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ENERGY FOR LUNAR RESOURCE EXPLOITATION

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Abstract

Humanity stands at the threshold of exploiting the known lunar resources that have opened up with the access to space. "Historically, wealth has been created when the power of the human intellect combined abundant energy with rich material resources. Now America can create new wealth on the space frontier to benefit the entire human community by combining the energy of the Sun with materials left in space during the formation of the Solar System."¹

America's role in the future exploitation of space, and specifically of lunar resources, may well determine the level of achievement in technology development and global economic competition.

Space activities during the coming decades will significantly influence the events on Earth. The "shifting of history's tectonic plates" is a process that will be hastened by the increasingly insistent demands for higher living standards of the exponentially growing global population. Key to the achievement of a peaceful world in the 21st century, will be the development of a mix of energy resources at a societally acceptable and affordable cost within a realistic planning horizon. This must be the theme for the globally applicable energy sources that are compatible with the Earth's ecology. It is in this context that lunar resources development should be a primary goal for science missions to the Moon, and for establishing an expanding human presence. The economic viability and commercial business potential of mining, extracting, manufacturing, and transporting lunar resource-based materials to Earth, Earth orbits, and to undertake macroengineering projects on the Moon remains to be demonstrated. These extensive activities will be supportive of the realization of the potential of space energy sources for use on Earth. These may include generating electricity for use on Earth based on beaming power from Earth orbits² and from the Moon to the Earth³, and for the production of helium 3 as a fuel for advanced fusion reactors.⁴

Lunar resource utilization will require that power be available for a wide variety of activities on the Moon. The associated power generation infrastructure and technologies would be commercialized with the combined efforts of industry and government. Innovative approaches will be required to maintain steady progress over a long-term time horizon.⁵

This will involve the evolution of an enabling legal and regulatory framework. To meet projected requirements power could be generated directly on the lunar surface, transmitted via power beaming to distant work sites, beamed from the Earth to the Moon, or from power stations in a suitable Lagrangian orbit or lunar orbit. Power beaming technologies using microwaves or lasers operating in selected portions of the electromagnetic spectrum are being developed in Europe, Japan, U.S., and U.S.S.R.⁶ Thus the architectures considered for the permanent human presence on the Moon⁷ are of increasing commercial relevance, and key to maintaining the U.S. position as a space-faring nation and gaining public support for the Space Exploration Initiative (SEI). The overarching objective for SEI should be economic advancement, societal progress, and safeguarding the Earth's ecology.

This objective should animate U.S. space policy and programs, and be in consonance with the motivations of the science and technology space community. Other nations are beginning to recognize the value of exploiting extraterrestrial energy and materials resources for an environmentally sustainable world economy. It will be done. It is just a matter of by whom.⁸

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ENERGY FROM THE SUN AND MATERIALS FROM THE MOON

Humanity is facing daunting challenges as we look towards the 21st century. Among these challenges whether they be political, economic or environmental the availability of energy is key to the continued striving for acceptable living standards of the world's growing population.

Total world energy consumption has more than quadrupled since the 1950s. Nearly 90% of current energy demands are met by the combustion of fossil fuels. The inequitable availability of these fuels is resulting in widening disparities between developed and developing countries, and are the cause of increasing threats to the Earth's ecology and climate.

Exponential population growth is leading to a possible doubling of the world's population by the middle of the 21st century. This wave of humanity will have to be fed, clothed and housed to achieve a tolerable living standard. The resulting predictable and escalating deterioration of the biosphere has to be mitigated while seeking ways to advance the development of the majority of humanity. These challenges will be explored at the United Nations Conference on the Environment and Development, Rio de Janeiro, June 3 to 15, 1992.

The key to achieving this advancement is to have adequate supplies of energy at an affordable cost, and to place increasing reliance on renewable or inexhaustible energy sources that are compatible with the environment. There is a window of opportunity that may be open for only a few decades to develop energy options that no longer rely exclusively on terrestrial sources of energy. Terrestrial sources are either finite, subject to diurnal changes or weather, lead to unacceptable environmental impacts, or cannot reach the required scale to meet increasing global energy demands.

