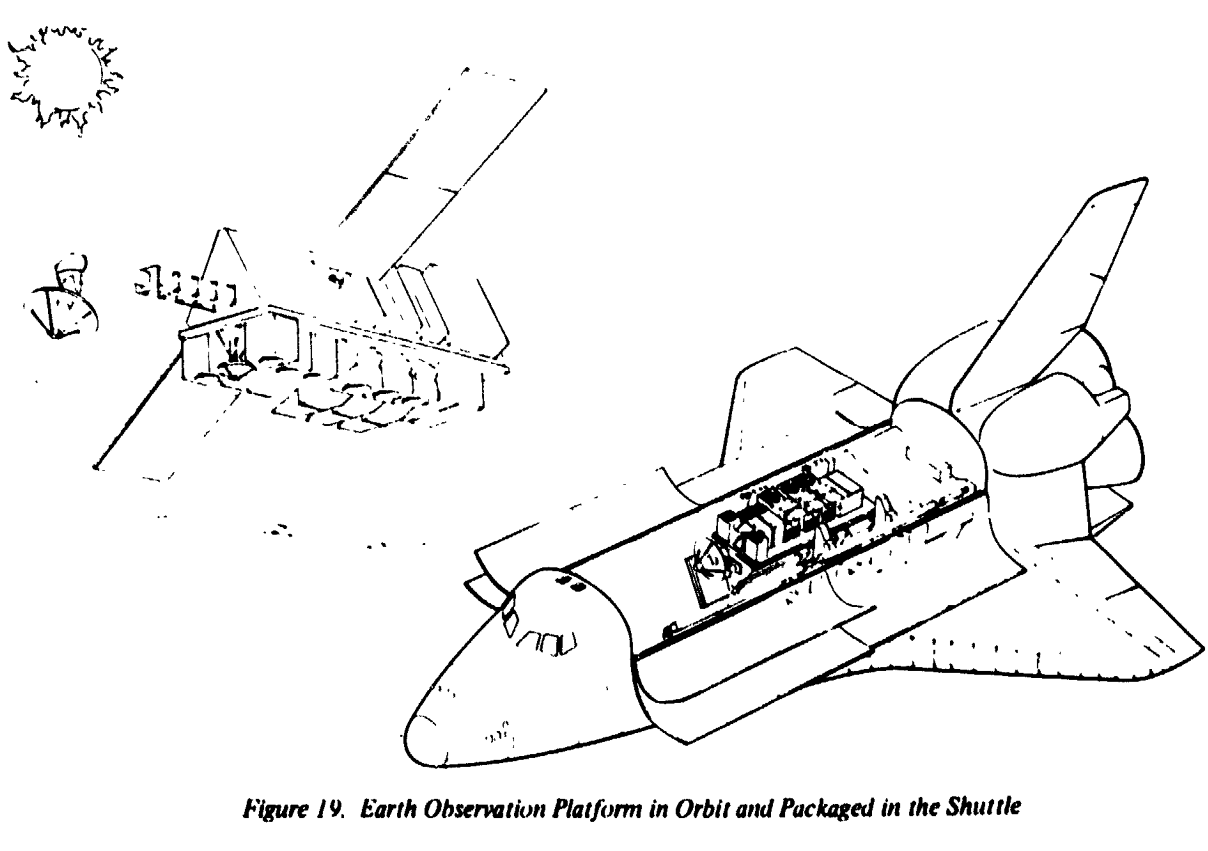


Figure 19. Earth Observation Platform in Orbit and Packaged in the Shuttle

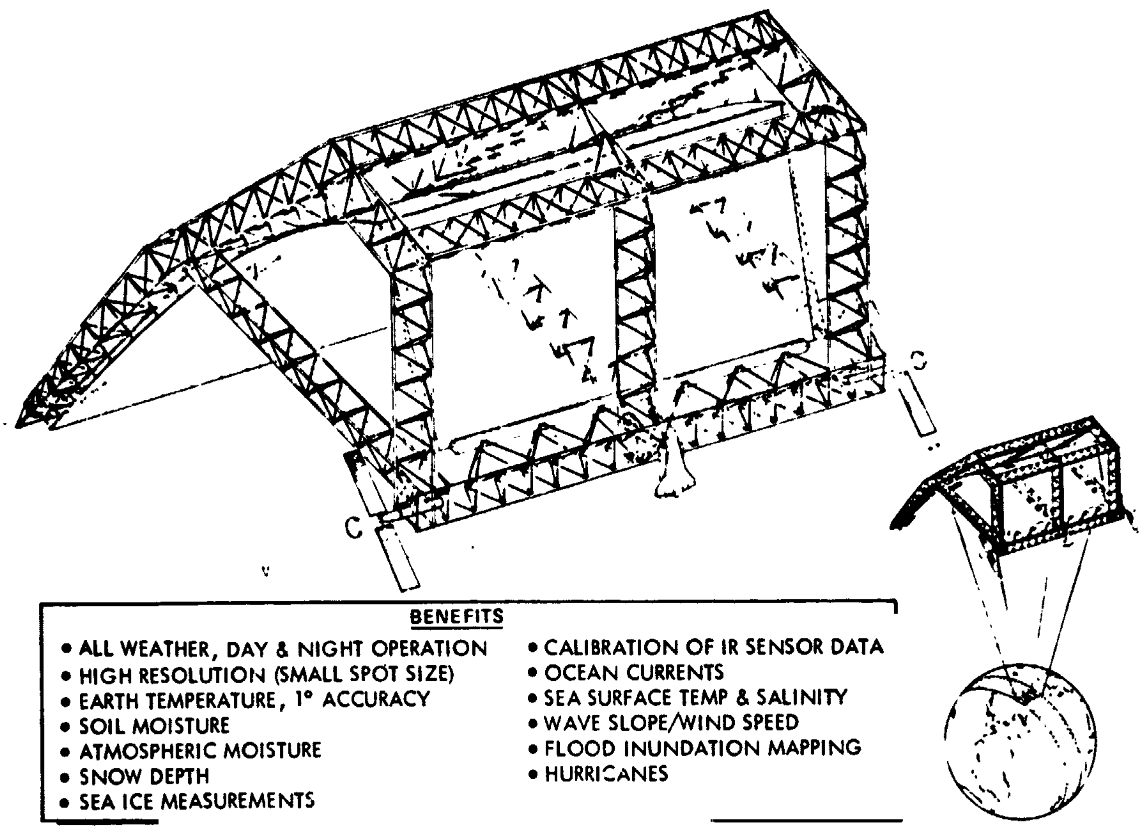


Figure 20. Orbital Microwave Radiometer

THE MICROWAVE RADIOMETER

Except for the satellite power system, the microwave radiometer (see Figure 20) is the largest space structure expected before the year 2000. It measures 262 by 200 meters and weighs approximately 250,000 kg. The docked Shuttle near the center of the drawing provides a convenient size comparison. The large size of the microwave radiometer is dictated by the desired sensitivity and resolution. Power is provided by two 25-kilowatt solar power modules shown affixed to opposite ends of the lower front beam.

Because a major portion of the earth must be viewed to provide the desired data, a high inclination orbit is required. Repeating ground tracks would be provided on an 18- to 20-day cycle. Some of the areas that would benefit from the microwave radiometer are those listed at the bottom of the figure. As in the case of the earth observation platform, data would be relayed via TDRS to ground stations or to a data processing station in a low altitude orbit.

THE SPACE PROCESSING FACILITY

The Space Processing Facility (see Figure 10) consists of two basic structural elements: a solar cell power array and a modified external tank left in orbit by an earlier Shuttle. The solar array accommodates six gallium-aluminum arsenide cell blankets that measure 16 by 14 meters. The structure is assembled from four space-manufactured beams that are connected to the interstage area of the external tank. Total length of each beam is 106 meters.

On orbit, the entire configuration is oriented with the solar cell panels normal to the sun, providing a peak power of 560 kilowatts. The interior of the LH_2 tank is configured for equipment insertion while on orbit. For space processing, a continuous power level of 300 kilowatts is available from a bank of nickel-hydrogen batteries assembled in a 4-meter-diameter module which is 12 meters long. The remainder of available length (approximately 11 meters) in the LH_2 tank is reserved for process equipment of various types (furnaces, magazines, etc.). The present configuration is estimated to weigh approximately 68,000 kg, with the external tank accounting for 34,000 kg of this weight. Raw material resupply is estimated at 45,000 kg per year including expendable gases.

