REPORT OF THE NASA LUNAR ENERGY ENTERPRISE CASE STUDY TASK FORCE

EXECUTIVE SUMMARY

The Lunar Energy Enterprise Case Study Task Force was asked by NASA to determine the economic viability and commercial business potential of mining and extracting He-3 from the lunar soil, and transporting the material to Earth for use in a fusion reactor to generate electricity. While the Task Force concentrated its efforts on the He-3 concepts, two other space energy projects, the Space Power Station (SPS) and the Lunar Power Station (LPS), were also reviewed because of several interrelated aspects of these projects, such as the use of lunar material, the possibility of manufacturing some elements of the project systems on the Moon, and the need of all three projects for space transportation and space station requirements, in varying degrees. Additionally, the SPS and LPS projects have the capability of providing energy for lunar-based activities.

In carrying out its assignment, the Task Force considered:

1. The legal and liability aspects of the He-3 and other space energy projects.
2. The long-range need for electricity and the energy options to meet these requirements.

3. The state of knowledge of the He-3 and other space energy projects and the time frame for their development.
4. The commercial potential of the He-3 and other space energy projects, and the role industry might be willing to play in their development and use.

The information made available to the Task Force by NASA and other sources suggested no inhibiting legal and liability factors which would prevent the use of Moon resources for the space energy projects. But further study is recommended. While the Task Force did not develop any long-range global electricity forecasts, and while such long-range judgments are difficult to make with a high degree of accuracy, there appears to be general agreement that the use of electricity will continue to increase, particularly in developing countries if they are to raise the standard of living of their citizens. Thus the need to examine long-range electricity options is essential. Most electricity growth will be met in the next several decades by utilizing current technology and terrestrial fuel resources, particularly in developing nations. But long-term, there could be limitations in the use of our current means of producing electricity, as emerging environmental concerns and resource availability suggest a changing character to the energy policy decisions that must be made in the future. Environmental concerns have momentum, and, if nothing else, they have the potential to increase the real costs of producing electricity with the use of fossil fuels as resources become more expensive to produce (particularly oil and gas) and the capital cost of the facilities to burn fossil fuels (particularly coal) in an increasingly strict environmentally acceptable manner becomes more expensive. These cost factors make serious consideration of extraterrestrial energy options a matter of national interest. Synergism with future space policy directions may also be a factor that would influence future energy supply choices. Long-term global ecological concerns cannot be quantified nor can the long-term production costs of current, or as yet developed energy options, but it is, nevertheless, important to have these additional options. The Moon can provide these. All three options considered in this Report (He-3, LPS and SPS) have the potential promise to provide a practically inexhaustible, clean source of electricity for the U.S. and worldwide, without major adverse impacts on the Earth's environment.

Total industry responsibility for pursuing any of the three extraterrestrial energy concepts considered in the Report is not possible at this time because the risk is high; the payout period is long; technological feasibility is not fully developed, and thus requires considerable R&D investment; and near-term energy investments are more attractive. Pursuit of these energy concepts requires the combined efforts of government and industry. Indeed, total and sole government responsibility would inhibit progress. Innovative forms of government and industry cooperation must be developed and implemented over the next several decades. The Report describes one such innovative approach. There are probably others which further detailed analyses by financial experts might suggest. The arrangement outlined in the Report is based on the conviction that the commercial development of extraterrestrial energy and the development of a lunar base can be linked effectively. The lunar base can serve as a development step of many of the technologies needed for the energy system, and can be a customer for services at pilot production levels.

The Moon must play a role in long-term terrestrial electricity supply matters. Early commercial involvement in this task is of paramount importance in achieving this objective and a meaningful leadership role for industry is potentially possible. But total industry responsibility for projects of this financial magnitude is not initially possible and government involvement through subsidies or other means, such as co-funding or enabling contracts, is vital. The mining of He-3 for transportation to Earth is a potentially viable, economic concept but understandbly on a long-range schedule and subject to government/industry cooperative arrangements outlined in the Report. The two solar power concepts likewise could have long-range economic potential as extraterrestrial electric power sources but the three concepts were not rated in terms of potential economic viability, although it is evident that each concept has both promise and problems.

The factual case for the Report's findings needs further development. NASA and DOE should continue to support studies that will better frame the development of the projects and provide the additional technical, economic and financial information that will be necessary for greater commitments. These studies, however, should not be contracted for under normal government procedures. Industry should be given a primary role in planning the overall program, perhaps through the establishment of a high-level private sector advisory committee. High-level representatives of the Administration, appropriate government agencies such as DOE, EPA and NASA, the energy, environment and space leadership of the Congress, electric utilities, the space and energy supply industries, and the financial community must consider looking beyond Earth for our long-term electricity needs because of potential damaging ecological impacts with continual major dependence on fossil fuels for terrestrial energy needs. This is a revolutionary concept, and is based on a crucial observation regarding long-term environmental consequences of our current energy production options. There must be understanding, agreement and long-term commitment, and the national will to implement the commitment as a matter of national policy.

Lastly, we must recognize that other nations, notably Japan, West Germany and Russia, are proceeding with very aggressive programs to investigate and develop space-oriented, energy systems. It will be done. It is just a matter of by whom.

REPORT OF

THE NASA LUNAR ENERGY ENTERPRISE CASE STUDY TASK FORCE

BACKGROUND

The Lunar Energy Enterprise Case Study Task Force (the Task Force), a group of professionals with diverse backgrounds and responsibilities (membership list attached as Appendix A), was asked by NASA to determine the economic viability and commercial business potential of mining and extracting He-3 from the lunar soil, and transporting the material to Earth for use in a fusion reactor to generate electricity. In order to bring perspective to the study, two other extraterrestrial electric energy production projects were considered as "straw men". One was to collect and convert solar energy into electricity and beam it to Earth from a space power station (SPS) and the other from the Moon, a lunar power station (LPS).

