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SQT-III

(NASA-TM-79360) THE NEXT 25 YEARS: INDUSTRIALIZATION OF SPACE: RATIONALE FOR PLANNING (National Aeronautics and Space Administration) 29 p HC A03/MF A01 CSCL 22A

N78-18091

Unclas
G3/12 06981

THE NEXT 25 YEARS: INDUSTRIALIZATION OF SPACE

— RATIONALE FOR PLANNING —

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Presented at
SOUTHEAST 2001: THE NEXT 25 YEARS
World Future Society Conference
Urban Life Center, Georgia State University
Atlanta, Georgia. November 12-13, 1976.

THE NEXT 25 YEARS: INDUSTRIALIZATION OF SPACE

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1. Humanizing Space

Dreams about mankind emigrating into space are as old as science fiction. Concepts of permanently occupied and self-sufficient extraterrestrial outposts, bases, habitats, and colonies for settling space have long been envisioned in Earth orbits, on the Moon, and on other celestial bodies such as Mars or larger asteroids. More recently, serious writers have suggested that such goals are possible in reality within the foreseeable future, e.g., O'Neill in 1974 (Reference 1). Results from recent NASA studies are generally in support of this work (Reference 2). Some of these projections have included the suggestion that space colonies would be the answer to the "population explosion" on Earth.

Should our next major goal in space, then, be to

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establish a colony in space for - say - 10,000 people as proposed by recent studies?

The industrially advanced nations are no longer threatened by overpopulation as are many developing nations. Thus, by not answering a demographic or social need for that part of the world that would have to underwrite the effort, space colonization _per se_ is unable to contribute to a lessening of population pressures in the relevant future.

While space colonization as initial objective and dominant program thrust is clearly not the answer, mankind's expansion into space will be unavoidable in the long run for sheer survival. There can be little doubt that permanent settlements in space will be in mankind's future, and it is one of our most important obligations to future generations to keep these and other growth options open at this time where we are but at the threshold of new frontiers. As the uncertainty about these new frontiers and the possibility of future crisis conditions rise, "safety" lies in maximizing the option potential open to future mankind, to avoid foreseeable and reduce unforeseeable problems.

At the same time, planning of the next steps must be responsive to mankind's near-term needs and wants, while building a solid foundation of ethical responsibility and technological capability from which an open, choiceful long-term future (or futures) becomes accessible. That alone will provide validity to the Space Program.

In planning the long-range space program based on essentially utilitarian aspects of the near-term without losing sight of the more humanistically significant long-term, and to forecast associated technology requirements, a planning methodology was developed which has recourse to a combination of two basic modes of planning (FIG. 1), extrapolative and normative (Reference 3). In the extrapolative view, responding to the "Push", alternative futures are projected on the basis of past and current trends and tendencies. In the normative view, establishing a "Pull", some ideal state in the far future is envisioned or postulated, and policies and decisions are directed toward its attainment. While the extrapolative view is strictly rational, "cold", and without value statement, the normative planning is truly idealistic, by basing its futures on human values and aspirations, and it would therefore require a value consensus ("Whose norm?"). By not limiting the norms under investigation and keeping all those future options open that appear to be supported

INTEGRATED LONG-RANGE PROGRAM PLANNING

TWO BASIC MODES

EXTRAPOLATIVE VIEW ("PUSH")

- PROJECTS ALTERNATIVE FUTURES ON BASIS OF PAST AND PRESENT TRENDS
- BASES POLICY GUIDANCE ACCORDINGLY
- MAY MISJUDGE CURRENT TREND(S)
- OFTEN FAILS TO SEE THAT SHORT-TERM ACTIONS LEAD TO LONG-TERM CONSEQUENCES THAT MAY BE UNANTICIPATED AND UNDESIRABLE
- IS ESSENTIALLY VALUELESS, BUT CAN MODIFY TREND LINE IF FUTURE CONTEXT CHANGES

NORMATIVE VIEW ("PULL")

- ENVISIONS IDEAL STATE IN FAR FUTURE AND DIRECTS POLICY & DECISION TOWARD ITS ATTAINMENT
- DEVELOPS FUTURE(S) BASED ON HUMAN VALUES AND ASPIRATIONS
- "FEEDS" FUTURE IMAGE BACK TO PRESENT PERCEPTION OF REALITY AND FACILITATES VALUE-CONSCIOUS PLANNING (TIME REVERSAL OF CAUSALITY)
- REQUIRES VALUE CONSENSUS ("Whose norm is to be used?")

REALISTIC APPROACH

- COMBINATION OF BOTH MODES
- PROJECT FORWARD FROM PRESENT WITH EXTRAPOLATION ADJUSTED OVER TIME
- FEED BACK FROM IDEAL FUTURE, RELYING ON EXTRAPOLATIVE GROUNDINGS
- IN PRACTICE: DEVELOP "STEPPING STONES" (INCREMENTS) TO THE FUTURE WHICH ALLOW
  - ASSESSMENT OF BOTH THEIR "BEFORE" AND "AFTER" IN NORMAL AND TIME-REVERSED CAUSALITY.
  - AD HOC ADJUSTMENT OF TREND LINE IN RESPONSE TO NORMATIVE CONTEXT AND EVOLUTIONARY TRENDS.

ORIGINAL PAGE IS OF POOR QUALITY

FIG. 1

by some consensus at present, the problem of deciding whose norm should be baselined can be avoided. A combination of both modes can then yield a more realistic approach to integrated long-range planning by tieing time-reversed vectors of the future to extrapolated, trend-oriented vectors of the quasi-present in a "tree of relevance". By defining development plateaus, common stepping stones can be identified. The "Push/Pull" planning approach, for the first time, appears to offer a useful relationship between utilitarian and humanistic goals of space flight (FIG. 2.)