The facility is outfitted primarily for zone refining and crystal growth. Its 15 furnaces are capable of producing 750 boules of finished product every 60 days. With Shuttle servicing of raw material magazines and return of finished products, the space processing facility produces 4500 boules weighing 21,150 kg in a typical year. Thus it would take a total of 30 Shuttle flights per year to service ten such processing facilities with a total annual yield of over 200,000 kg of finished products.

COST ESTIMATES

To assess the programmatic impacts of the proposed Space Industrialization program, it was necessary to estimate the recurring and nonrecurring costs required to implement each of the 65 anchor opportunities. The objective of this analysis was to produce cost estimates that would be valid within a range of ±50 percent. Four sources of potential funding were evaluated for each anchor opportunity: (1) NASA, (2) other U.S. Government agencies, (3) foreign governments or consortia, and (4) commercial interests. Of course, NASA's charter restricts it to developmental and supporting activities. Consequently, funding for the acquisition of the productive, operational satellites was assumed to come from the specific government agency having jurisdiction over the function supported by the satellite.

Figure 21 shows the cumulative funding curves for the case in which a go/no go decision is to be made on the development of an operational SPS by the year 1987. The two bar charts represent the funding magnitudes for 1983 and 1987–the two years with the peak funding requirements. Note that even in these peak years, the total requirement from all sources combined never exceeds $3.8 billion per year. The peak in 1983 stems primarily from electronic mail and SPS development, which together totaled $1.7 billion. The average funding between 1981 and 1987 (the SPS decision point) turns out to be a little less than $3 billion per year.

Estimates were also made on the annual number of extra Shuttle flights required to carry out the Space Industrialization Plan. Bar charts defining these numbers are presented in Figure 21. As can be seen, the number of flights devoted to space industrialization approaches 40 per year in the late 1980's.