While the Task Force concentrated its efforts, in accordance with its NASA charter, on the He-3 concepts, the other two projects were also reviewed because of several interrelated aspects of the projects, such as the use of lunar material, the possibility of manufacturing some elements of the project systems on the Moon, and the need of all three projects for space transportation and space station requirements, in varying degrees. Additionally, the SPS and LPS projects have the capability of providing energy for lunar-based activities.

DISCUSSION

The Task Force has met five (5) times to carry out its responsibilities. In addition, various subgroups of the Task Force have met to consider detailed technical or financial issues. During the course of its study, the Task Force has considered:

1. Legal/Liability Aspects -- can we conform to legal requirements and utilize the Moon in the manner contemplated (i.e., can the laws be adapted to facilitate use of the Moon for an enterprise)? What about compensation for damages? Who will bear the risk?
2. Long-range Need for Electricity -- is there a market for the projects' output?
3. Long-range Electric Generation Options and their Environmental Impact -- can the He-3 fusion concept compete? Is it or the other extraterrestrial concepts more compatible with the environment than current terrestrial electric power production facilities?
4. State of Knowledge -- what do we know? What remains to be done? What about costs, etc.?
5. Time Frame of Development -- when might the He-3 fusion concept or the other extraterrestrial concepts be capable of reliable performance? How do they, or can they, tie into other NASA programs or objectives?

6. Commercial Potential -- what role would industry be willing to take in the extraterrestrial projects, under what circumstances and when?

Given the limited resources of the Task Force, time constraints and a charge to investigate only whether further detailed study, presumably with adequate resources, should be undertaken, the Task Force in many instances was capable of rendering only qualitative judgments. It has, however, collected or developed significant technical information. The highlights of these data are attached as Appendices B-1, B-2, B-3, B-4, B-5, and B-6 to this Report.

Legal/Liability Aspects - The NASA staff provided the Task Force with a brief verbal report on the legal aspects of a U.S. entity utilizing the Moon for the production of electricity for terrestrial purposes, with a conclusion that it would be possible to do so in a manner that would meet international treaty intents regarding "Benefits to All Mankind". Some members of the Task Force, however, believe that obtaining title to lunar real estate might be necessary to attract venture capital for lunar enterprise projects.

A February 1989 report by the Wisconsin Center for Space Automation and Robotics for the NASA Office of Commercialization reviewed the He-3 concept and concluded that an acceptable basis can be found for cooperative international production of lunar He-3, should the U.S. decide to do so.

Space treaties also address liability aspects of the projects being considered, specifically stating that government indemnification would be available to cover commercial projects.

The information available to the Task Force, and the expertise of certain members of the Task Force suggest that the legal issue does not appear to be a "show stopper". Nevertheless, further independent study should be undertaken.

Long-Range Electricity Needs - Fully supportable, long-range projections of electricity use (25 to 50 years), particularly on an international basis, are difficult to make. Nevertheless, some observations about the future use of electricity can be made with a high degree of confidence. From 1972 to 1988, U.S. energy use rose by less than seven percent, but electricity use grew by 55 percent. It is expected that in the U.S., electricity will continue to be the energy of choice for end-use purposes and its use, relative to other energy sources for end-use purposes, should continue to increase. Based on an extensive review of economic, societal and technological trends, the Edison Electric Institute* recently issued a report entitled, Electricity

* The Edison Electric Institute is the national association of the investor-owned electric utility industry.

Futures - America's Economic Imperative, which projects that the total U.S. electricity consumption will grow by 2.6 percent annually until the Year 2000, and then by 1.5 percent annually in the 15-year period 2000 to 2015.

In order to increase and sustain economic growth, even greater electricity growth rates must be achieved by developing countries. A 1988 report of the Working Group on Long-Term Forecasting of the Organization for Economic Cooperation and Development (OECD) estimated that electricity projections for the OECD regions (North America, Western Europe and the Industrialized Pacific) would double during the period 1985-2030, while there would be an eight-fold increase in projected electricity usage in the developing countries during the same period. Conservation may work "wonders" in societies where waste exists, but does not solve the energy production needs of the majority of mankind.

Long-Range Electricity Supply Options - Most electricity growth will be met in the next several decades by utilizing current technology and terrestrial fuel resources, particularly in developing nations. For the most part, these will be provided by coal and nuclear fission. But long-term, there could be limitations in the use of our current means of producing electricity. It is beyond the scope of this report to quantify these limitations and when they might influence energy policy at both the national and international levels. But emerging environmental concerns and resource availability suggest a changing character to the energy policy decisions that must be made in the future. For example, Western European per capita energy consumption applied worldwide would lead to the inane energy consumption of 40,000 million metric tons of coal equivalent per year!* And yet, economic aspirations require increased energy availability particularly to poor countries. Forests are a poor and limited source to meet such needs. And their use as combustible fuels would add to, not decrease, environmental impacts.

We have already seen environmental issues raised to a global level with concerns about global climate change. One of the solutions suggested to mitigate global warming is a reduction in the use of fossil fuels to decrease CO_2 emissions by 20 percent as early as the Year 2000. Only time will tell how urgent is the problem and how Draconian will be the solutions. But the global environmental concerns have momentum, and, if nothing else, they have the potential to increase the real costs of producing electricity with the use of fossil fuels as resources become more expensive to produce (particularly oil and gas) and the capital cost of the facilities to burn fossil fuels (particularly coal) in an increasingly strict environmentally acceptable manner becomes more expensive.

* According to the 1986 Energy Statistic Yearbook of the United Nations, world consumption of energy in 1986 was 9322 million metric tons of coal equivalent.

Currently, in the United States, nuclear fission is not considered a near-term, viable electricity option for new capacity for several reasons which need not be discussed in this Report. And, although it is, and will continue to be, a viable option in other nations, and, although many believe it will, and should, be a revitalized option in the United States in the near-term future, there is the possibility in the longer-term future that thermal pollution, nuclear proliferation and nuclear waste concerns will continue to impact adversely on its use.

