The Biosphere: Problems and Solutions, edited by T.N. Veziroğlu
Elsevier Science Publishers B.V., Amsterdam, 1984 — Printed in The Netherlands

ENERGY AND LEGISLATION IN OUTER SPACE

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ABSTRACT

The evolution of man into space can open new resources for the collective development of all humanity. One of the major questions before each nation is whether or not we of this generation will continue to develop our technological capability to use these new resources. The answer to this question lies within the limits of our imagination. The first movements into space, which culminated in Apollo, catalyzed our imagination. The Space Shuttle now gives license to our creative exploration. The economic utilization of the solar system's vast resources--minerals, energy, various chemical compounds, etc.--will begin to be realized. What is needed now is the development of the proper energy technology, with a closer look at solar, MHD, MPD, and various renewable energy alternatives so that we can expand our capabilities. We must aim for a unified effort that will provide an efficient network of commercial development with the technical capacity of interfacing spacecraft from many nations. This unified effort will have to come via careful space legislation, taking into account such factors as the ecology of space and the type and purpose of vehicles sent into space.

1. INTRODUCTION: THE ENTERPRISE OF SPACE

In the real world our planet functions as an aggregate of some 140 nations. Their means and capabilities have differed widely at any given point in history. The creation of wealth through the machine age made possible great social and economic advances. The industrial revolution necessarily triggered an environmental expansion. Techno-scientific advances continue to intensify the industrial process in response to the pressure of needs as well as the promise of new options. The industrial revolution is not completed until the environmental revolution has restored an open energy environment commensurate with the growth and survival needs of the metabolic life form of which man is a sovereign guardian. For these reasons, the energy demand has expanded the environment not only into the deeper layers of the Earth's crust, but into the high frontier of space where new energy sources and strategies compete with the imagination of scientists, engineers and businessmen.

The evolution of man into space can open new opportunities for us and for all mankind. There are new resources that have never before been available. One of the major questions before each nation is whether or not we of this generation will continue to develop our technological capability to use these new resources. The answers to this question lie within the limits or our imagination. The first movements into space, which culminated in Apollo, catalyzed our imagination. Skylab gave direction to our imagination. The Space Shuttle now gives license to our imagination.

Originally space, like atomic energy, existed as a technological focus of endeavor--initiated by the military; however, the motivations of many of the space science pioneers were and are non-military. Their visions are of people in space and human exploration of the solar system. Moreover, the Space Act declares that the U.S. is to develop space for peaceful purposes, for the benefit of all mankind, and mandates cooperation by the U.S. with other nations and groups of nations.

Few of the originators of the Space Act (1) envisioned how quickly the day would come when space would serve as the site of routine operations. Now that space exploration has paved the way, the next obvious step into the outer regions is the establishment of manned habitats and space law to govern these extraterrestrial stations. The next generation of space development envisions establishing the essential controlled environment for living comfortably in space, initially in confined artificial environments.

It will be an era of planetary engineering in which, for example, remote operations of machinery, artificial intelligence, micro-electronics, microsensors, learning and adaptive computers will dominate and will find new and unusually sophisticated applications. With these tools, economic utilization of the solar system's vast resources--minerals, energy, various chemical compounds, etc.--will begin to be developed in automated factories by computer-aided manufacturing.

Presently, we are developing astronomical observatories, that is, sophisticated space platforms with large assemblies of optical and radio telescopes. Soon thereafter, spacecraft orbiting the outer planets will be essential for understanding space phenomena and exploring new resource areas, such as those observed by the Voyager spacecraft. Space platforms of 10 to 100 tons with a power supply of at least several 100 kilowatts--perhaps as great as one megawatt--could be developed and deployed in low-earth or geosynchronous orbit in the 1990s.

2. THE POTENTIAL OF SOLAR ENERGY

A collecting surface of 10 kilometers square in space could gather 10-100 gigawatts of solar power. Hundreds of such collectors gathering solar flux otherwise lost to the Earth would provide energy equivalent to the present world energy needs. This solar flux alternative could be either beamed directly to the ground or converted into electrical energy in space and transferred to Earth by high-power microwave beams. (2) With such collectors we could change, by utilizing new technology, nearly 1% of the solar flux reaching Earth either by adding to it reflecting additional energy, or by reducing solar flux by "shadowing". A few large power stations in synchronous orbit could potentially provide power for different types of minor weather intervention on the ground, such as the dispersing of fog on the ground and protecting tender crops from frost--thus eliminating crop damage in crucial fruit areas such as Florida. With more powerful stations we might provide weather and even climate control, perhaps coping with changes in climate either by natural forces or human activity.

A larger alternative energy strategy envisions the full control of the solar flux on the Earth with a system of perhaps 10 million free-flying solar collectors in the vicinity of the Lagrangian point between the Earth and the sun, where the gravitational pull of solar sails is clearly within our present technological capability.

A serious difficulty with the development of a Satellite Power System (SPS) is the volume of material that engineers would need to take into space to build the solar platforms. Hundreds of tons of material would have to be lifted off the Earth every day. According to NASA projections, we may be able to build such platforms from minerals mined from the moon: a NASA study has reported that 90 percent of a satellite power system could be built from the silicon, oxygen, and various metals found in lunar rock.

A lunar factory weighing perhaps 100 tons might produce a space Satellite Power System utilizing 10 billion kilograms of aluminum, titanium and silicon in a few generations. These huge factories, whether on lunar soil or in the sky, would make little use of old energy technologies for space operations. Moreover, several criteria must be met when choosing manufacturing methods for use in space. For instance, they could use solar energy and local materials as far as possible and they should be suitable for automation. NASA has discovered that a cruder form of silicon of a metallurgical grade can be used for the manufacturing of solar-cells. It is now known that less-pure forms of silicon, such as metallurgical-grade, are less expensive than semi-conductor-grade material and would help to lower the cost of solar-cells. However, typical metallurgical-grade silicon contains titanium in concentrations of 10^{14} or more atoms per cubic centimeter, which seriously degrades solar-cell performance.