In thus aiming at long-range goals of humanizing space through colonization, Space Industrialization must first generate an open world that would - through its "re-started" growth processes - make space colonization tenable, supportable and practical. Once established in space, permanent settlements will tap the energy and resources of space, thus easing the mounting human pressure on Earth's dwindling resources, helping remove much industrial activity from the fragile biosphere of Earth, and providing new "frontier" challenge and new worlds for humankind.

MAN'S PROGRESS IN SPACE

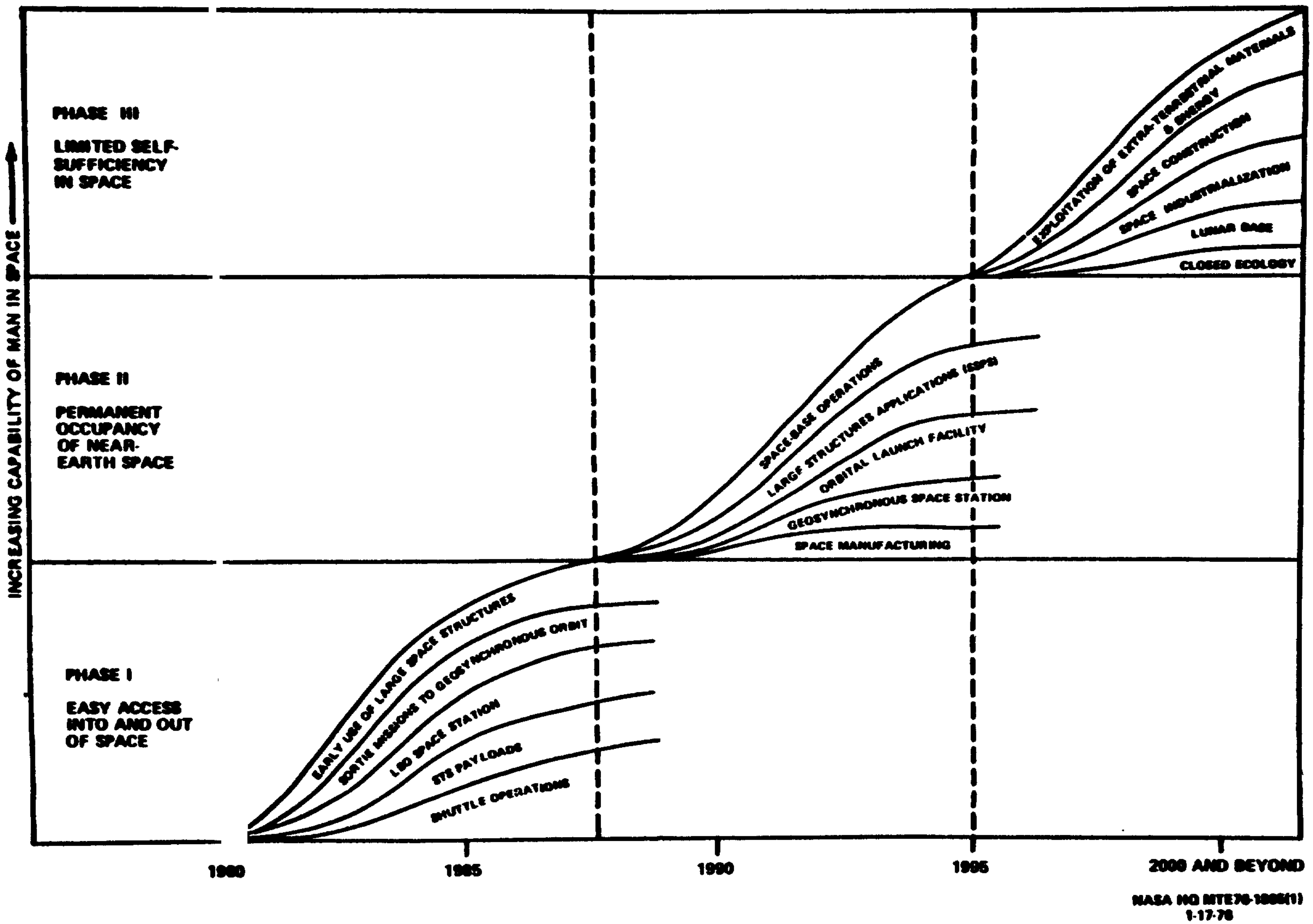


FIG. 2

2. Opening the Closed World

In our present world, both the industrialized and industrializing countries are facing monumental problems. But even more alarming is the dilemma of the nonindustrialized, undereducated, undernourished and undercapitalized nations. Rapidly approaching or already faced with excess population levels, they must undergo social changes at a considerably higher rate than all other countries in history. Their combined growth, based on current rate, will result in well over a billion new people in the next 20-25 years. Extrapolations of this type have led concerned people to seriously consider the Unspeakable, - namely, the imposing of "limits to growth".

There are no longer empty continents with lush vegetations into which excess populations could migrate. Space colonization, as stated before, is not (yet) an answer. Population control is an important nearer-term response, but the inertia-like time lag between birth-rate decline and slowdown in population growth and population stabilization will be many decades (typically 100 years to level off assuming the net reproduction rate reduced to 1.0 by 2025) during which population will continue to grow vigorously (to 10-12 billion at level-off point). Higher productivity through industry, generation of more capital in the undercapitalized world, and creation of new values and jobs will have to go hand-in-hand with population control to bring the standard-of-living - and the natural acceptance of lower birth rates - of the "developed", highly industrialized countries to both the developing but raw-material-rich and the developing and raw-material-poor nations, in terms of gross national product (GNP), per capita income, energy, food and material consumption, and population index (Reference 4).