Any development of long-term (25 to 50 years) scenarios of international energy production and use is fraught with problems. It is very difficult to suggest that fossil fuels, and more recently, nuclear fuels, which have served us well and in which governments and industry have huge investments, should not remain, along with conservation and end-use efficiency, the cornerstone of our near-term energy future. The long-term is not so clear.

The only apparent choice with today's technology is coal and nuclear fission power. They will and should be used. Also to be considered is the D·T fusion reactor and Earth-based solar power. But these energy options have drawbacks. The D·T reaction results in radioactivity and Earth-based solar power is limited to cloud free daylight hours of operation. Consequently, it is important to have additional options. The Moon can provide these.

All three options considered in this Report (He-3, LPS and SPS) have the potential promise to provide a practically inexhaustible, clean source of electricity for the U.S. and worldwide, without major adverse impacts on the Earth's environment.

Deep and growing concerns regarding environmental pollution, thermal limits, potential fuel scarcity, and the non-uniform international distribution of fossil resources suggest cost factors that will influence future directions, and make serious consideration of extraterrestrial energy options a matter of national interest. Synergism with future space policy directions may also be a factor that would influence future energy supply choices.

Extraterrestrial Electricity Supply Options - As stated in the background section to this report, NASA requested the Lunar Enterprise Case Study Task Force to assess the economic viability of mining and burning lunar He-3 to produce terrestrial electric power. In order to provide perspective to the assessment, the Task Force was requested to consider two other extraterrestrial electric energy production projects, the solar power satellite (SPS) and the lunar power system (LPS). What follows are brief technical descriptions of the three concepts. More detailed information about the concepts is provided in appendices B-1 to B-4. Appendix B-5 provides additional information on the space transportation requirements and operations aspects of space energy systems. Appendix B-6 provides additional information on the He-3 concept.

Helium-3 System Concept

According to plans prepared before a source of He-3 was discovered, the first fusion reactors will be fueled by two isotopes of hydrogen, deuterium (D) and tritium (T), to produce energy, neutrons and helium. One of the drawbacks of this process will be the radioactivity which accompanies the neutrons and tritium, orders of magnitude less than from fission reactors, but undesirable nevertheless.

He-3 combines with deuterium in an alternate fusion reaction. This reaction produces fewer and lower energy neutrons and almost no tritium but as much energy as the D•T reaction. Besides generating critical reaction energy and reduced radioactivity, the D·He-3 reaction could ease the development, licensing, and maintenance of fusion reactors. The D·He-3 fusion process produces charged particles. This holds the potential for a large increase in the conversion efficiency to electric power by avoiding the step of thermal conversion. However, compared to the D·T reactor, the D·He-3 reactor may be larger and will operate at a temperature three times as high.

Fusion of He-3 has received little emphasis in the Department of Energy development programs because not enough He-3 was available on Earth to support a commercial reactor. Research and demonstration reactors are feasible with the terrestrial He-3 supply, and the Joint European Tokamak research reactor has already produced 100 KW of D·He-3 thermonuclear power. However, in the early 70's, lunar scientists noted that a large quantity of He-3 had been implanted by the solar wind in the lunar soil and that this He-3 could be used as a fusion fuel. It has been estimated that 25 tonnes of He-3, reacted with D_2, would have provided for the entire U.S. energy consumption in 1987. Although lunar He-3 is not renewable, it is estimated that there is sufficient He-3 on the surface of the Moon to satisfy the world's current electric energy needs for over a 1000 years. Thus, the He-3 concept, shown in Figure 1, involves going to the Moon to separate the He-3 from the lunar soil, and return it to Earth for use as a fuel in specially designed commercial fusion electric power plants.

To achieve this goal, will require large-scale lunar mining, soil processing, and separation of He-3 from other released volatiles, transportation of this helium to Earth, and development of the D·He-3 fusion reactor. Definition of each of these steps has been initiated. A lunar miner which returns soil to the trench after removing volatile substances, including

He-3, is in a preliminary conceptual design stage. Separation of He-3 from other gases could use available technologies. Volatile by-products, such as hydrogen, oxygen, water, and nitrogen, in quantities much larger than that of He-3, will be produced. Important space applications may exist for these materials. Concepts for transporting the He-3 to Earth and for fusion reactors to burn it are also being studied.

He-3 could sell on Earth for a half million dollars per pound, according to preliminary benefit analyses. This could make He-3 an ideal space product worth the expense of the mission. In addition, the accumulation of volatile by-products on the Moon could be worth as much, financially, as production of He-3. Thus, in a preliminary sense, the He-3 concept appears to have great economic potential.

The Solar Power Satellite (SPS) Concept

The objective of the SPS is to convert solar energy in space for use on Earth. Its most significant benefit is the potential for continuously generating large-scale electric power for distribution on a global basis. The SPS concept is shown schematically in Figure 2.

An SPS system would consist of many satellites in geosynchronous Earth orbit, each SPS beaming power to one or more receiving antennas at desired locations. The system, as studied by NASA and DOE in the 1970's, provided 5000 Mw of electric power to the Earth from a single satellite. Use of modern structural techniques in a 1990's design would substantially reduce the mass and further enhance SPS feasibility.

Solar radiation received in geosynchronous orbit is available 24 hours a day most of the year. With this year-round power capability, SPS could be used to generate base load power on Earth with a minimum requirement for energy storage.

Microwave beams, or laser beams, would be used to transmit the power generated by the SPS to receivers on Earth. With microwave power transmission, for example, generators are incorporated in the transmitting antenna, which is designed as a circular, planer, active, slotted, phased array. To provide microwave power from geosynchronous orbit, the transmitting antenna would be about 1 kilometer in diameter, and the receiving rectenna on Earth would be about 10 by 13 kilometers, at 40 degrees latitude. The microwave receiving and converting antenna (rectenna) has already been demonstrated to convert a microwave beam into direct current electricity with an efficiency of 85 percent.