Historical developments indicate that the changes from one global energy source such as wood to coal and coal to oil, took place during successive intervals of about 75 years. This will also be the case when new energy sources are applied on a global scale. Because of these protracted time scales required for potential measures to mitigate global ecological deterioration and the potential effects of global warming, it is critical to start now developing and selecting promising energy production options that can sustain global economic growth without creating irreversible damage to the ecology. This also is the context for energy conservation measures, and human behavioral adjustments resulting from lifestyle changes.

As part of any assessment of alternative energy technologies, extraterrestrial resources deserve to be seriously considered. This will provide an understanding of the inexhaustible and renewable energy options available at various stages of global development in the 21st century. "Historically, wealth has been created when the power of the human intellect combined abundant energy with rich material resources. Now America can create new wealth on the space frontier to benefit the entire human community by combining the energy of the sun with materials left in space during the formation of the solar system."¹

More than two decades ago the solar power satellite (SPS) was proposed as a major option for the continuous generation of electricity to meet future global energy needs.² Over the intervening years the SPS has been assessed and analyzed and technical, economic and societal issues have been debated.³ Today the SPS is no longer relegated to the pages of science fiction magazines. Efforts to develop a range of technologies applicable to the SPS are under way in Europe,⁴ Japan,⁵ U.S.,⁶ and the former USSR.⁷

In the early stages of a program, such as the SPS, with potential global applications several decades in the future, it is difficult to project how an SPS program can best be pursued until information on technical, economic and societal issues from seemingly unrelated programs can be applied to guide the selection of appropriate development approaches. During this period different paths may have to be explored so that the most effective generic technologies can be identified, assessed and analyzed, and the most promising options selected. This selection must be based not only on technical criteria but also conform to economic requirements, and be in consonance with societal considerations and preferences and the legal and regulatory framework. By analogy to other technology developments that had major impacts both on a national and international scale, the success of programs such as global aviation and satellite communications and their successful applications would not have been possible without a staged development effort extending over a period of decades. A necessary prerequisite for the growth of these programs was the evolution of international agreements, national and international policies and regulations, and the increasing confidence of both public and private sector investors in the applicable technologies based on demonstration projects of increasing scale and complexity, market assessments and customer identification. Satellite programs for global communications and navigation resulted in the formation of international organizations such as Intelsat and Inmarsat which are examples of the organizational, legal and regulatory framework that will be required for the evolution of a global SPS system.

Although the concept of a global SPS system can be visualized in broad outline, it is no more possible now to describe in detail future steps beyond those which can be taken in the near term than it was possible to project, at the time the DC 3 airplane was being designed, the development of large passenger jet aircraft capable of meeting the needs of international travelers decades later.

Rather than focusing attention exclusively on a possible design of SPS that would operate in the 21st century, it is important to select near-term applications of space power to supply elements of the evolving space infrastructure, to identify markets and customers willing and able to pay for the power supplied in space,⁸ and to obtain financing for commercial applications.

Demonstration of space power beamed to meet customer requirements in space,⁹ e.g. , to the space shuttle and Space Station, will assist in the development of policies and the legal and regulatory framework which will have to be in place so that investment capital can be made available to specific space power projects including power beamed from Earth to orbiting satellites and relayed across large distances to users,¹⁰ e.g. , Australia to Japan and Africa to Europe.

However, it is necessary to recognize that planning should proceed now towards the future development of an SPS system that can meet energy needs of both developed and developing nations in the 21st century, so as to guide near-term technology development and project selection. As practical applications of space power are demonstrated in space and eventually on Earth, societal acceptance of SPS will be of increasing importance. Therefore, assessments of any adverse impacts that may be associated with a global SPS system will be essential to permit mitigation measures to be developed concurrently. The lessons learned from the development of other globally applicable energy resources including coal, oil, natural gas and nuclear power should be applied to the SPS development so that the potential for ecological deterioration will be minimized, adverse health effects avoided, and ecologically compatible energy production methods developed before an SPS system would be introduced on a global scale.

The SPS should be viewed not as a stand-alone program to meet all global energy demands. Instead, it should be part of a global effort that reconciles energy demands with human values and ecological concerns. Ultimately, a global SPS system will operate in concert with other energy

production systems. The objective is to choose the options that will meet human needs without the long-term adverse effects of existing energy production methods.