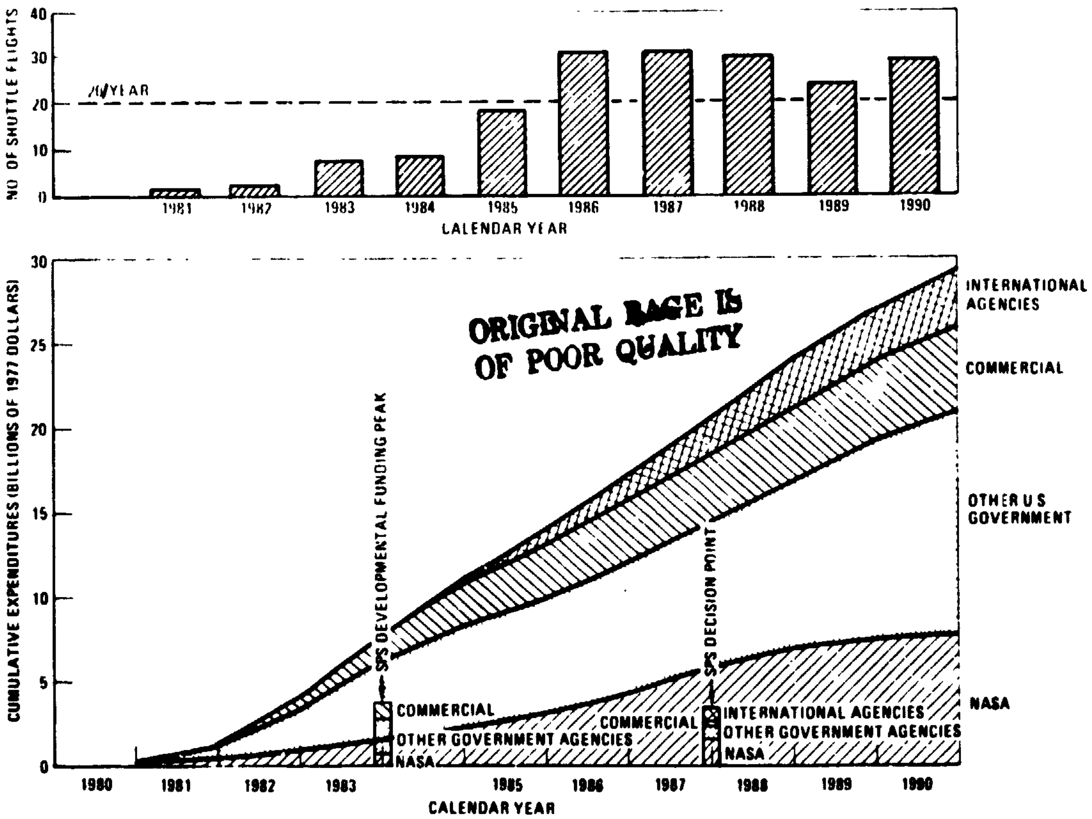


Figure 21. Cumulative Expenditures and Annual Number of Shuttle Flights for Space Industrialization

The costs associated with this rather ambitious program are quite modest. And when these costs are spread out over the enormous number of people who would benefit, the annual per capita expenditures turn out to be a pleasant surprise. Table 8 presents some of these per capita costs for a representative sampling of the anchor opportunities. As this table shows, each individual's annual cost for having the opportunity to utilize the pocket telephone is on the order of 33 cents; his annual cost for having the opportunity to watch five additional nationwide television channels is 32 cents. Note that these figures do not include the purchase price of the user sets nor the user fees for those who decide to exercise these options. However, because of the scale of the services being provided, these costs, too, are expected to be quite modest.

Table 8. Annual per Capita Costs of Representative Opportunities (Based on Capital Recovery in 10 Years at 10 Percent per Year)

Anchor Opportunity	Cost per Capita per Year (USA)*
Pocket telephones	33 cents
Direct broadcast education (5 channels)	32 cents
World medical advice center	20 cents
Medical aid and information	37 cents
National information service (Library of Congress)	39 cents
Crop measurement	23 cents

*Costs shown are system costs and do not include user charges.

CONCLUSIONS

The overall conclusions of the Rockwell International Space Industrialization Study are summarized in the following paragraphs. Although forecasting 30 years or more ahead is always suspect, some trends are fundamental. One of these is that we will almost certainly experience a doubling or tripling of world population in the next 100 years. Barring major catastrophies, an ever-increasing majority of the people on earth will live in developing countries. These countries will control vast mineral resources and a huge potential pool of labor; but without the technology of the developed world, their full potential will not be realized—at least not within this century. The relationship between the rich and poor nations is thus one of the major determinants shaping our national as well as our global future. The industrial utilization of space can be of paramount importance to this nation, and it can facilitate the advancement of developing countries throughout the rest of the world.

The most immediate rewards and the most attractive investment opportunities in the 1980's will be in electronic services. These service opportunities include both information transmission and data acquisition. The number of market opportunities is quite large, yet these opportunities can be implemented by a relatively few large, highly common electronic payloads. The economic viability of these services is a direct by-product of the capability of the Space Transportation System (particularly, the Space Shuttle) to economically deliver, assemble, and maintain the orbital facilities.

The international aspects of services, both information transmission and earth observation, are also particularly important. In many cases, this market potential is enormous. However, some benefits (such as weather, climate, and environment prediction and control) are not easily marketable and transcend political boundaries. If possible, these projects should be conducted with international participation and international funding.

Energy, of course, is a fundamental key to the creation of new wealth for the benefit of all mankind. Many problems, including food and mineral shortages, can be alleviated if we can produce abundant quantities of low-cost energy. Space will provide important long-range benefits in the conservation of energy and in the creation of new energy sources, particularly if the SPS proves to be viable and economically sound. The recommended direction of the space program is therefore to let the SPS development activities be the catalyst and technology determinant for the next few years but to structure the individual steps along the way so that each step returns immediate, concrete benefits.

Large space structures and large photovoltaic power systems are particularly crucial to the SPS. Fortunately, these developments are also important to the geosynchronous platforms, large space factories, and solar electric propulsion systems. Since the most attractive early markets and benefits lie in information systems, advancement in this area of technology is a fundamental key to the future. There is no doubt that manned operations in space will be necessary. However, man's costly presence can be justified only if his productivity is extremely high. Therefore, relatively large investments in man-operated machines must be a vital part of these large-scale operations.