To be commercially competitive, the SPS will require a space transportation system capable of placing payloads into low orbit and geosynchronous orbit at substantial lower cost than possible today. This will require an advanced launch system similar to several now being considered. If SPS power could be supplied on a small scale to evolving space projects, such as Space Station Freedom, overall SPS feasibility may be enhanced.

From a technology viewpoint, SPS does not require a return to the Moon; however, SPS would benefit economically from the establishment of a lunar base and the development of processing technologies for lunar materials. Transportation of all the required materials from Earth on a scale required to build up a global SPS system may result in environmental damage from propulsion by-products. Since less energy is required to move mass from the lunar surface to geosynchronous Earth orbit than from the Earth's surface to the same orbit, it will be advantageous -- potentially even mandatory for economic feasibility -- to obtain materials for the construction of the SPS from the Moon. If processing and the transportation of materials from the Moon to geosynchronous orbit could be accomplished at costs comparable to the launches of payload from Earth, conceivably, more than 90 percent of the mass of an SPS could be mined, refined, fabricated, and transported from the Moon.

In summary, lunar resources, such as metals, glasses, and oxygen, promise to provide materials for the construction of the system of solar-powered satellites in geosynchronous orbit provided that the use of these resources can be competitive with terrestrial materials. Also, through the SPS reference system study of the 1970's, it has been demonstrated that the technology for transmitting power from space to Earth is amenable to evolutionary development and that the SPS concept is technically feasible. If placed near the Moon, an SPS could provide power to a lunar base as a first, important technology demonstration project of far-reaching importance.

Lunar Power System Concept

The lunar power system (LPS) is a microwave power-beaming concept which uses the Moon rather than Earth-orbiting satellites for collecting and transmitting power. The elements of this system can be understood from Figure 3. The LPS will collect solar energy at lunar power bases located on opposing limbs of the Moon. Each base contains solar converters and microwave transmitters that transform the solar power into microwave power. This is beamed to receivers on Earth and in space, which convert the microwaves back to electric power. Most of the components of the base will be formed from lunar materials. Initial estimates suggest that only one tenth of a tonne of components and consumables will be required from Earth to implace one megawatt of received power.

To use a lunar power base during lunar night, additional sunlight will be reflected to the base by mirrors in orbit about the Moon. Microwave reflectors in mid-altitude, high inclination orbits about the Earth, will redirect microwave beams to rectennas that cannot directly view the Moon. The sunlight and microwave reflectors can eliminate the need for power storage on the Moon or Earth, permit the LPS to follow the power needs of each receiver, and minimize the need for long-distance power transmission lines on Earth. The complete lunar power system consists of the power bases, the orbital mirrors around the Earth and Moon, and the rectennas.

The billboard-like antennae of one LPS base are arranged over an area of the limb of the Moon so that when viewed from the Earth they appear to merge into a single, large, synthetic aperture transmitter with a diameter of 30 to 100 kilometers. The transmitted beams are convergent toward a point well beyond the Earth. Each beam can be intensity-controlled across its cross-sectional area to a scale of 200 meters at the Earth. This allows the LPS to uniformly illuminate rectennas on Earth that are larger than 200 or 300 meters across.

A given base on the Moon is adequately illuminated only about half of the days of the lunar month. It is preferable to keep the lunar bases illuminated and delivering power continuously.

Large mirrors, "Lunettas," will be placed in orbit about the Moon and oriented so as to reflect sunlight to the bases. A "Lunetta," a version of the solar sail, will have low mass per unit area, be of low optical quality, and be constructed primarily of lunar materials.

A station on Earth will receive power directly from the Moon when the Moon is approximately 10 degrees above its local horizon. To provide continuous power to rectennas that are blocked by the Earth or attenuated by long paths through the atmosphere, microwave mirrors in Earth orbit are required. Each microwave mirror will be approximately 1 kilometer in diameter and be continuously oriented so as to reflect the microwave beam from the Moon to a rectenna on Earth.

The lunar power system is complex but has the advantages of enormous power potential, support for both continuous base load and load following power and global coverage. If developed in conjunction with a lunar base, it could supply power to the lunar base as a means of starting the commercialization process.

<u>Commercial Potential</u> - In evaluating the commercial potential of a concept, industry considers many factors including degree of risk, payout period, potential market, technical feasibility, R&D investment requirements and competition of alternative methods.