Cells composed of 15 to 50 micron-m-thick epitaxial layers on metallurgical-grade silicon substrates have efficiencies as high as 11.7 percent, whereas cells composed of diffused junctions in the same metallurgical-grade material have a top efficiency of 8 percent. (3) As a result of solar-cell innovation, current carriers in a vast array of applications in space will travel a shorter distance in the epitaxial layer than they do in the relatively-thick diffused layer.

The state-of-the-art for the Satellite Power Stations (SPS) would involve perhaps 100 satellites in geosynchronous orbit approximately 36,000 km above the Earth. Planners in the U.S. think that in building a complete satellite solar power system, reusable vehicles would be needed, shuttles capable of carrying tremendous weight, as much as 400 tons, compared to the 30 ton capacity of the present Space Shuttle.

Each 5 GW power factory would be 10 km long and 55 km wide (considered roughly the size of Manhattan Island) and weigh some 50,000 tons. One surface would be covered with silicon cells to convert solar energy to electricity. In energy transfer an array of microwave tubes would transform the electricity into radiation which would be sent to a receiving antenna (called a rectenna) on Earth. The rectennas (one for each satellite) would convert the microwaves to electricity and conduct it to population centers.

The European Space Agency has studied this subject since 1976 (4), although it has no full Satellite Power Systems research program. In particular, the agency commissioned Hydronamic, a Dutch firm of civil engineers, to investigate sites in Europe for rectennas which would be huge structures covering 100 square km. Among the sites the firm proposed are several in the North Sea area.

Several technologies that would be important in a satellite power system are under study--control systems to position objects accurately in space within a configuration of large satellites. Each satellite would contain some 1000 million cells; and to be competitive they would have to cost 300 dollars for every kW that they produce--which is 5% of the price of the cells that are used on Earth today.

To most of us, earth-based manufactured space systems large enough to provide energy for a high standard of living on Earth (containing as much as ten billion kilograms of material) is inconsistent with the preservation of the Earth's natural environment. The alternative is the industrialization of space and the development of the bountiful resources of other celestial bodies--the moon, asteroids, comets, and planets.

In summary, future technological breakthroughs in space can be envisioned in two major areas of advancement. The first envisions applying lunar based industrial systems in space. Here one or more self-contained factories on the moon could manufacture solar collectors using abundant lunar aluminium, titanium and silicon for sail-like solar collectors. Light-weight, intelligent components will be supplied from the Earth.

The second follows an exponential system, in which a single, highly sophisticated materials-processing and construction facility is sent to the moon: to utilize lunar materials for building large solar energy collectors but at the same time, to build additional factories in which collectors can be built. Under this scenario, a 10 billion kilogram solar energy system with 10 million collectors might be constructed and assembled in 20-30 years. However, this requires a technological breakthrough where a self-reproducing robot technology would strengthen new technological and energy developments that lead directly to continuing applications.

2.1 Industrial Robots and Energy Production

A microprocessor-controlled system comprising a solar-cell preparation and an industrial robot has been used to reduce labor in assembling photovoltaic solar panels. The preparation station prepares a cell for soldering; the robot picks up the cell, heats it to soldering temperature, and solders it in place as it positions the cell. While carrying the cell to the solar panel, a coil in the end effector heats the cell to soldering temperature by RF induction. The robot then simultaneously positions the cell and solders it in place in the panel.

Jet Propulsion Lab has developed a robot hand that heats a solar-cell to soldering temperature while the robot transports the cell from a preparation station to a solar panel where the cell is simultaneously placed in position and soldered. (5) The use of RF induction heating allows the cell to be heated without requiring direct mechanical and thermal contact of a bonding tool such as a soldering iron. By the time the solar-cell arrives at the panel, it is hot enough to reflow the solder paste applied to the cell and to solder the cell to the interconnects of the next cell in the string as the robot places it in position. A configuration of robots preparing large solar arrays underscores a growing emphasis in considering robots and unmanned space missions as drivers of basically new technology.

With a few new advancements we can see, from a general economic point of view, how the satellite power system could rapidly turn into a big new industry. At any one time, several hundred people would be working in space to construct the space platforms; and the project would require many times this number of technicians and engineers on Earth. Later, there would be other developments. The continuous availability of solar energy in space would make it economically feasible to site factories in orbit rather than on the ground. And, ultimately, people will mine other bodies in the solar system, such as the moon and the asteroids, for minerals which the space factories will process. For example, the European Economic Community imports virtually all its chromium, cobalt, nickel, tin, copper, manganese, titanium, tungsten and half of its aluminum, lead, zinc and iron. The only way that the European Economic Community (EEC) can reduce this dependence on other countries is to explore ways of obtaining the vital materials from space inexpensively. An automatic or preprogrammed response from robots in various mining endeavors through remote viewing, automata and teleoperators might be appropriate in the absence of laws governing space chattel. But these are just the types of complex problems that would be challenging to those who are researching adaptive and learning computers for robotic systems. (6) The attractiveness of collecting solar power in space and beaming it back to Earth depends on the development of either low-cost photovoltaic solar arrays or solar energy concentrators with thermal converters deployed on extremely light-weight structures.

2.2 Mobile Photovoltaic Generators

New ways have also been developed to deploy small scale solar generators. A compactly folded reflector can be deployed easily to form corner reflectors for a solar array. The reflector concept, developed for a solar electric-propulsion space vehicle, is applicable also to mobile solar electric-generators on Earth. As envisioned, in a simplified model, a flat box is deployed as a reflector comprising two panels. The panels direct sunlight into the arrays of solar-cells that are deployed with the panels.