The SPS concept encompasses a broad range of possible technologies.¹¹ Some will reach operational readiness during this decade, and others only after several decades of development. SPS will at first utilize terrestrial and subsequently extraterrestrial resources, to meet an increasing share of global energy demands. For this reason, it may be necessary to consider a growth path for implementing a global SPS system extending over several decades into the 21st century, as *Figure 1* shows.

Although the SPS represents a grand vision for the future, it is not possible to anticipate the complex changes in technology, political circumstances, and economic expansion that will result in sustainable global development.

Therefore, this path for technology development should be integrated with efforts to reduce the uncertainties in climate change predictions, improve energy use efficiency, and develop effective applications of terrestrial renewable energy technologies. Demonstration of SPS-related technologies should be started in the 1990s so that the most promising technologies are selected, their economic value established, and societal concerns associated with environmental impacts assessed and mitigated. For example, technologies applicable to high-altitude, long-endurance aircraft that receive propulsive and payload power beamed from the ground are under development. A successful demonstration of a small scale aircraft was sponsored by the Canadian Department of Communications in 1987. Kyoto University's Radio Atmospheric Science Center is expected to fly a similar aircraft designed to relay radio signals for mobile communications with the express purpose to test technology applicable to the SPS, and a demonstration of a IOMW SPS is being planned for the end of this decade by Japan's Institute of Space and Astronautical Sciences.

The past three decades of the space era have demonstrated that humanity's evolutionary progress need not be confined to the Earth's surface. Satellites for communication, navigation and Earth observation are using solar energy as a means to power various systems that have already significantly affected life on Earth. All indications are that there is no limit to the uses of space technologies for the benefit of society, and achieving the vision of humanity reaching towards the stars. The capabilities of an increasingly industrialized global civilization to develop new technologies can be applied to the production of energy conversion systems in space to supply the Earth on a scale that may not be possible for such systems installed on Earth.

The challenges to develop extraterrestrial energy and material resources are formidable. International efforts and coordination will be required over a period of decades to make the transition from the current to 21st century energy production methods.

It is in this context that lunar resources development should be a primary goal for science missions to the Moon, and for establishing an expanding human presence. The economic viability and commercial business potential of mining, extracting, manufacturing and transporting lunar resource-based materials to Earth, Earth orbits, and to undertake macroengineering projects on the Moon remains to be demonstrated. These extensive activities will be supportive of the realization of the potential of space energy resources for use on Earth.

Lunar resource utilization will require that power be available for a wide variety of activities on the Moon. The associated power generation infrastructure and technologies would be commercialized with the combined efforts of industry and government. Innovative approaches will be required to maintain steady progress over a long-term time horizon. This will involve the evolution of an enabling