3. Goals of Space Industrialization

The intensification and expansion of Earth-based industrialization to support such a global-wide standard-of-living increase at the population levels predicted for the next 30-40 years (requiring an increase of industrialization above current levels by an estimated factor of 35-40) has given cause for serious concern of energy and raw materials availability as well as environmental burden due to waste products, waste heat, and pollutants, supporting the simple fact that in a limited world - as in a shrinking droplet of water - growth is limited. For humans living in such a no-growth world, there will be only one choice: to organize scarcity. As a result, their future will quite likely be characterized by scarcities, deficiencies, shortfalls, defensive Earth resources policies, regression to intensified battle for survival, and new fragmentation of mankind. Thus, in a closed world, a fourth complex of problems joins the dilemma of population increase vs. living standard vs. environment: social strife and warfare.

For the opening of the essentially two-dimensional world with its "flat", closed surface limited in resources, energy and human real estate, to the three-dimensional environment of space to be effective, space must contribute to removing the limits to growth by not only generating new products and services but, in fact, by "shunting" energy- and pollution-intensive components of Earth industry into space where both energy and waste reservoir are plentiful (Reference 5). In addition to organizing scarcity to preserve, recycle and substitute for limited resources, a second choice becomes viable: the creation of wealth for all mankind without detrimental environmental impact.

Foremost among the needs faced by the large majority of mankind (over 70%) are industrial development and diversification, unemployment, population growth rate, agricultural development and food supply, rural and urban development, and health and education. For the industrialized nations, additional concerns pertain to energy shortage and independence, raw materials depletion, environmental burden, and inflation/recession. Clearly, to be morally supportable, Space Industrialization must contribute to the solution of these problems, both on a national (U.S.) level and - eventually - on a global scale.

The goals of NASA's Space Industrialization program, thus, include making a major contribution to increased productivity on Earth without taxing the environment, generating new values through extraterrestrial productivity, and providing new growth options for the future which would include permanent settlement of space and long-range colonization and exploration projects.

The task of balancing the needs of mankind with the requirements of maintaining the Earth's biosphere through the industrialization of space will - by necessity - be approached through a step-by-step evolution.

4. Stepping Stones

Space Industrialization, by developing the permanent and productive use of environments beyond Earth, must be based on the economic principles of cost effectiveness and commercial competition. This in itself presupposes the introduction of "stepping stones" to the overarching concept of Space Industrialization in order to facilitate the transfer of the investment capitalization from the public (Federal Government) sector to private industry. Since capital cost and interest rates are significantly affected, as is inflation, by the length of time and the extent to which investment capital is tied down unproductively in development (requiring discounting), return (pay-back) times on investment and the time until breakeven must be minimized. In addition, the higher the confidence level that influential features of the future Space Industrialization systems/programs can be maintained within acceptable tolerance bands, the lower the risk to the investor. Both arguments stipulate a stepping-stones approach that provides "manageable" increments within the "Push/Pull" force field of the overarching (long-range) concept.

In addition to providing reduced investment steps and shorter pay-back times, the pre-planned plateau approach (Reference 3) or "technique of small steps" allows

- Goal-oriented program planning and management,
- Built-in "holds" for successive re-evaluation of subsequent goals and objectives,
- Built-in "holds" for introduction of new technologies, both improvements and replacements/breakthroughs, and
- Better assimilation of space progress in Earth's culture and concurrent consolidation of technological progress with (slower) humanistic/cultural development.

By expanding the biosphere to include the space dimension, access is obtained to functionally infinite materials and practically infinite energy supplies. Some of the attributes and resources of space that are of relevance are listed in TABLE 1.

Based on this wealth of potentially attractive features, the guiding principles of Space Industrialization must therefore be to (a) exploit the availability of virtually unlimited energy, (b) exploit the excellent transmission characteristics for energy and information, (c) exploit the large geometrical coverage, and (d) exploit the benign environment (except for radiation belts). A summary of candidate activities is given on FIGs. 3a and 3b (Reference 4).

- Easy gravity control from ambient zero-g (or micro-g) to any desired rotationally induced multi-g-level
- Absence of atmosphere -
  - unhampered viewing of space for astronomy, astrophysics, etc.
  - perfect vacuum and freedom from seismic, acoustic, and convection disturbances
- Comprehensive overview of Earth surface and atmosphere
- Isolation from Earth's biosphere (for hazardous processes)
- Freely available light, heat, and power
- Infinite natural reservoir for
  - unlimited disposal of waste products
  - safe storage of radioactive products
- Super-cold temperatures (heat sink)
- Large, three-dimensional volumes (storage, structures)
- Variety of non-diffuse (directed) radiation
- Magnetic field
- Extraterrestrial raw materials

USEFUL ATTRIBUTES OF SPACE

TABLE 1

SPACE INDUSTRIALIZATION
EXAMPLES OF OPPORTUNITIES - 1

INFORMATION TRANSMISSION FOR PUBLIC SERVICES

- COMMUNICATION: Person-to-person, Voting/polling, etc.
- DATA TRANSMISSION: Electronic mail, Package tracking, Surveillance
- NAVIGATION/TRAFFIC CONTROL: Personal, Air Traffic, Ships
- INFORMATION STORAGE: For Recall from Earth or Space, Computer in Space.
- PUBLIC INFORMATION SERVICE: Education, Cultural/entertainment programs.