In the era of the 1980's, a relatively small number of new hardware elements will be needed, and their total cost turns out to be surprisingly low. The entire list of anchor opportunities (excluding energy) could be accomplished for less than $2 billion per year—a figure which amounts to an increase in NASA's budget of one one-thousandth of our country's current gross national product. In general, the ground-based portions of the system will be economically viable in their own right; that is, they constitute markets rather than added costs. Morever, these markets are not just domestic; they are also strong candidates for international trade.

Our study clearly indicates that the 1980's will be the opportune time to bring space into our social and economic mainstream. Space industrialization should not be viewed as a competitor to science and exploration; rather, the vigorous program we have outlined can be the main impetus for expanding the scope of science and exploration. Likewise, the proposed program is not in conflict with the increasingly prevalent dream of young people to travel into space. Indeed, that dream will inevitably become more credible and attractive in the next few years as the Space Industrialization program develops and evolves into a mature undertaking.

NEAR-TERM RECOMMENDATIONS

A clearly defined long-term plan such as the one described in this study will help direct the space industrialization efforts into the most potentially fruitful channels, but it is of foremost importance that these efforts begin in the proper way. The near-term actions we recommend are listed in Figure 22. The boxed headings in the left-hand column of the figure are traditional types of NASA activities; those in the right-hand column do not fit as easily within the traditional NASA charter. Nevertheless, we believe both categories of near-term actions are vital to the success of the Space Industrialization program.

Specifically, we recommended that NASA take a lead role in the geosynchronous orbit activities by developing a detailed, evolutionary plan as to what should occur at the geosynchronous altitude and when it should take place. In particular, we believe that a rapid transition needs to be made from small satellites serving large, expensive antennas toward the complexity inversion concept in which much larger satellites interface directly with miniaturized and inexpensive devices owned by a multitude of ground-based users. Most likely, this controlled transition will first occur within the United States, but the biggest benefits to mankind will come when complexity inversion begins to serve people on an international basis. A key issue in the overall strategy centers around how we should handle the reliability problems associated with these large-scale geosynchronous satellites. For if the complexity inversion concept begins to flourish, as we believe it should, millions of people will come to depend on continuity of service. With current small-scale satellites, duplicate on-orbit spares can be switched on whenever an operational satellite happens to fail. Of course,