A box holds two hinged flat containers that rotate to deployment-ready position and a counterbalance beam that rotates into position after the containers. Each container holds a thin-membrane reflector, folded like a fire-hose. A mast is gradually extended from the box and unfolds the reflector membrane from the two containers. The mast moves the counterbalance beam, which is connected to the supporting structure. In effect, the unfoldable-membrane reflector swings open for deployment and opens up a new range of applications for mobile photovoltaic generators.

2.3 Components for Space Power and Energy Futures

The basic areas for understanding our energy futures in space can be modeled as follows (Fig. 1):

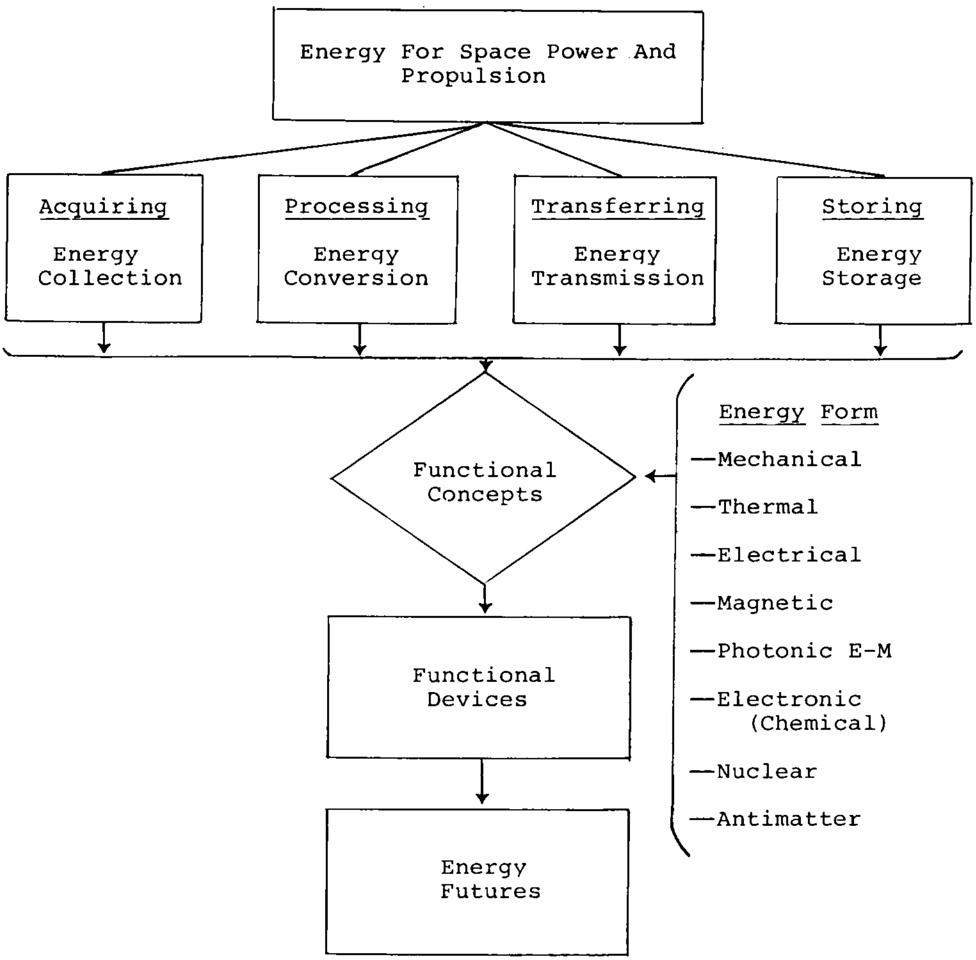

Fig. 1. Flow Diagram for our Energy Future in Space.

3. MANAGEMENT OF ENERGY AND TECHNOLOGY FOR SOLUTIONS

Future space missions will require significant improvements in data handling capability with respect to a variety of energy sources. This will demand high-density data processing systems and memories with low power requirements.

3.1 Conversion from Electro-magnetic (Photon) Energy

Photon energy from the sun or a laser beam may be converted to propulsive energy. To enable space travel NASA has researched the Shuttle's ability to use a solar electric propulsion (SEP) configuration. Here parameters for photovoltaic cells and power processors are combined with mercury bombardment thrusters. The knowledge garnered by NASA using solar cells with the Space Shuttle can now deliver about 600 kilowatts with the aid of reflectors to concentrate the sunlight on individual photocells. Such a system could remain operating in space for 15 years (and over that time, its power-generating ability would not drop below 440 kilowatts). Lockheed studies for NASA indicate that SEP could provide more thrust from less propellant than rockets. A SEP vehicle could undertake interplanetary missions without being encumbered by a large propellant tank. For missions beyond Jupiter, however, NASA would have to design a more sensitive solar array.

Solar sails have also been considered for years as a possible means of low-cost propulsion. A form of Solar sail engineering has already been successfully tested near the planet Mercury (7), but Shuttle operations would provide the first opportunity for relatively low-risk "on-orbit" deployment of the required extensive light-weight structure. The vehicle uses a stiffened mylar structure with vanes for attitude control.