DATA ACQUISITION/TRANSMISSION

- METEOROLOGY: Accurate Weather Predictions
- PROBING OF ATMOSPHERIC LAYERS: Ozone layer, Ionosphere
- LAND MONITORING: Resources, Fault zones, Earthquake areas, coasts.
- OCEAN MONITORING: Currents, Wave conditions, Icebergs, Marine life
- COLLECTION/TRANSMISSION FROM SURFACE BUOYS AND BALLOONS
- SOLAR ACTIVITY MONITORING: Flare warning, etc.

EARTH-ORIENTED TELEOPERATION AND TELEMONITORING

- LONG PIPELINES AND POWER LINES
- REMOTE INDUSTRIAL FACILITIES: Desert Solar Power Stations, etc.
- REMOTE AGRICULTURAL FACILITIES
- REMOTE HUMAN ACTIVITIES: Expeditions, Search/Rescue, etc.

NUCLEAR WASTE DISPOSAL

- FROM EARTH SURFACE: To long-lifetime orbits or Sun
- FROM VICINITY OF ORBITING INDUSTRIAL FACILITIES

FIG. 3a

NASA HQ MT76-4087A (1)
8-24-76

SPACE INDUSTRIALIZATION
EXAMPLES OF OPPORTUNITIES - 2

MANUFACTURING IN LOW EARTH ORBIT

- HIGH-COST LOW-WEIGHT/VOLUME PRODUCTS: from Earth-supplied Materials
- STRUCTURES & STRUCTURAL ELEMENTS FOR SPACE FACILITIES: from Earth- or Moon-supplied Materials

SPACE LIGHT (ILLUMINATION FROM SPACE)

- INDUSTRIAL/AGRICULTURAL OPERATIONS, COMMERCIAL TRAFFIC, URBAN AREAS
- FOOD PRODUCTION: Plankton growth, etc.
- WEATHER MODIFICATION: *Crop damage prevention.*

SPACE MICROWAVE POWER (ENERGY FROM SPACE)

- LONG-DISTANCE RELAY OF POWER FROM SOURCE TO USER CENTER
- SPACE-GENERATED POWER TO TERRESTRIAL USER CENTER
- SPACE-GENERATED POWER TO SPACE INDUSTRIAL FACILITIES

LUNAR INDUSTRIALIZATION

- SUPPLY OF OXYGEN FOR ROCKET PROPULSION/LIFE SUPPORT: Transportation
- STRUCTURAL & MANUFACTURED GOODS TO ORBITING FACILITIES
- PRIMARY COMMODITIES & MANUFACTURED GOODS TO EARTH

HUMAN ACTIVITIES

- MEDICAL/THERAPEUTIC SERVICES/OPPORTUNITIES: Curative & Alleviative
- RECREATION: Space Tourism Facilities

SOLAR SYSTEM INDUSTRIALIZATION

- MARS: STAGING & SUPPLY BASE FOR ASTEROIDAL UTILIZATION
- ASTEROIDAL METALS FOR EARTH
- HELIOCENTRIC EXPLORATION

FIG. 3b

NASA HQ MT76-4087B (1)
8-24-76

As a logical consequence, Space Industrialization introduces several new and interlinked commonality features that will become characteristic of future space activities, viz.,

- Large structures in space
- Complex systems in space
- Long flight durations
- Manned orbital service and maintenance.

While the long-range motivation of Space Industrialization, the "Pull", is physical and humanistic expansion - and thus survival - of mankind, the nearer-term goals of Space Industrialization are three-fold: provide energy from space, provide space-derived products or goods that are salable and profitable, and furnish space-derived services for which agencies, industries and the public are willing to pay.

5. Applications

ENERGY. The problem of satisfying the energy demand of the industrialized world, as currently perceived, will reach near-critical proportions over the next 25 years. The electric power capacity of the U.S. alone is expected to triple (from 500 GW to 1500 GW) before 2000, requiring investments on the order of a trillion dollars, and to continue to grow. There is no obvious single source to supply this demand growth: Oil, gas and conventional nuclear power generation uses depleting, irreplaceable resources (i.e., living off "capital"); nuclear fusion development is uncertain at this time, and its costs are unknown; solar-terrestrial power (photovoltaic, thermal, wind, etc.) appears to be penalized by high cost and the problem of energy storage.

Without Space Industrialization, prospects for power sources by 2000 appear to be limited to coal, using existing technology, and breeder reactors, requiring development.*) For both options, there exist problems of environmental burden and potentially high cost. An additional problem, pointed out by K. Ehricke, is the high cost of electrical power transmission, requiring presently more than 400,000 miles of high-voltage lines in the U.S., with 11,000 square miles of right-of-way real estate.

The potential benefits of Space Industrialization to the energy problem can be three-fold:

*) First breeder reactor is expected to come on line about 1992-93, with doubling time (for fuel) of 30-60 years, improving to 20 years thereafter.

- by providing technology useful for generating and/or transmitting power on the ground,
- by providing RF power reflectors in space for passively relaying electrical power from ground power plants to ground users, and
- by generating power in space for transmission to the ground.