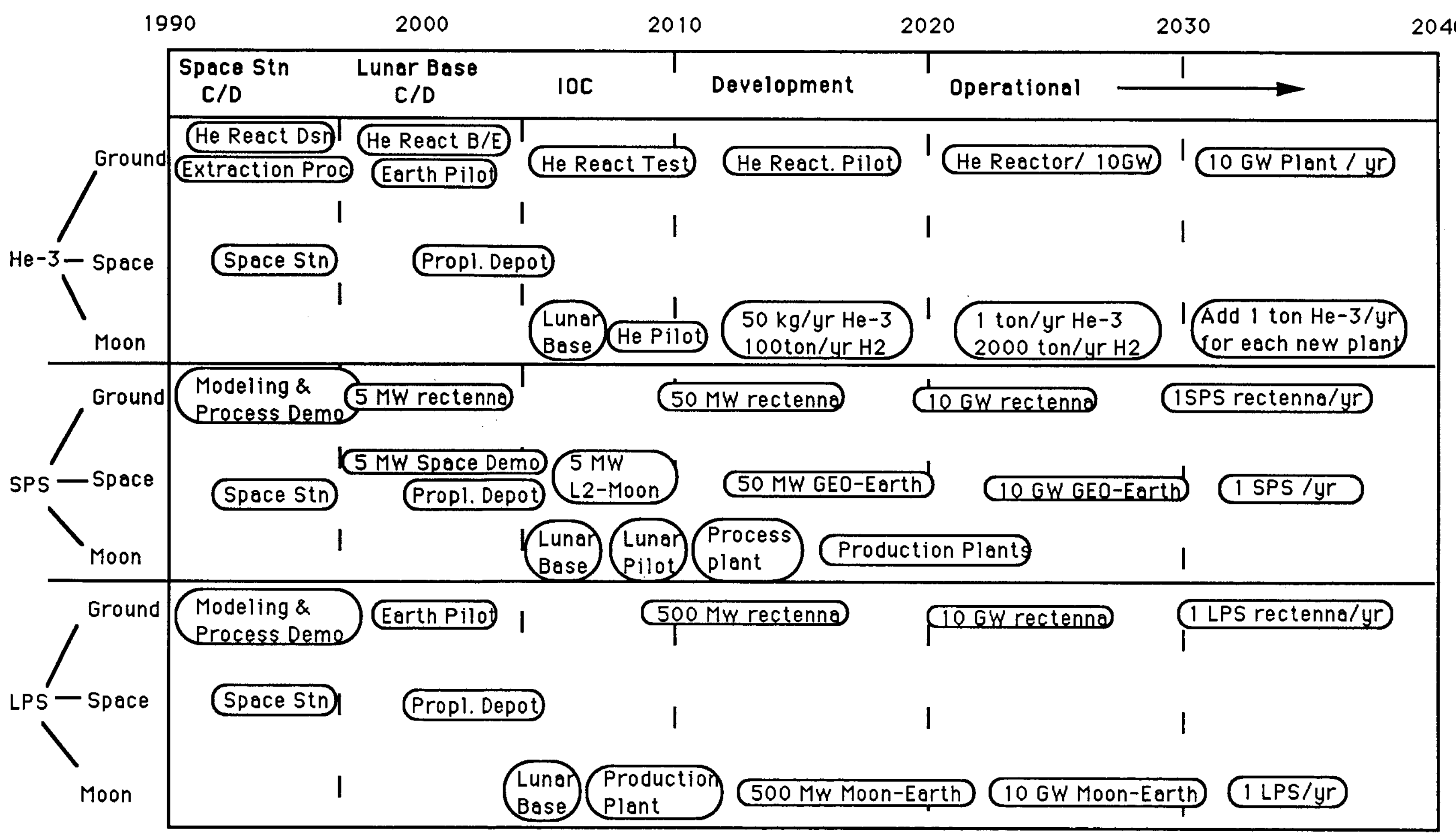
If these criteria are applied to the end-stages of the He-3 fusion project or other extraterrestrial concepts at this state of their early development, it is not surprising that industry will not invest now in these concepts when compared to other financial opportunities. But the same conclusion was understandably reached about nuclear fission at a similar stage in its development.

Commercialization of new concepts takes the combined efforts of government and industry. The Task Force believes a similar approach is possible and should be considered in exploring means to develop long-range, terrestrial electricity supply using extraterrestrial resources, principally the Moon. The Japanese government/industry approach, embodied in MITI, has been successful in providing Japan with the means of gaining leadership in many high technology undertakings. This approach should be considered by the U.S. Government and industry in developing extraterrestrial energy supply.

The Task Force also firmly believes that complete government assumption of total project responsibility would inhibit the advantages of commercial involvement. Furthermore, a development program that will evolve over a longtime horizon (50 years) is outside the time horizon normally considered even by very innovative industries and corporations, although it is comparable to the perspective of some natural resource industries. Yet, extraterrestrial energy projects require such a long-term outlook. Hence, there is an intrinsic need for an innovative approach to the industry and government cooperation. In addition, the long-time horizon (50 years) makes it very questionable to use standard tools of quantitative economic and econometric analysis (prices, technologies, demand, etc.), since they shift significantly and in unpredictable ways.

With these project characteristics and requirements in mind, the Task Force, during the course of its deliberations, discussed the proposed Lunar Outpost, which was briefly described in the NASA Office of Exploration 1988 Annual Report to the NASA Administrator. The review indicated some coincidence between the Lunar Outpost development time scale and those of the He-3 fusion project and the other extraterrestrial energy projects. This is shown on the chart on the following page.

LUNAR BASE AND ENTERPRISE CONCEPTS TIME LINE



The coincidence demonstrated on the chart on the preceding page suggested a possible innovative, government/industry co-operative approach to developing and eventually utilizing extraterrestrial resources to help meet terrestrial energy needs. This approach -- and there probably are others which further detailed analyses by financial experts might suggest -- is based on the conviction that the commercial development of extraterrestrial energy and the development of a lunar base can be linked effectively. The lunar base can serve as a development step of many of the technologies needed for the energy system, and can be a customer for services at pilot production levels.

The three options considered in varying degrees by the Task Force (He-3, LPS, SPS) differ significantly in both the services and side products each may offer for the Lunar Base deployment and subsequent expansion. Solar power technologies can be designed to provide early power services for Lunar Base operations, as well as efficient lunar-Earth transportation. He-3, per se, could provide power only at some distant future time. However, power sources needed for mining, beneficiation, and processing also could provide early power services to a Lunar Base. On the other hand, He-3 mining operations can provide very large amounts of significant side products (H_2, O_2, C, Al, Si, etc.) for lunar and space operations.

Based on these observations, the following opportunity for industry and government cooperation might be considered:

- An industry consortium and NASA could enter into a joint development effort for providing energy/utility services to the Lunar Base, with a view to have early industry involvement also in the RDT&E of any of the three (and potentially other) lunar-based energy options.
- To accomplish this arrangement, innovative legal and statutory forms of long-term cooperation between industry and NASA would have to be explored, ranging from a long-term service contract for providing these services (energy supplies to the Lunar Base and later production of energy for use on Earth and in Space), combined with possible co-funding of RDT&E on critical technology components, to rights of first refusal to any intellectual and patent rights developed as a result of this development effort.
- In addition, the opportunity for industry involvement would be improved with a streamlining of government supervision, regulation, duplication of administrative and accounting functions. The consortium should be entrusted with the procurement of necessary technology components, and the examination of options and alternatives within each of the key technologies.*

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* The precedent set in the development of commercial space communications by the COMSAT Act may be followed.