A third method being investigated is "beam heated" thermal rocket engines. A laser beam source is located on the ground or in orbit around the Earth. Energy transmission is thus achieved by a collector on the spacecraft. This collector then focuses the energy through windows in a thrust chamber where it is absorbed by a propellant which is heated and exhausted through a nozzle (e.g., H_2). Exhaust velocities of the order of 7.5×10^3 to 2×10^2 m/s are possible if the hydrogen can be heated to temperatures of 2,500 to 20,000 degrees Kelvin. Critical developments required for this device, in addition to beam generator technology, are windows for high-intensity beam transmission, means for energy absorption by the propellant, and chamber thermal protection. Laser beam conversion by electric propulsion may also be evaluated by relating laser energy to solar energy at 1 atomic mass unit(s). (8)

3.2 Conversion from Nuclear Energy

The specific mass and cost benefits of nuclear power capabilities in space are a necessary complement to solar power for many applications. High levels of operational power must be supplied for long durations in situations where solar energy is not available. The cost-effective solution is the employment of nuclear energy storage converted to tens of kilowatts to megawatts of electric power in space. Development of a fission nuclear power system of 100 to 500 kWe can be used for providing power for spacecraft in the first phase of space engineering. If nuclear propulsion is to be used for high-load transportation such as placement of solar power stations in synchronous orbit, multi-megawatt systems should be produced. With proper safeguards, a "two-track system" could produce a quantum leap in energy futures.

Radioisotopes provide a very efficient mechanism for storing energy. When used at power levels below 10 kWe, in conjunction with thermoelectric or thermionic conversion, radioisotopes provide electrical energy on a mass-per-unit energy basis three to four orders of magnitude more favorable than electrochemical batteries. Projected improvements in thermoelectric or thermionic converters and in isotopic fuel can significantly reduce costs from today's high costs in fossil fuels which portend a major unfavorable impact on the Earth's biosphere.

Nuclear electric propulsion offers the potential for low thrust propulsion at a very high exhaust velocity ($V_e \approx 4$ to 6 x 10^4 m/s), as with solar electric propulsion, but with a system that is independent of solar distance. Working parameters that are forecast for the 120 kWe to 1 MWe power levels are consistent with use of thermionic or fluid dynamic conversion devices, electric propulsion power processors and mercury electron bombardment thrusters. Although detailed studies of 1 to 10 MWe systems have not been accomplished, it is anticipated that dynamic conversion or magnetogasdynamic cycles would be applicable to that size range appropriate for missions in deep space. (9)

The Soviet Union has concentrated on this area of energy research and is entertaining it for its satellite efforts. (10) This research probably will not severely affect the development of solar or other alternative technologies. Efforts will continue to increase the present low efficiency of solar technologies and lower the cost of the system components. For example, advanced engineers, generators, and power conditioning devices can make solar-thermal electro-power generation economically very attractive.

3.3 Chemical, Liquid and Laser Propulsion

Rocket motors now used for propulsion utilize the stored electronic energy in the chemical bond, released through a combustion process, to provide thermal expansion and high-velocity exhaust of the combustion products. Forecasts are presented for liquid propellant rocket motors, solid propellant rockets, and a conceptual system using metastable hydrogen as a propellant.

Other energy technology such as liquid-propulsion activities will undoubtedly be affected by the efforts required to bring the Space Shuttle into full operation. The use of the Space Transportation System (STS) will dictate the trends in new systems and liquid-rocket technology in the coming years. Bipropellant systems are expected to be developed for guidance-and-control roles on highly maneuverable upper stages and low-altitude anti-missile defense systems. Emphasis will also be placed on propulsion technology for highly maneuverable anti-satellite missiles

Another key area of energy is the use of laser propulsion in space. A solar-pumped laser has been developed that can be used for: 1) remote power transmission for propulsion of orbital-transfer vehicles; 2) power beaming from space to provide laser-powered aircraft propulsion systems; 3) power beaming from space to Earth to provide electric power, and energy for materials processing and for fuel production; and 4) power for space-based science missions such as particular physics.

The allure of laser systems is their conceptual simplicity and potency. Although ballistic missile defense is the most dramatic application of laser weapons, so far more money has been spent trying to develop more mundane energy applications. The arguments for space law seem eminently reasonable when the most controversial role envisaged for laser weapons is in orbiting battle stations that would defend against nuclear attack.

3.4 New Ion Propulsion

Early versions of the engines being developed for Ion Drive were placed in Earth orbit in 1969 during the Space Electric Rocket Test (SERT) Program under the direction of Lewis Research Center. Electricity-producing solar arrays have long been the mainstays of space power-production, although on a much smaller scale than will be used for Ion Drive. The development of large arrays is made possible by new methods of stowing deployment and improved solar cell technology resulting in ultrathin light-weight cells (50 microns or 3/1000 inch). This will enable the spacecraft's solar wings to be deployed much like roll-down window shades.

Once boosted into space by the shuttle, flexible thin blankets of solar cells wrapped tightly around a central core will be unrolled by the Ion Drive craft to begin power generation. The engines will then be ignited and the ion-powered trajectory to distant targets will begin. With solar array wings fully extended, the craft will resemble a huge galactic butterfly, spanning the length of one and a half football fields.

1983 saw great advancements in the elements of ion propulsion. Using electromagnetic propulsion, NASA engineers achieved an increase in MPD (magneto-plasma-dynamics) thruster efficiency to over 40% at 3,000 to 3,500 sec. I_{sp}. Experiments recently performed at the Japanese Institute of Space and Aeronautical Sciences, using improved cathode materials, promise very large increases in MPD operating life through order-or-magnitude decreases in erosion rates. In related research, TRW installed a thrust stand to evaluate a 1-m-diam pulsed inductive thruster operated on argon. Preliminary data indicate thruster efficiencies from 28-44% at I_{sp}s from 1,100-2,400 sec, respectively, as well as close agreement between the direct thrust measurements and thrust levels derived from probe data in the accelerated propellant.