Replacing the current 64 kV transmission lines with higher-voltage cables is one answer to the power transmission problem. Switching from AC to DC power may be a better, more economic solution, according to Rockwell International, but it would require high-voltage AC/DC rectifiers and inverters. Such devices use terrestrially produced silicon crystals of 4-7 cm diameter (where size determines maximum power level). By producing these crystals in space, a choice of sizes up to 15 cm could be provided, allowing a reduction in number of crystals needed for a given power level to 7% of the number of 4 cm crystals. Potential cost savings due to reduced construction requirements are estimated at $76.5 billion by 2000 (assuming 1000 GW generating capacity).

Even more significant may be the impact of "clean" power generated from solar energy from space. For solar-terrestrial (ground) collectors, availability of the Sun is roughly 17% of the time in Arizona and 6% average nation-wide (Reference 6). By relocating the solar collector array from the day/night cycle and atmospheric environment of the ground to a suitable Earth orbit, solar radiation would be available over 99% of the time, limited only by occasional passes through Earth's shadow. This means that a power collector in space (11,800 kWh/m^2 per year) would intercept almost 6 times as much as one in Arizona (2000 kWh/m^2 annually), and almost 17 times as much as the U.S. ground average (700 kWh/m^2-year).

After collection of the energy in geosynchronous orbit, electricity would be generated in space through one of a number of possible conversion techniques, listed below. For subsequent transmission to Earth (or to a space-based industrial facility complex), the DC electricity would be converted to microwave RF through amplitrons (vacuum-tube type amplifiers such as klystrons are unnecessary in the vacuum of space), and beamed to a receiver antenna (rectenna) on Earth. Atmospheric transmission losses for microwave energy at the 2.45 GHz level would amount to no more than 2-8%. The entire DC-to-DC transmission chain itself is expected to achieve a level of about 58% efficiency (Reference 7).

Conversion techniques, presently under investigation by NASA and its contractors, may be photovoltaic (light energy) or solar-thermal (heat energy). The latter category includes thermionic, Brayton-cycle, thermionic Brayton-cycle, and Rankine-cycle systems. The former uses vast arrays of solar cells (silicon). Overall efficiencies of solar power satellites (from interception to AC ground power busbar) are estimated at 4-8% for photovoltaic, 6-17% for thermal systems.

To make the solar power satellite system economically viable, a considerable amount of power must be delivered, requiring very large collector arrays. For a ground power output of 10 GW, a photovoltaic array would cover an area of 129 km^2 and have a mass of 34,000 metric tons. Its development costs are estimated at $50 billion, its energy production cost at 27 mils/kWh. For comparison, a Brayton-cycle thermal satellite system would require only 70 km^2 of size, but 151,000 tons of mass, $59 billion of development cost, and 50 mils/kWh of energy production cost (Reference 7).

If sold "at cost" of $.027 per kilowatt-hour, the power output of a photovoltaic satellite would yield an annual revenue of $2 billion, i.e., a square kilometer of space would return more than $15,500,000 each year.

<u>PRODUCTS (Goods and Services).</u> Exploitation of the unique environment of space for processing of commercial inorganic and biological/pharmaceutical materials as well as manufacturing of new products designed to enhance productivity on Earth are expected to develop very high industrial potential. Not only would such activities affect world trade and lead to lower costs, thus benefitting national and global economy, but they would also be of importance to human health by benefitting disease prevention and more effective treatment.

At present, we know of five basic types of industrial processes that require a zero-g environment for improved material quality, more efficient material utilization, commercially significant production volume, and lower cost:

1. Crystal growth, including growth from a melt, growth in solution, and growth from the vapor phase.
2. Purification/separation.
3. Mixing.
4. Solidifications.
5. Processes in fluids.

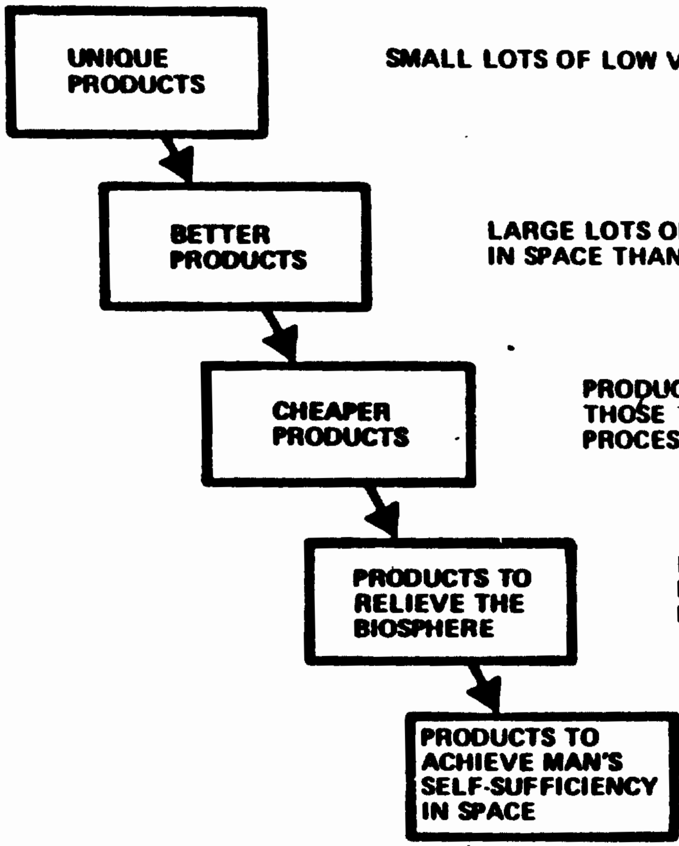
Other processes require high vacuum, such as vapor deposition techniques.