- An important key to lowering the public cost to this enterprise would be the granting of mining concessions and rights to the extracted resources to the consortium. Innovative international legal precedents also may have to be established.
- The By-Laws of the consortium would provide for a "plowback" of part of the revenues from the sale of service to NASA and technology advances to benefit the enterprise effort.

Assuming that such a consortium could be formed to the satisfaction of both industry and government, broad service goals and a scenario for such a consortium over the next 50 years might comprise the following:

Phase I: Initial Lunar Outpost.

He-3 experimental mining to provide materials to the Outpost and support fusion experiments on Earth - A 5-MW Satellite Power System Prototype for solar electric propulsion and for energy supply to the initial Lunar Base from one of the libration points. NASA would enter into a services contract with the consortium for use of the plant(s), as well as participate in the funding of the RDT&E. Technology components for large-scale power systems, such as space-to-earth energy transmission links and fusion reactors, would be developed in this phase.

Phase II: Lunar Base.

Continued supply of utilities to the expanding Lunar Base - Large-scale mining begins leading to the development of a 50-MW power plant either on the moon or at the libration point(s) for laying the "energy base" for substantially expanded Lunar Base operations. The He-3 extraction prototype process is developed and tested end-to-end. Prototypes of the key technology components would be tested "in-situ" at the Base. The knowledge base (technology, costs, risks) of each of the three options could be established for large-scale prototype developments.

Phase III: Large-scale Prototype(s).

This phase will see the deployment of one or more of the three energy options at a scale of several Gigawatts to tens of Gigawatts.

Phase IV: Operations for Commercial Use on Earth.

Operations of the first power system and expension of capacity to meet global energy needs - This would be the ultimate goal of the Lunar Enterprise (i.e., the consortium). Important contributions simultaneously made to the supply of energy and material needs in Space for expanded Space exploration and applications.

CONCLUSIONS

The fundamental conclusion of the Task Force is that the Moon must play a role in long-term terrestrial electricity supply matters. The Task Force also believes that early commercial involvement in this task is of paramount importance in achieving this objective and that a meaningful leadership role for industry is potentially possible. But it recognizes that total industry responsibility for projects of this financial magnitude is not initially possible and government involvement through subsidies or other means, such as co-funding or enabling contracts, is vital.

The primary focus for this study, namely the mining of He-3 for transportation to Earth, is a potentially viable economic concept but understandably on a long-range schedule and subject to the establishment of specific conditions, including:

- Required space/lunar infrastructure to be put in place with preponderant government financing.
- Involvement of the private sector in defining and developing this infrastructure.
- Development of a private sector/government relationship that will provide for early private sector involvement which, as stated above, would not be possible under traditional financial and commercial considerations.

- Close coordination between NASA and DOE in the development of a commercial fusion reactor to utilize the lunar He-3 fuel.

The Task Force also reviewed the two solar power concepts, SPS and LPS. On the basis of information provided to the Task Force, these concepts likewise could have long-range economic potential as extraterrestrial electric power sources. The Task Force, however, was not in a position to rate the three concepts in terms of potential economic viability. But it did conclude that each concept has both promise and problems.

A great amount of technical information about all three concepts was developed by, and for the Task Force but more remains to be accomplished to assure confidence in the potential technical feasibility of the systems; much more detailed information concerning cost and scheduling must be developed to provide economic input; and commercial schemes must be developed in some detail to achieve realistic private sector involvement. To this end, we would recommend that NASA and DOE expand its work with academia, industry, and the financial community to further develop the technical, economic and commercial parameters that will better identify extraterrestrial energy options.

But of equal importance is the development of a clear understanding on the part of government and industry, at high levels, of the fundamental Task Force conclusion that we must look beyond Earth for our long-term electricity needs because of potential damaging ecological impacts with continual major dependence on fossil fuels for terrestrial energy needs. This is a revolutionary concept, and is based on a crucial observation regarding long-term environmental consequences of our current energy production options. There must be understanding, agreement and long-term commitment, and the national will to implement the commitment as a matter of national policy. It also is extremely important to realize that the concept of extraterrestrial energy supply is not the responsibility of any single government agency nor will it seriously be considered if there is not a national commitment.

Lastly, we must recognize that other nations, notably Japan, West Germany and Russia, are proceeding with very aggressive programs to investigate and develop space-oriented, energy systems. It will be done. It is just a matter of by whom.

RECOMMENDATION

As stated in the conclusions, there is need for, and economic potential for the use of the Moon's resources in long-term, terrestrial electricity supply matters. The factual case for this finding, however, needs further development. Because of the long-range nature of these extraterrestrial projects, industry is not currently capable or willing to assume financial responsibility for these undertakings. The Task Force, therefore, recommends that NASA and DOE continue to support studies that will better frame the development of the projects and provide the additional technical, economic and financial information that will be necessary for greater commitments. The Task Force recommends, however, that these studies not be contracted for under normal government procedures but rather that industry, the financial community, and academia be given a primary role in planning the overall program. This could be accomplished through the establishment of a high-level private sector advisory committee.

The Task Force also recommends that a Workshop be held in accordance with its conclusion that national policy on extra-terrestrial energy supply concepts must be developed. The purpose of the Workshop would be to expose the issue of long-term energy supply options to high-level decision makers, provide understanding about the issue, and seek policy direction and commitment. To be successful, the participants must include high-level representatives of the Administration, appropriate government agencies such as DOE, EPA and NASA, the energy, environment and space leadership of the Congress, electric utilities, the space and energy supply industries, and the financial community. Of equal importance, is detailed planning for the Workshop. The Task Force recommends that the suggested private sector advisory committee's participation in the planning aspects would be essential.