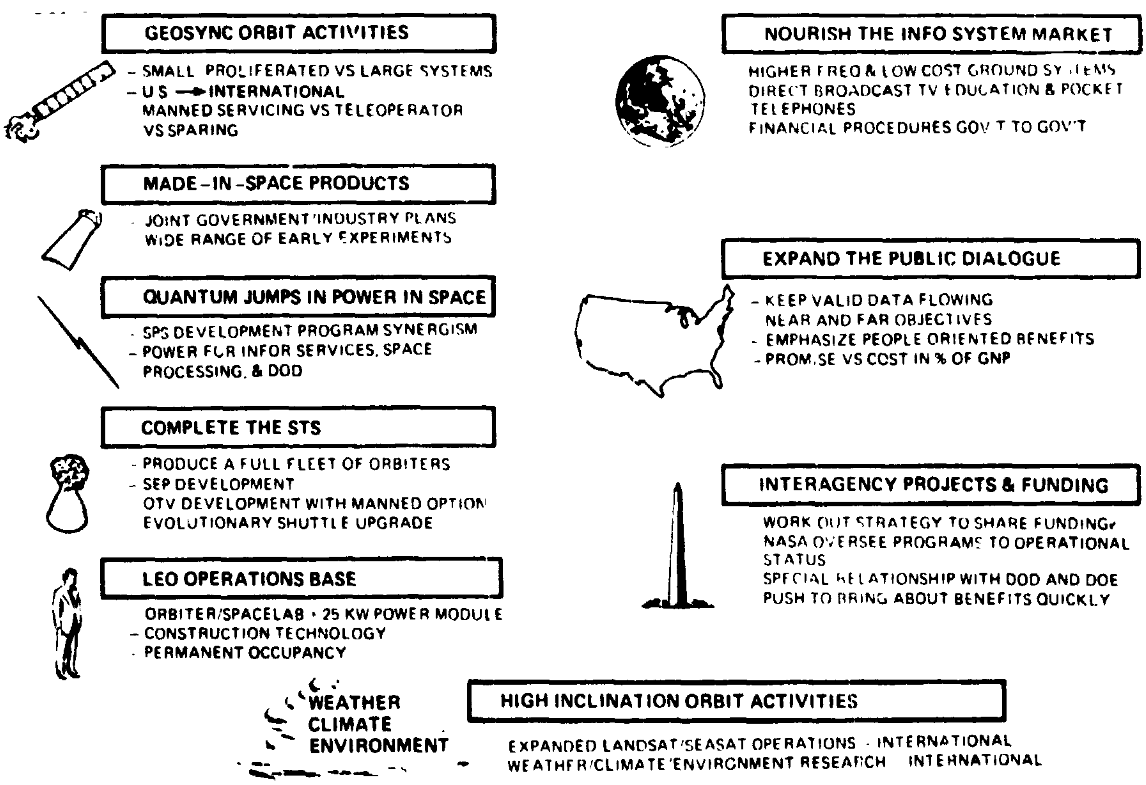


Figure 22. Near-Term Action Recommendations

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spares could be used even with large-scale satellites, but manned servicing or an on-board teleoperator may be more economically viable alternatives. Our study indicates that the expense of manned servicing at the geosynchronous altitude could be delayed until a pressing need has been clearly established. In the interim, it is our belief that an advanced teleoperator could do an excellent job of modification, maintenance, and repair. However, before funds are firmly committed, these multimillion dollar issues should be studied carefully.

For the manufacture of products in space, we recommend early development of joint government/industry agreements and a wide range of early materials-processing experiments. The issues of cost-sharing and the proper protection of proprietary rights will also require careful attention.

The availability of adequate quantities of electrical power in space at timely intervals is vital to the success of several phases of the Space Industrialization program There will be a need for several distinct order-of-magnitude jumps in power production in space before we can hope to construct an operational SPS. We believe that the program should be structured so that each of these quantum jumps is useful in its own right, as well as being a manageable stepping stone toward an operational SPS. Potential uses for these large-scale power supplies include the Shuttle power module, the multifunction geosynchronous platform, and large space processing factories.

The program we envision will require the introduction of increasingly sophisticated transportation systems at the appropriate times. Accordingly, we should complete the Shuttle transportation system, including advanced orbital transfer vehicles, and add a complementary capability for permanent manned operations in low-altitude earth orbits. Advanced capability in high-inclination orbits is also clearly warranted and will probably lead to manned operations in the long run.

The three items in the right hand column of Figure 22 underlie an expanded role for NASA. First, we need strong leadership to regain and maintain the information systems market that the American-owned companies should enjoy. One of the surest ways to minimize our balance-of-trade difficulties is to maintain a strong posture in the high-technology marketplace. Within this marketplace, advanced communication satellites are one area where we can choose to maintain a clear-cut role of vigorous leadership.

Viewed in a broader context, we believe that space industrialization should play a major role in the opening of the "high frontier" for the benefit of all mankind. We are convinced that the public will support an expanded space program if it returns immediate and tangible benefits while promising the fulfillment of even more ambitious long-term goals. We have found that the promise of space versus its relatively modest costs can best be grasped by those outside the industry if these costs are presented in terms of our total expenditures as a nation rather than just a percentage of the federal budget or a percentage of another agency.

Finally, as we begin to marshall our resources to capitalize on each of the more promising space industrialization opportunities, we will undoubtedly find that the fulfillment of these opportunities tends to involve beneficial activities that mesh with the responsibilities of other, often unfamiliar, agencies. Therefore, NASA should work closely with these agencies, particularly other departments of the United States Government, to share funding and bring the benefits of space quickly and decisively into our nation's economic and social mainstream For only in this way can the citizens of the United States and the other countries of the world reap the full benefits that will come from the large-scale industrialization of the space frontier.

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