The possible evolution of Space Processing and Manufacturing of Goods along plateaus or stepping stones of immediate and contemporary benefit toward far-future goals of Space Colonization are highlighted in FIG. 4. Again, the stepping-stone approach would allow sponsorship by the Government during the high-risk concept formulation phase, with subsequent shift of emphasis to private/commercial investment. The detailed plans for government/industry interaction have yet to be constructed and are presently under early study; however, they can be expected to vary with the product or service produced.

Top candidates on NASA's list of inorganic commercial products made in space are semiconductor materials such as silicon or gallium-arsenide ribbons for wafers and chips, vapor-deposited solar cells, and niobate crystals for lasers and memories. For example (Reference 8), producing crystal chips in the gravity field on Earth from cylindrical boules yields 37% of useable wafers which in turn are processed into 21% of tiny electronic chips for integrated circuit (IC) substrates, resulting in an overall yield of 8%. For comparison, processing of the semiconductor material in zero-g in ribbon-form would bypass the wafer stage and lead directly to chips, with an overall

EVOLUTION OF SPACE INDUSTRIALIZATION

EXAMPLE: SPACE PROCESSING & MANUFACTURING OF GOODS



SMALL LOTS OF LOW VOLUME/HIGH VALUE GOODS THAT CAN ONLY BE MADE IN SPACE

LARGE LOTS OF HIGH VALUE GOODS THAT CAN BETTER BE MADE IN SPACE THAN ON EARTH

PRODUCTS THAT ARE CHEAPER MADE IN SPACE, SUCH AS THOSE THAT RESULT AS BY-PRODUCTS FROM PRIMARY PROCESSES

LARGE VOLUME/LOWER VALUE GOODS REQUIRING ENERGY- AND POLLUTION-INTENSIVE PRODUCTION

SPACE COLONIZATION

FIG. 4

NASA HQ MT76-1182 (1)
11-10-75

yield of 35%. There would thus be an improvement, i.e., profit margin, of 4½ to 1 over ground processed chips.

According to Western Electric Manufacturers Association (WEMA), the market for ICs in the free world was on the order of $5 billion in 1975, with $6 billion predicted for 1977. Extrapolation leads to an annual average of $19 billion between 1985 and 1989. The share of silicon, as raw material, in this market is estimated at about 10%.

Among the space-manufactured metals of interest are materials for high-strength permanent magnets, turbine blades, and X-ray targets.

Even more important will be separation and culture-growth processes of biological products such as pancreatic cells (insulin), pituitory cells, edothelial cells (macrophages), bone marrow, blood cells (lymphocytes, granulocytes), sperm cells (control of sex in farm animals), and enzymes. Space-processed biologicals include the enzyme urokinase with the potential of preventing up to 50,000 deaths per year in the U.S. due to thromboembolisms (blood clots), and erythropoietin for the treatment of kidney failure and anemia. In the U.S. alone, the annual requirements for urokinase are 500,000 doses at an Earth-produced cost of $2.5 billion. If produced from spaceenriched material, the cost would amount to only $400 million (Reference 9).

Similar considerations apply to space-processed lymphocytes (for prevention of organ transplant rejection) and macrophages (for early detection of immunological reaction).

<u>PUBLIC SERVICES</u>. Basic concepts of making space useful and directly relevant in the everyday life of large numbers of ordinary citizens involve the placing of very large satellites and antenna structures into orbit.

In a reversal of a previous space flight principle which required that spacecraft be kept as simple, light-weight and reliable as possible by relegating functions associated with complexity and weight to ground stations, the achievement of easy access to and from space and permanent occupancy of space by people will permit us to develop and operate large and complex satellites.

NASA studies indicate that in many applications of information transfer minimum total system cost might be achieved by deliberately making satellites large and highly capable, accepting their expense in order to allow the user equipment to be tiny, highly portable, and inexpensive. Because of the vantage point of geosynchronous altitude, millions of Earth-based users can be serviced by one or only a few satellites, and the cost of even very large and capable satellites and antennas could be expected to be less than that of the terminals, resulting in minimum total cost while simultaneously performing functions of unprecedented system utility not possible with simpler and smaller satellites. By using people in space for assembling, maintaining and servicing advanced systems of this type, these satellites can reach very large size. Due to the weightlessness of space, however, the erection and assembly of large antennas and reflector structures will not be subject to the constraints of weight deflections. Typical active multi-beam antennas for RF and microwave output identified to date would measure 200 to 600 feet in diameter and operate at power levels of 20-150 kW. Passive space reflectors for beaming light to Earth or relaying energy can reach diameters of 1000 to 3000 feet (Reference 10). Space power collectors may measure miles in length and width, as stated before.

The new, almost unlimited opportunities offered by space communications using these advanced systems have the potential to answer many serious needs of mankind in numerous personal, civic, government, industrial, and international applications in the next 25 years and beyond.

For improved personal communications, for example, a single 200-ft satellite could service 2,500,000 people with two-way voice and data communications, using ground user radio sets no larger than a "Dick Tracy" wristwatch radio. For improving mail communications, a multi-beam satellite with total U.S. coverage may relay up to 30% of U.S. mail electronically (100 billion pieces per year) and accrue cost savings on the order of $1 billion/year. Improved educational opportunities would become available with a large, high-power TV direct broadcast satellite bringing televised programs to mountainous, rural and remote areas of the world. Multi-beam satellites that provide citizens via wrist radio with around-the-clock access to police headquarters, and police with jam-proof communications from any location, will reduce crime rates. Improved public and governmental services could be obtained by using multi-beam satellites for direct and immediate communications to disaster areas as well as direct, instantaneous individual voting and polling. Intrusion detection of ships, personnel and goods across borders and coasts by large RF arrays in space, global communications with ocean vessels via space-based low-frequency loop antennas, and 24 hr/all-weather monitoring of global air and ocean traffic with a large microwave antenna satellite could improve national security and international air/sea traffic lines (Reference 10).