Concept Description
HELIUM-3 FROM THE MOON

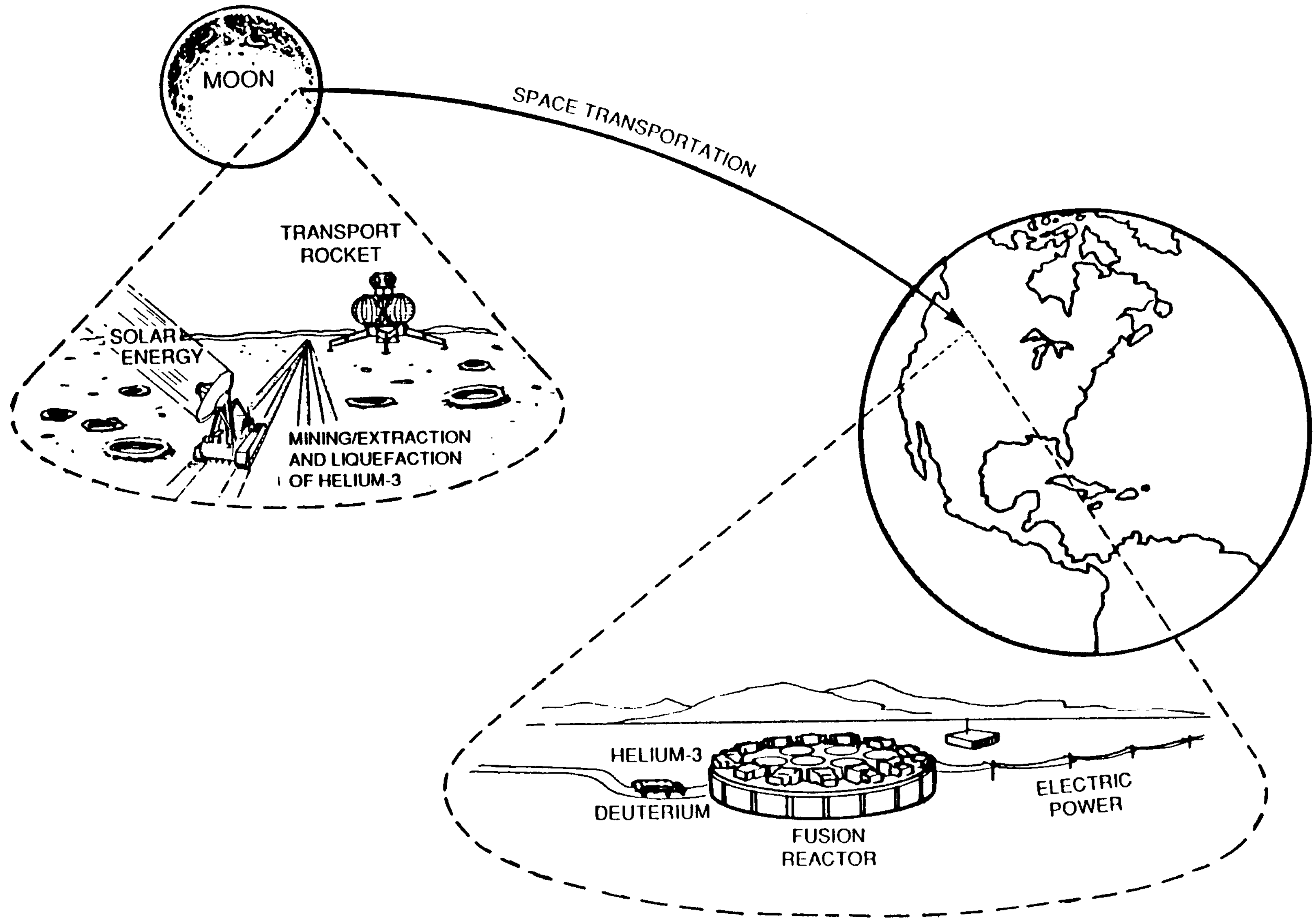

FIGURE 1

Concept Description
SOLAR POWER SATELLITES

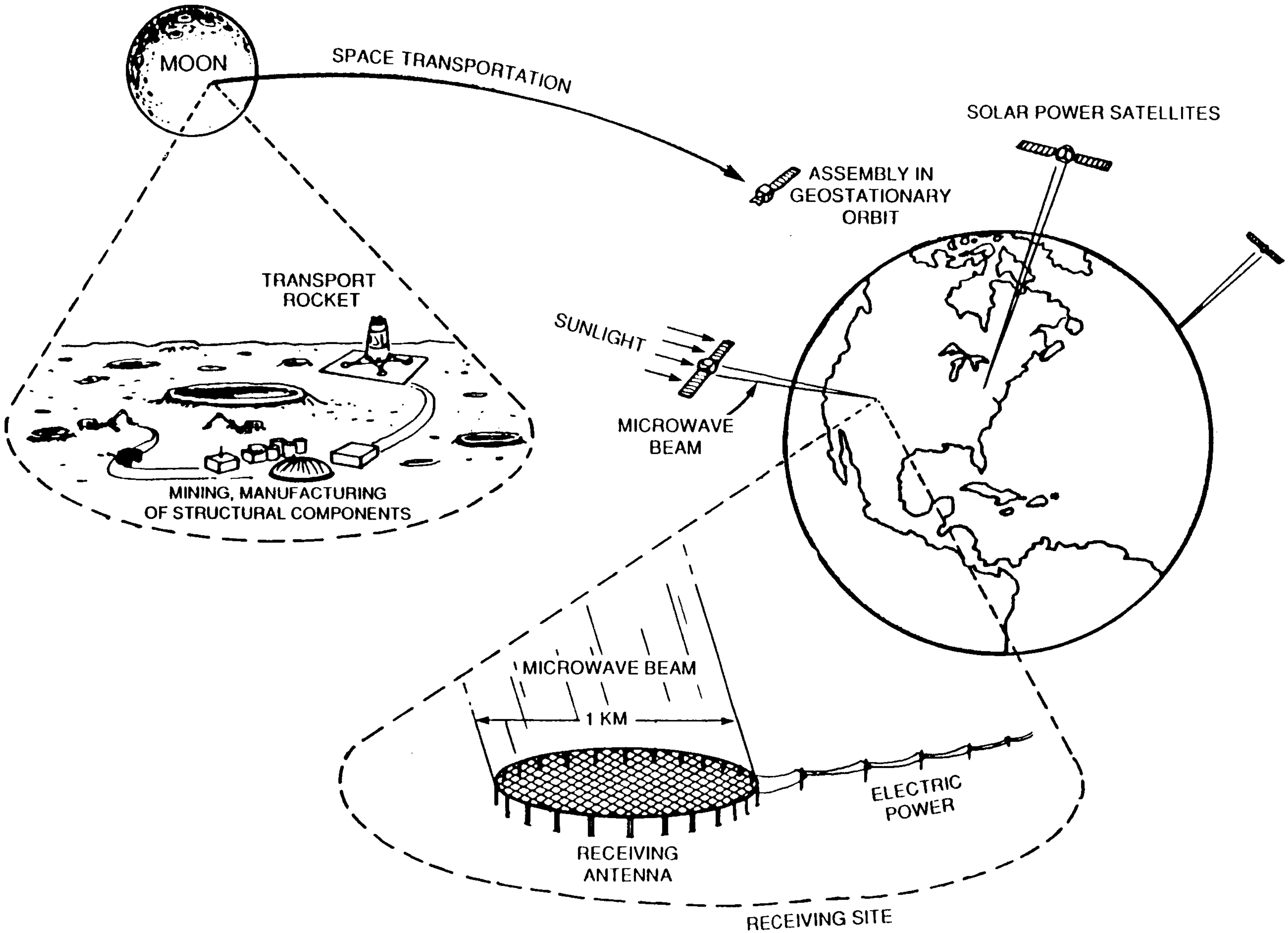

FIGURE 2

Concept Description