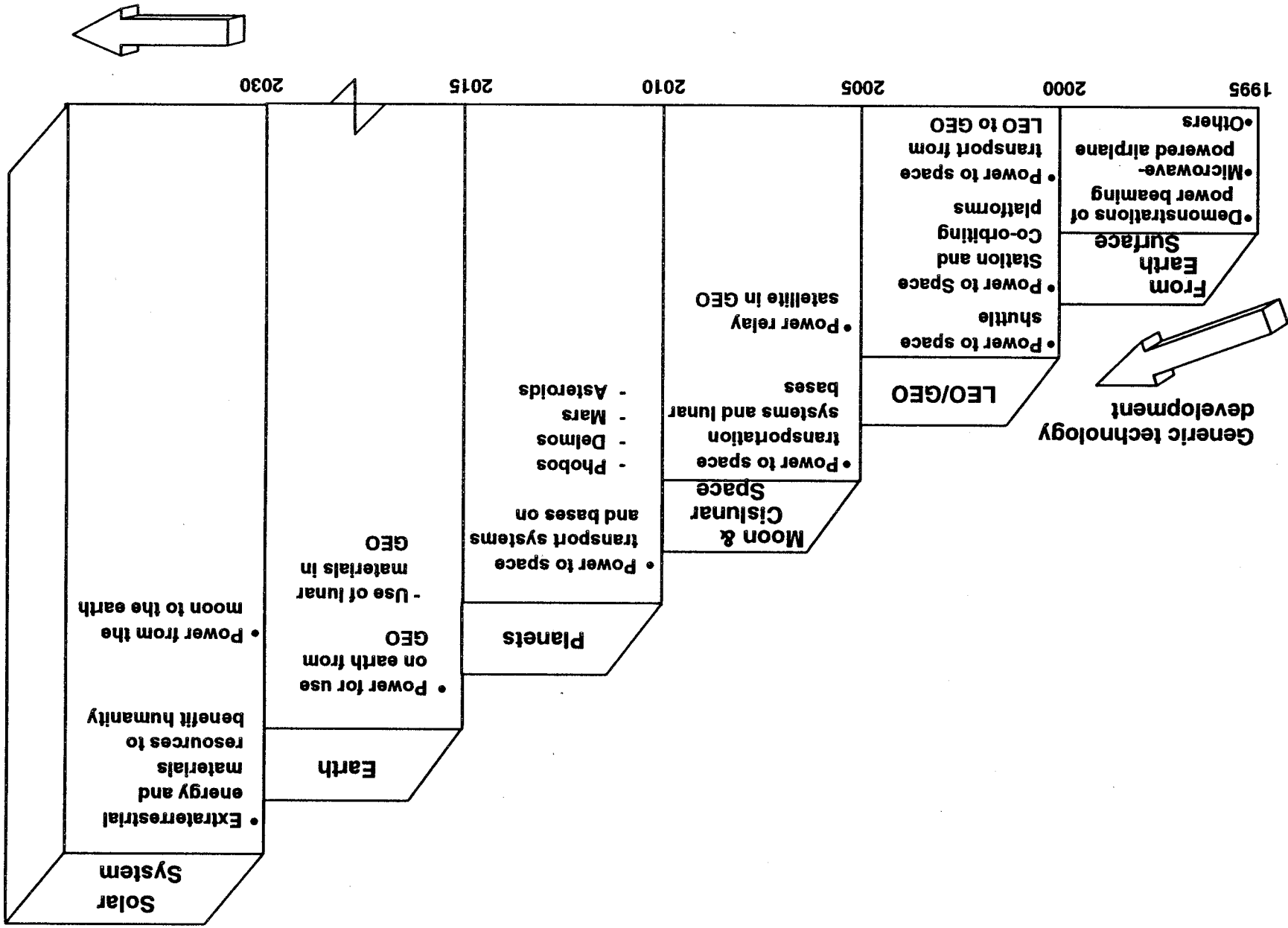


Figure 1: A Growth Path for the Evolution of the SPS

legal and regulatory framework for lunar resource exploitation.

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Thus the architectures considered for the permanent human presence on the Moon" are of increasing commercial relevance, and key to maintaining the U. S. position as a space-faring nation and gaining public support for the Space Exploration Initiative (SEI). The overarching objective for SEI should be economic advancement, societal progress and safeguarding the Earth's ecology.

Now is the time to take a positive view of the achievable objectives of global space endeavors, and to recognize the constructive and catalytic role that solar energy received in orbit, on the moon, and on Earth can play in sustaining the evolution of the planet Earth civilization. Strategic planning by the public and private sectors in several nations is underway now to ensure that space power will be able to make an increasingly important contribution to meet global energy demands. The challenge is not only to arrive at an unbiased assessment of viable options that can meet energy requirements at various stages of human development, but also to recognize that management of both terrestrial and extraterrestrial resources will be required on an unprecedented scale.

There may be only a limited time left, measured in a few decades, to open up the space frontier so that the contribution of space resources can be demonstrated. The space-faring nations are in a unique position to lead this effort as discussed at SPS 91. The question is no longer whether humanity will effectively use space resources but who will be in the vanguard.

The SPS represents a unique opportunity for the nations of the world to constructively use extraterrestrial energy and materials resources to advance global development efforts and to ensure that the ecological integrity of the Earth is preserved. "Five centuries after Columbus opened access to The New World we can initiate the settlement of worlds beyond our planet of birth. The promise of virgin lands and the opportunity to live in freedom brought our ancestors to the shores of North America. Now space technology has freed humankind to move outward from Earth as a species destined to expand to other worlds."⁽¹⁾

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