To achieve these long-range goals in a practicable step-by-step "Push/Pull" development, Space Industrialization would make use of a Space Construction Base (FIG. 5) in the early 80's to (a) develop and demonstrate concept technology, (b) erect, assemble and test large structures in space, and (c) develop the first operational communications systems by transferring complexity from ground to space.

Early NASA studies of a Public Service Platform (PSP) indicate that integrated platform concepts with multiple functions may be superior to non-integrated separate satellites with dedicated antennas. A typical first stepping stone, by 1985, may be a demonstration antenna of about 2400 m^2 area and 7 kW of RF power in a 500 km orbit, with four different voice/data transmission functions. Subsequent growth to a 3-antenna platform with 13 functions (voice/data transmission functions, voice/video/imaging functions, and security/safety detection and control functions) and relocation from low Earth orbit

SPACE CONSTRUCTION BASE
EARLY SYSTEM OBJECTIVES

- CONSTRUCTION RELATED
  - SATELLITE POWER SYSTEM
  - NUCLEAR ENERGY
  - EARTH SERVICES
  - SPACE COSMOLOGICAL R&D
- SPACE MANUFACTURING
  - SPACE PROCESSING
- SUPPORT OBJECTIVES
  - CLUSTER SUPPORT SYSTEM
  - DEPOT
  - MULTIDISCIPLINE SCIENCE LAB
  - SENSOR DEVELOPMENT
  - LIVING AND WORKING IN SPACE

NASA HQ78-77-131
10-4-78

FIG. 5

to geosynchronous altitude could be achieved as next step in 1986/87 (Reference 11).

6. NASA Studies

The total, overarching concept of Space Industrialization is currently becoming subject of intense study. These efforts, contracted with Rockwell International and Science Applications, Inc. (Reference 12), are primarily a planning activity intended to lay the necessary groundwork for subsequent implementation phases of a Space Industrialization program and the required support programs, including space transportation systems, domiciliary facilities in space, and space assembly/manufacturing facilities. Prime objective of these efforts is to develop an evolutionary Space Industrialization program which leads from Shuttle/Spacelab and early Space Station/Space Construction Base experiments to the permanent, practical and commercial utilization of space.

7. Summary

Space Industrialization has joined science and exploration as a major concept of space activity that introduces new themes of human space flight (FIG. 6).

NEW THEMES FOR MANNED SPACE FLIGHT

- **ON-ORBIT EXPERIMENTATION, INSTRUMENT DEVELOPMENT, SERVICING & MAINTENANCE**
  - PRODUCTION AND MANAGEMENT OF FOOD AND FORESTRY RESOURCES
  - PREDICTION AND PROTECTION OF THE ENVIRONMENT
  - PROTECTION OF LIFE AND PROPERTY
  - ENERGY AND MINERAL EXPLORATION
  - TRANSFER OF INFORMATION
- **SPACE ASSEMBLY, CHECKOUT, EMPLACEMENT, AND SERVICING OF LARGE STRUCTURES**
  - SOLAR POWER CONVERSION AND TRANSMISSION
  - TERRESTRIAL POWER RELAY
  - SPACE LIGHT ILLUMINATION
  - RADIO-ASTRONOMY
  - AID TO CIVIL PROBLEMS (OBSERVATIONS. COMMUNICATIONS, SUPPORT SERVICES)
- **SCIENTIFIC AND COMMERCIAL UTILIZATION OF SPACE**
  - BASIC PHYSICS AND CHEMISTRY
  - MATERIAL SCIENCE
  - COMMERCIAL INORGANIC PROCESSING AND MANUFACTURING
  - PRODUCTION/ISOLATION OF BIOLOGICALS (e.g., BLOOD CELLS, VACCINES, INSECTIDES)
  - EFFECTS OF GRAVITY ON TERRESTRIAL LIFE
  - MAN LIVING AND WORKING IN SPACE
  - PHYSIOLOGY AND DISEASE PROCESSES
- **STEPPING STONES FOR FUTURE HUMAN NEEDS AND OBJECTIVES**
  - IMPROVEMENT OF TECHNOLOGY/CAPABILITY (TRANSPORTATION, HABITATION, OPERATION)
  - DEVELOPMENT OF CLOSED ECOLOGY SYSTEMS (SPACE-BASED AGRICULTURE, ATMOSPHERES)
  - DEVELOPMENT OF HUMAN PHYSIOLOGICAL ADAPTATION TO SPACE
  - ACCESS TO EXTRATERRESTRIAL RAW MATERIALS AND ENERGY

- SPACE INDUSTRIALIZATION	- MANNED MARS EXPLORATION
- OCCUPATION AND SETTLEMENT OF THE MOON	- HUMAN EXPLORATION OF THE SOLAR SYSTEM
- COLONIES IN SPACE	- INTERSTELLAR FLIGHT

FIG. 6

NASA HQ MT76-J10 (1)
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In mankind's long-range drive to humanize space and achieve eventual space colonization, the industrialization of space can offer a realistic approach to developing a progressive program to provide permanent, practical and commercial utilization/tools of space through products and services that create - in the long run - new values, jobs, and better quality of life for all mankind.