3.5 New MHD Alternatives

Magnetohydrodynamics is the branch of continuum mechanics which deals with the motion of electrically conducting media(s) in the presense of magnetic fields(s). A MHD electric power generator utilizes an electrically conducting media moving through a magnetic field to generate electric currents. The electric output depends on the media's conductivity, the velocity of the media's flow, and the field strength of the magnet. By setting the magnetic field as a constant (i.e., assuming the same magnitude of magnetic flux for each generator configuration), the output power of a MHD generator becomes the function of the media's electrical conductivity and the velocity of its flow through the electrode area (magnetic Reynolds number parameters).

Research into MHD generator technology has defined two different types of electrode configurations: those with electrodes in the duct and electrodeless generators. Due to the relative simplicity with respect to the theoretical analysis, experimental verification, and low ionization potentials of thermally ionized (burning of gases, etc.) plasmas, earlier efforts to produce electric outputs via MHD generators have emphasized the development of various DC electrodes in the duct designs.

Electrodeless MHD generators are based on induction coupling of the magnet(s) to the kinetic energy of the flowing conducting media (similar in concept to conventional electric generators). Because of the high input energy requirements and the numerous technological problems encountered in fostering the plasma conditions necessary for this type of MHD generator, this electrodeless generator design has had minimum research prior to the cycling path generator concept. What has prompted continued research into this type of MHD generator is the theoretical efficiency; as the magnetic Reynolds number parameters increase, the performance of this type of generator continues to improve. Thus, significant improvements in plasma conditions make this technology a most attractive technique for generating electric power (especially when compared to other conversion technologies). Cycling the residual energy improves the plasma conditions.

Early radiative energy ionization research into MHD generators was limited to approaches to improve magnetic Reynolds number conditions; as electromagnetic particles will only ionize along their path. Nonresonance techniques places the energy source within (or direct the input signal into) an oscillator cavity. However, the cycling path concept directs the "left over residual energy" exciting from the generator back into the generator system. This technique combines the entrancing energy with the cycling residual energy to improve the plasma's flow conditions and the energy flux densities (leading to improved output power conditions).

The cycling path generator design parameters offer a number of different conversion inputs (i.e., solar energy driven, atomic energy driven, and laser/microwave transmission line driven). Limiting further generator description to the solar energy driven units, there are three different systems; a large utility generator; a small user generator (which is now in development stages); and a transportation generator (for space propulsion, etc.). Each of these generators offers extremely high conversion efficiencies and can be scaled to any desired output.

Presently, thermally ionized MHD generators require a solar collector area of over 8,000 square meters. New research has indicated, however, that a MHD generator configuration can be built which would require only twenty square meters of solar radiant energy for a collection area. Initial research and testing indicates that this theoretical conversion ratio is feasible even for larger size units, offering a powerful source of space applications that would need major power from a small MHD cycling path generator technology. It has been brought to my attention that the first permanently-manned space station launched by the U.S. in the 1990's could have such an innovative solar-MHD power system. (11)

3.6 The Parameters of Space Energy Systems

The following schematic (Figure 2) indicates the propulsion devices (not including mechanical and thermal) arranged according to the type of energy from which conversion is made, viz., electrical, photonic, chemical, and nuclear. Pertinence performance is placed in a profile for each device or system forecasted. The schematic displays the various program options being entertained in energy futures.

As has been described, space technology finds wide application in energy systems. Some of the applications, for example, propulsion, are obvious. Other applications have developed through study of energy needs and comparison with NASA interests and capabilities.

It is possible that most of the likely candidates for the use of aerospace technology for energy have been studied. There are, however, more opportunities, but the discovery of new roles in energy, will still take effort and dedication on the part of the specialists to locate the need for R&D and formulate a means to meet the need. Some possible areas for the future include: 1) the problem of safety and quality assurance in the design, management, and operation complex and dangerous energy production systems; 2) management of global CO_2 and SO_2; 3) capabilities for controlling utility systems with a wide variety of energy sources; and 4) energy resource surveys that can help with the expanding frontiers of space.

Even more advanced propulsion and conversion concepts, which would be brought into operation after the turn of the century, offer the prospect of system mass per unit power levels two to three orders of magnitude less than is possible with currently envisioned solar and nuclear electic propulsion. Exotic work by elementary particle physicists on antimatter production, storage, and reaction may ultimately lead to an energy source with available energy per unit mass two orders of magnitude greater than fusion, but is clearly within the time frame of the 21st century.

A more important component of the creative role of energy is the consideration which has to be given to the appropriate form of social order for large space ventures. Translating our knowledge to the environment of space, and understanding the special problems and opportunities in space requires emphasis on space law.

PROFILES OF ENERGY FUTURES (Fig. 2a)

ENERGY FORM	FUNCTION				
		ENERGY CONVERSION			
	Energy Collection (Acquiring)	To Mechanical From:	To electrical From:	Energy Transmission (Transferring)	Energy Storage (Storage)
Electrical	Ionosphere grids Lightning rods	Arc & resistance heated thrusters Electron bombardment electrostatic thruster Colloid electrostatic thruster Electromagnetic accelerator	Science/housekeeping power conditioning equipment Electric propulsion power conditioning equipment	Electron beam generator Wire conductors Superconductors	Capacitors
Photonic (Electromagnetic)	Solar concentrator Laser collector Microwave antenna	Beam energy drive thermal rocket engine Solar sails Solar electric propulsion	Photovoltaic cells Thermoelectric Thermionic Dynamic cycles Dielectric converter	Laser generator Microwave generator	
Electronic (Chemical)	Chemical manufacture on Earth Extraterrestrial surface materials collection and processing to obtain chemical reactants Extraerrestrial atmospheric component collection and processing as chemical reactants	Liquid propellant rocket engines Solid propellant rockets Detonation rockets Metastable chemical rocket engines Atmosphere-breathing thermal engines	Fuel cells Dynamic cycles Magnetogasdynamic cycles		Primary batteries Secondary batteries Stable chemicals as reactants Metastable chemicals
Nuclear	Manufacturing processes	Fission: Solid core rocket engine Dust-bed rocket Light bulb/gas core rocket Nuclear electric Atmosphere-breathing thermal engines Fusion: Direct heat rocket engine Micro explosions	Radioisotope: Thermoelectric Thermionic Dynamic cycles Fission: Thermoelectric Thermionic Liquid metal MHD Magnetogasdynamic Dynamic cycles Gas/fluid core reactor/converter Fusion: Fusion energy conversion		Radioisotopes Fission reactors: Solid core, Fluid core, Gas core Fusion reactors