LUNAR POWER SYSTEM

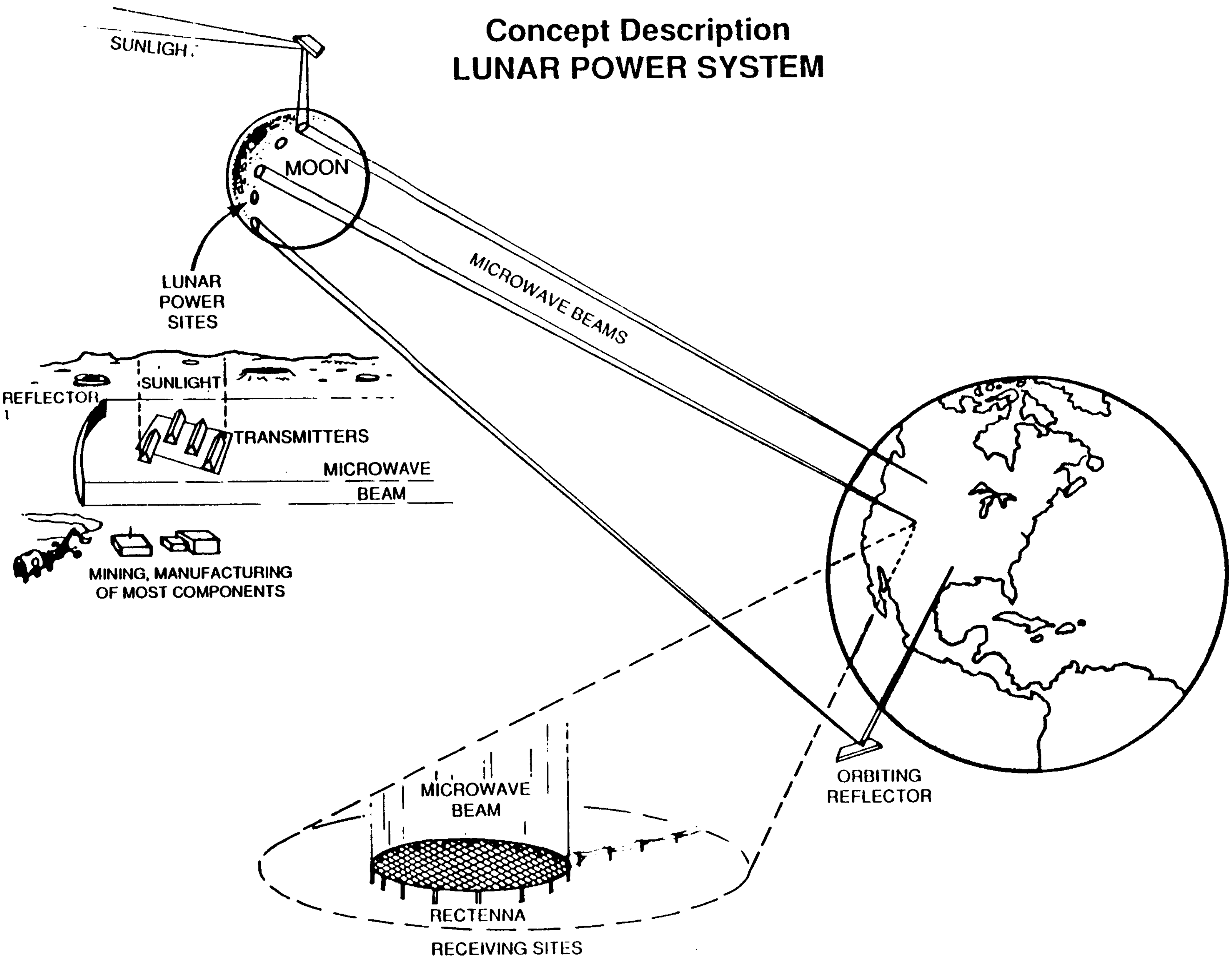

FIGURE 3

Membership Listing of

Lunar Energy Enterprise Case Study Task Force

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