The planning of such massive space endeavors as space colonization in the far future is quite helpful since it enables us to trace possible pathways of "Push/Pull"-type development through Space Industrialization back to the present. In thus establishing a "relevance tree" (FIG. 7) between far-future "dreams" and near-term realities and "pragmatisms", we are in a better position to identify major stepping stones which are useful to mankind in terms of contemporary benefits (short-term returns) while at the same time being relevant to future growth-type needs. Once these vectors are established, we do not have to be too specific about the actual far-future goals and can leave their selection up to our future generations.

EVOLUTIONARY PATHS TO FAR-FUTURE SPACE ENDEAVORS
(Relevance Tree)

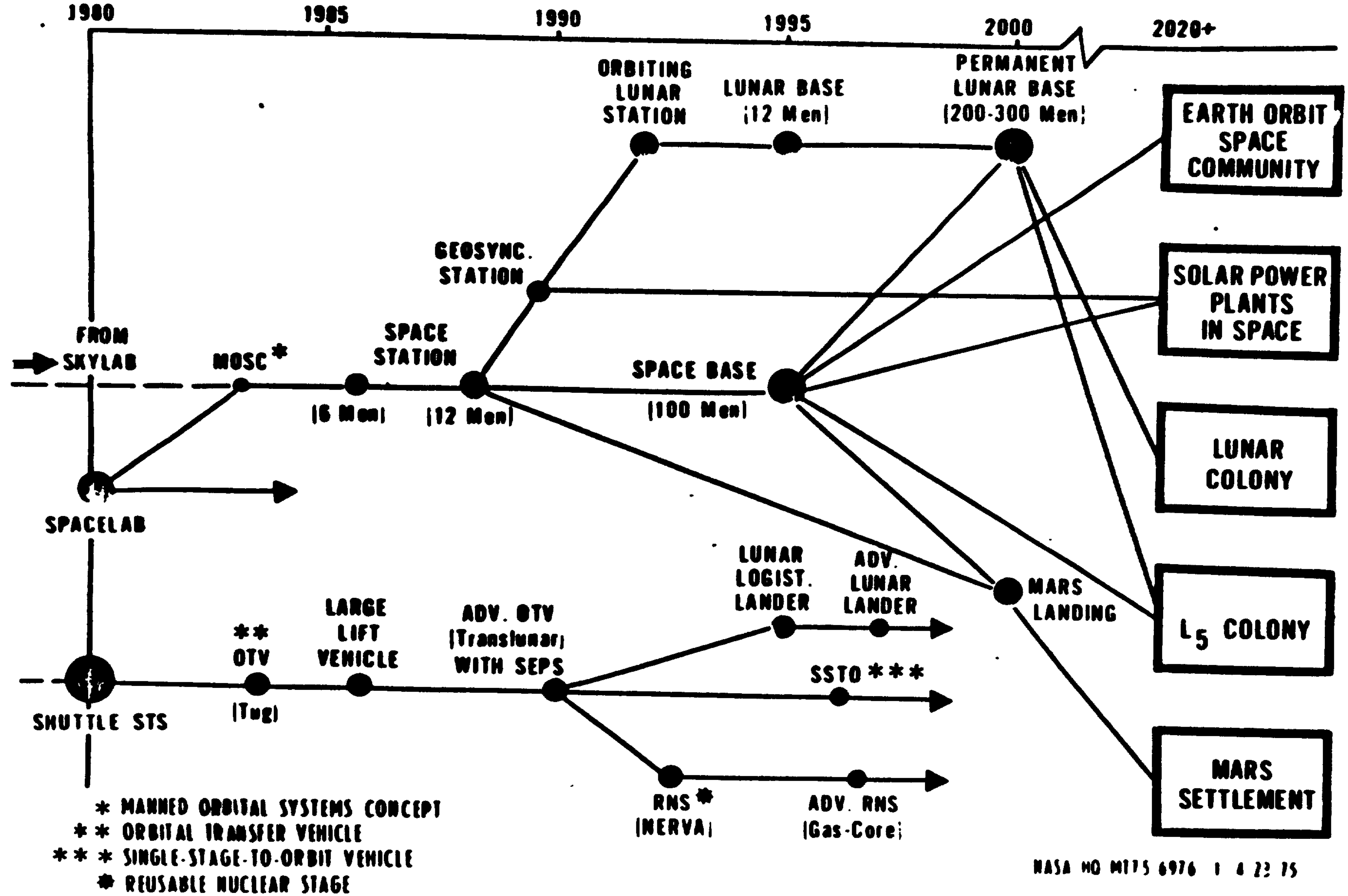

FIG. 7

This approach brings "dreams" into the realm of "strategic" thinking. It allows us to (1) give a larger purpose to our near-term "tactical" and pragmatic activities and thus re-introduce the "dream" in our "Now"-orientation, and (2) improve our ability to avoid dead-end "branches" in our major planning decisions for Space Industrialization.

The merits of Space Industrialization lie in the fact that they encompass all human beings. This is a new fundamental premise, untenable without highly developed industrial foundations. Knowledge, health care, and the satisfaction of other existential and higher needs no longer are privileges of a few but fundamental rights of all. While space colonization, if taken as initial goal and prime objective, would probably "benefit" only a relatively small group of people living in a space colony, Space Industrialization can benefit <u>all</u> people on Earth. Moreover, it would not preclude but in fact validate the option that the industrialization of space may subsequently grow into space colonization as full self-sufficiency in space is reached. By being basically non-elitist, Space Industrialization will thus introduce the true humanization of space.

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October 1976