APPROXIMATE SYSTEM PERFORMANCE PARAMETERS (Fig. 2b)

Description:	Year of Stated Parameter	a_{sp} (kg/kg)	a_c (kg/We)	η_c	V_e (m/s)
From Electrical					
Electron Bombardment Electrostatic Thrusters (Primary Hg Propellant)	1975-2000	1.5×10^{-2} 0.85×10^{-2}	5.0×10^{-3} 3.5×10^{-3}	0.7	2.9×10^4
Colloid Electrostatic Thruster (auxiliary) Cesium Propellant	1985-2000	1.6×10^{-2}	0.9×10^{-3}	0.65	2.9×10^4 10^5
Electromagnetic Accelerator (Steady 1MW)	1985-2000	0.3 0.17	1.5×10^{-4}	0.3 0.5	10^4 Adjustable
From Electromagnetic					
Beamed Energy Driven Thermal Rocket Engine	1985-1990	0.05	10^{-4}	0.2	10^4
Solar Electric Propulsion System (Mercury Propellant)	1985-2000	1.5×10^{-2} 0.85×10^{-2}	40×10^{-3} 20×10^{-3}	0.63 0.70	2.9×10^4 4.0×10^4
From Electronic (Chemical)					
Liquid Propellant Rockets (Pump Fed)	1985-1995	0.05	6.0×10^{-7}	0.95	4.6×10^3 5.5×10^3
From Nuclear Fission			a_c/η_c (kg/W)		
Solid Core Nuclear Rocket (F=70,000N)	1985	0.05	7.0×10^{-6}		9.0×10^3
Nuclear Gas Core Rocket	1990-2000	0.05	1.0×10^{-5}		4.0×10^4
Nuclear Electric Propulsion Thermionic (120kWe to 240kWe)	1985-1995	10^{-2}	3.0×10^{-2}	0.65	4.0×10^4
MHD (1MWe)	1990	10^{-2}	2.0×10^{-2}	0.65	4.0×10^4
(10MWe)	2010	10^{-2}	1.0×10^{-2}	0.7	6.0×10^4
From Nuclear Fusion					
Fusion Rocket Engine (Jet Power=200MW to 1GW)	2000-2010	0.17	10^{-3}	0.25	10^4-10^6
Fusion Microexplosions	1990-2000	0.17	10^{-4}	0.15	10^5

4. SPACE ENVIRONMENT AND ENERGY RESOURCES FOR MANUFACTURING

Non-terrestrial options--both in terms of production and resources may literally seem too futuristic to a good many business people. But the commercial development of space require few scientific breakthroughs--only a great deal of engineering--to establish technical, economic, and environmental viability.

In the past, expendable launchers imposed overwhelming constraints on payloads sent into space. These contraints no longer exist. Now, the new marriage between space technology and private enterprise brings a new range of possibilities in the spin-offs of the Space Shuttle's flexibility. Four space-manufacturing activities seem especially promising: pharmaceuticals, electronic devices, glass products, and advanced alloys. The efforts to interest commercial investors in space futures bore fruit in 1979 with the signing of an unprecedented agreement between NASA and McDonnell-Douglas Astronautics, which in turn signed an agreement with a nonaerospace user corporation (Ortho Pharmaceutical). The aim was to evaluate possibilities such as vaccine production in space that requires a delicate process called electrophoresis.

This cooperative agreement was an imaginative legal milestone for work in space, for it gave Ortho sufficient proprietary rights to test data to make the sizable investment of pharmaceutical production in space financially strong without violating federal antitrust or freedom-of-information statutes. Furthermore, it clearly demonstrated that the Federal government was willing and even eager to subsidize this new industry, just as it had done previously with Comsat Corporation in the development of the commercial communication satellite network. With the help of the AIAA Corporate Associates program, major companies such as Dupont and Exxon began to look at the potential of commercial returns on investments in space technology. Thus, even before the first successful flight of the Space Shuttle, Beckman Instruments, 3-M and other pioneers in industry joined with TRW in leadership of a broad-base segment of private industry known as the ad hoc Materials Processing in Space Industrial Committee.

In the pharmaceutical sector, it becomes increasingly desirable to separate and concentrate living cells that are capable of producing medically important substances. Earlier space experimentation had shown that pure materials could be developed for medical uses when molecular separation (the basis of electrophoresis) was not complicated by gravity-induced convection and sedimentation. Under zero-gravity in space, living cells (whose mass/charge ratios differ) can be separated efficiently and accurately by applying weak electric fields.

The effectiveness of this method is strongly impeded in the presence of a sizeable gravitational force. Electrophoresis has a wide range of medical and biological applications. An early promising use is isolation of the human kidney cells that produce the enzyme urokinase, a substance with a potential effectively preventing and dissolving blood clots and fatty material of heart attack victims. The pioneering work was done by Dr. Maurice

Mazel, and has now been cleared for large scale production in outer space. There, in the clean energy environment, it is considered that the ideal environment will contribute to its production as the miracle medicine of the late 1980's and 1990's.

Even at the present cost of $1,200 dollars per dose the 500,000 doses currently needed annually in the U.S. alone cannot be produced by the present method that extracts one dose of urokinase from more than one ton of urine. The "electrophoretic method" can also be applied to separate other kidney cells that produce erythropoietin (an anti-anemia hormone stimulating the production of red blood cells in bone marrow); to a host of needed enzymes controlling a wide variety of metabolic functions (and malfunctions); to white blood cells and antibodies (effecting tumor growth, transplant rejections, etc.); to chromosomes (x, y, types affecting cattle population through artifical insemination); and possibly to nerve cells (neurology). The total benefits from medical and the biological sciences to research in agriculture cannot even be estimated today from a clean energy environment.

In the electronic product area, value lies in the growth of mono-crystalline semiconductors of highest perfection and purity for a wide variety of applications. The same space features of null-gravity--eliminating convection current in metals and ease of levitation in melting (no contamination through wall contacts) also permit the production of glasses of very high purity and optical quality as needed for high-power laser systems, fibre-optic transmission lines, and high-resolution optics.

Thus it seems to me that the space frontier and the technological frontier are in a sense "meant for each other." with their interaction serving as the wellspring for the new developments that might help space trade-offs in technological leadership and economic well being.

Possibly the most urgent area of space law that requires attention is the extension of medical, corporate and patent law to cover the infinite range of treatment, research and industrial activities that will soon begin in space. Precedents are being set which may not be in the right direction either with respect to the interests of business, international development of planetary resources, and the interests of future consumers and pioneers of the interests of our planetary society.

5. PERSPECTIVES OF SPACE LAW ON NEW RESOURCES

As civilization places permanently manned orbital stations and a host of high-tech factories in space, it will have to establish a commensurate set of laws for space management, interplanetary activities and exoindustrial operations.

In preparation of what could be called an extraterrestrial imperative to develop space, a subset of international law, recognized as "space law," has been developing in stages since the 1950's. Since about 1959, jurists, legal scholars, and pundits have elaborated with increasing detail and expanding scope the principles, rules, and regulations under which spaceflight activities have progressed.

The first essential and pragmatic international steps were taken out of operational necessity, in the form of bilateral agreements. Between 1959 and 1969 the United States had established more than 40 bilateral agreements involving manned-flight support communications, earth-orbiting satellites tracing and telemetry facilities, reimbursable launch arrangements, unmanned scientific and application satellite programs, and deep-space network support for tracking, telemetry and control of space objects on trajectories away from the Earth.

When Sputnik I went up, there was a truly global response. Among the first major undertakings of the U.N. was the identification, analysis and prioritization of the legal problems and issues generated by spaceflight activity. Some of the immediately identified issues were addressed and resolved in relatively rapid formulation of fundamental principles that won early unanimous support.

Resolution 1721 of the Sixteenth General Assembly of the U.N. in December of 1961, articulated the rudimentary principles of emerging global space law, and laid out a program of work and study in areas of international cooperation, meterology, and communications.

The subsequent formulations of UNGA Resolution 1884 (XVIII), of October 17, 1963. and Resolution 1962 (XVIII) of December 13, 1963, became explicit references in the Preamble of the 1967 _Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies_. And with the entry into force of the treaty, the first decade of spaceflight was crowned with a charter of principles that would be decades more in elaboration.

The United States and the world community have come a long way in space law since Sputnik I. From the 65 national cooperative experiment called the International Geophysical Year (1957), we have evolved a 103-nation Intelsat Organization, a ten-nation European Space Agency, a 22-nation cooperative Arab Communication Satellite Corporation and other, newer international organizations for space application.

The search for new resources has dramatically increased pollution in low-earth orbits and biospheric space in the last twenty-five years. More than 170 communications satellites are already in the geostationary position or are planned. Add all the military satellites, together with those now planned for direct broadcasting of television programs, and the space left for more satellites in this orbit becomes very limited. International agreements ensure that the signals from satellites near each other are modified so that they do not cause interference.

Space nearer the Earth is also very crowded, with 3000 or so satellites "jostling for position" alongside bits of old rockets and other debris. The vastness of space makes collisions unlikely, but one day the shuttle may have to act as a "garbage vehicle" to retrieve space flotsam or nudge it into a different orbit so that it re-enters the atmosphere and burns up.

The law that is being formulated today, in the U.S., in Europe, in the United Nations, is law that is focused on the detailed regulation of technological development of the space frontier. We are setting up insurance provisions, we are covering liability risks, and we are concerned with international interpersonal relations between citizens of different countries flying in space on the spacecraft of a third country. (12)

In the U.N., countries are focusing on guidelines for remote-sensing operations, guidelines for direct television broadcasting by satellite, and possible regulation of the use of nuclear power sources in space. But there are other, more challenging, longer-term issues under debate as well. Should we define "Outer space?" Should the geostationary orbit have a special status? Under what kind of governing regime might we one day exploit the resources of the moon and other celestial bodies?

These are questions now on the agenda, not only of the U.N. Committee on the Peaceful Uses of Outer Space, but also of the U.S. Congress. And as Congress begins to move, for the first time to address issues of how to regulate extraterrestrial activity, what should be its guidelines, its guiding principles, its touchstone of validity?

In the plethora of commentary that emerged in the wake of Sputnik I, a great deal was written about the upper limit on national sovereignty. It is clear that over the new decades we are going to be busily engaged in perfecting our rules of behavior for our technological activities below and above that elusive limit, wherever it may be. As we seek to establish the first phase of a scientific civilization in outer space with new energy sources, we must begin to strain our limits and to think in new and unearthly ways about how to regulate man beyond his home planet, in a new environment, seeking to explore, to build new homes and factories, and to survive.

When Skylab and the Soviet satellite Cosmos 954 fell out of orbit, the incidents accented some of the dangers inherent in space propulsion systems. The fall of the Cosmos 954 spewed nuclear debris across part of Canada. The space accident illustrates a growing need for international cooperation to oversee the dimensions of "orbit" pollution. An international space organization might help to prevent such accidents and could help to resolve celestial "legalities" and difficulties stemming not only from the numerous nuclear-powered satellites, but also from the non-nuclear ferret, optical and electronic eaves-dropping satellites.

An international organization should be more reliable than individual nations at monitoring orbits and giving advance notice of satellites in trouble. The organization might even develop the technical know-how to alter orbits in terms of emergency, or provide consulting or servicing programs when circumstances warrant. It might, for example, direct a dangerous, unsteady satellite to a fatal orbit away from our planet, even toward the sun. At orbital levels, discarded launch stages and other debris are creating space "litter" that could obstruct future launches and experiments. An international organization would be useful in controlling space dumping. Privileges and penalties could be keyed into the signing of a custom model contract which would regulate "product deployment" and set aside a certain percentage of total systems earnings for "trust fund" benefits. Any nation that makes use of space should economically contribute to a trust fund according to its use of outer space.

There are also numerous legal and regulatory questions that arise when one contemplates solar power systems in snychronous orbit around the Earth. How do we establish national and international rates for the power generated and transmitted to receiving points on Earth? A subsidiary leasing program could be established, for example, which requires a down payment from each generator customer upon signing the contract, with penalties for withdrawal. A reasonable installation charge would be required. At the time of installation turnover, an additional payment, based on future lease service charges, would be required. The annual fee would include all maintenance and component replacement costs.

The space frontier can become the font of technological development or the frontier for powerful national interests depending on how precise the requirements of space law are articulated for all of humankind. The question of where the emphasis is placed in defining "Outer space" from "Earth-resources space" is fundamental in this regard. An important perspective for space law is the need to communicate and agree on a boundary between the "space of the Earth" and outer space. Accordingly, space is now considered an extension of natural territory under current international law. But "outer space" is considered open territory where nations enjoy a freedom to navigate much like the freedom of the high seas.

The U.S.S.R. would like to set a boundary between "air space" and outer space at about 100 kilometers, but the U.S. is hesitant to agree. We may want to operate the Space Shuttle at somewhat lower altitudes without having to worry about trespassing the boundary lines according to international law. Space law would thus soothe national viewpoints currently irritated by the presence of "foreign satellites" stationed over national regions. Some "Third World" nations even argue that satellites in "fixed position" still violate their territorial space even though they are 35,000 kilometers aloft.

Ultimately, space law specialists who argue for the need for "licensing negotiations" for use of low-earh orbits may have to define orbital usage for a defined licensee time period. Use would be defined according to "special energy configurations" to "service specific industries," while the orbit itself maintains a status of "economic free goods," that is, goods not diminished by utilization.

The Space Shuttle is the first major step in a positive answer to the question of energy markets in space. Once the Space Shuttle's "services loop" is economically established through continual automation routine, that is, when we have relatively economic and convenient access to the near-earth space environment, then imaginative use of that environment becomes possible.

6. CONCLUSIONS

The special requirements of energy recovery and processing in space, quite different from those typical of earth-based industrial processes, need to be aligned with space law management over the next one or two decades so as to control growing areas of space pollution. The resource areas that must be protected and enhanced are basically three in number: 1) Continuous and instantaneous view of the Earth, solar resources and energy materials; 2) An infinite quantity of clean, ultra-high vacuum; and 3) A weightless environment, that is, an environment free of gravitational stress, or "low gravity space" which would allow us to study and control the mixing of fluids, gases and solids which, on Earth, separate out because they have different densities.

In addition, man's application of new remote sensing systems shows unlimited potential. With quantum leaps of computer-robots in the last twenty years, it is possible that the "fifth generation" of computerized robots could be out-thinking "Man" in the not too distant future. (13) The question is, should humans be prepared for long-term operations in an outer space environment, or should we prepare "to govern" through "levels" of remote television "eyes," articulated "hands," radio "ears" and the means of locomotion for these extended sensors and doers? Space "law" will have to answer to both manned and unmanned complexities.

In the near future a half-dozen countries will be able to launch their own satelittes and, as the orbiting bodies proliferate, the right of satellite power and purpose in space will no longer be taken for granted. We may wisely evolve, in the co-operation between specialists in space programming and space law, a sliding criteria of "values" to cover what could be called "space chattel." In resolving the deeper nuances of "economic free goods," "space chattel" and "energy options," perhaps, the resolution of the "space-boundary issue" might make it easier for a better distribution of the energy resources and activity down here on planet Earth.

The underlying principles of the American space program have remained surprisingly constant. They include one basic theme that could be implemented through space law--namely, considerable openness in the technical programs, manifested by a strong emphasis on public information and a willingness to expose mistakes as well as successes. In addition to this theme, the basis for space law could use the Law of the Seas as a key map. The recent enactments following from the 1973 London Convention and the 1978 Protocol relating to the International Convention for Prevention and Pollution from Ships, entered-into-force in October, 1983, could provide for the legal norm, enforcement model, and act as a major criteria for the management of energy futures in the area of space law. (14)

To provide for the future of Man, space law must establish the proper "checks and balances" to promote the development of energy futures that will go to higher levels of autonomy creating a pollution-free environment in space and on earth. Indeed, we have the scientific techniques to assure a meaningful life for all earthlings through untapped resources. What we need is the vision to recognize that we are indeed all earthlings with a common destiny in space.

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