Space Solar Power— An Option for the Future

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In the movie "Apollo 13" the engineers had a discussion on how to get the astronauts home safely. A number of suggestions were made and they began to debate the options. One engineer stopped the conversation, and said: "**Power is everything.**"

None of the options was possible without power.

Our energy resources are indeed finite, on a much larger scale of course, but they must be managed. Today, more than 40% of the earth's five billion people are not connected to electric power grids. Although the United States' more than 250 million citizens, along with other industrialized nations, are the largest consumers of electricity, our consumption grows by only 1.4% per year. The rest of the world is increasing consumption by 2.5% per year.

The US Department of Energy has estimated that by the year 2015, the consumption of electricity in developing countries (80% of the world's population) will equal that of industrialized nations. Building more power plants that burn nonrenewable fuels has environmental impacts and nuclear energy receives significant opposition from the general public. No one energy source will satisfy this demand, so I would like to introduce to you an option that to the best of my knowledge has not been discussed in this or any AEE publication, that is *Space Solar Power (SSP).*

HISTORY

Mr. Peter Glaser originally conceived space Solar Power in 1968 to provide the earth's energy needs through the use of satellites in orbit. These satellites would be equipped with solar arrays to capture the sun's energy and beam it down to earth via microwave. A $20-million NASA/DOE study was done on a 5-gigawatts system in the late 1970's. The conclusion was that due to high costs and technical uncertainties the project was not feasible.

Recently, NASA did a "Fresh Look" study that examined new concepts, technologies, and markets for space power. Based on that study it may be time to consider SSP as a potential energy source for the next century. Several smaller scale designs in the 100MW range might be beneficial due to technical improvements.

DETAILED EXPLANATION

At the earth's orbit, sunlight in space carries about 1,358 kW of energy per square meter. Using advanced photovoltaic arrays, a solar power satellite can convert 20% to 35% of that energy into electrical current. From that solar array wires would carry that electric current to devices that would convert it into an electromagnetic beam, typically at microwave frequencies. These beam generators might be either solid state or electron tubes like those found in microwave ovens.

The microwave beam would be pointed by the transmitter toward a specific receiving antenna on Earth. Focusing and pointing the beam would be made possible by the phase and direction information provided by the guide beam coming up from the intended target receiver site. At the receiving site, a simple highly efficient system called a rectifying antenna, a "rectenna" would convert the incoming microwave beam once again into electrical current, which would then be conditioned and distributed to customers.

A solar power satellite (SPS) in geostationary earth orbit receives sunlight 24 hours a day 365 days a year. At lower earth orbits an SPS would pass through the earth's shadow at a varying length of time, and a moderate energy storage system would be needed on the ground to provided continuous power to customers. All solar power concepts, either terrestrial or space-based, require large areas. For example, generating a megawatt of power at Earth's distance from the sun would require a collecting area of 2,000 to 4,000 square meters in space and more than 25,000 to 50,000 square meters on the ground.

What were the requirements that had to be met to be considered a realistic design?

1. The cost had to be between one and ten billion dollars to begin generating power commercially.

2. The cost of electricity had to be no more than 10 cents per kilowatt-hour.

3. The system should serve global markets as soon as possible.

4. The system should be capable of self assembly and not require massive infrastucture in space.

5. The system should be modular and comprised of many identical, mass produced elements.

6. The system should be capable of being launched on space vehicles that are common to other markets, not unique to space solar power.

TECHNICAL HURDLES

There are many technical hurdles to be cleared before any viable system is deployed. They include manufacturing, construction, power collection, conversion and distribution. Aggressive technology development would be essential. Governments would have to be involved in long term research and development. The biggest hurdle is transportation. It only takes eight minutes to get to orbital velocity, but no vehicle in existence can do it cheaply enough to make this, or many other space ventures worth the risk to investors. There is hope that vehicles currently under development like Lockeed Martin's Venture Star (X-33) will drastically reduce launch costs.

Figure 1 shows the cost of power over a 40-year life span. Figure 2 shows the cost of building the power plant. "Terrestrial Solar" refers to any ground based solar collecting system with energy storage capability. "Space Solar" is a SSP system at 12000 KM above earth orbit. Here an SSP system would experience some periods of darkness. The SSP in geostationary orbit (Geo Space) would not be subject to periods of darkness; and would be positioned over the same part of the earth at all times. That is why it has lower capital costs and lower power generating

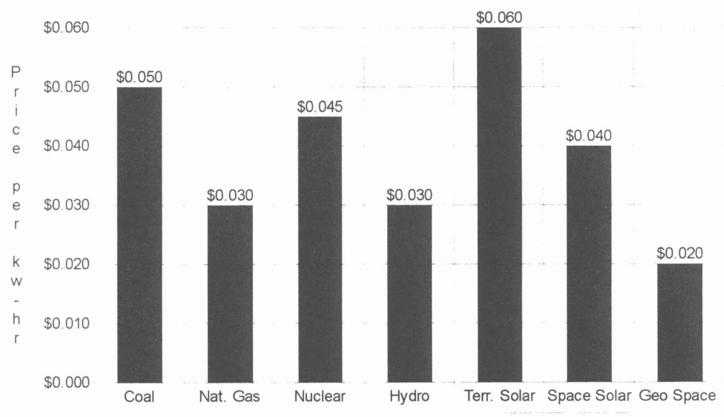
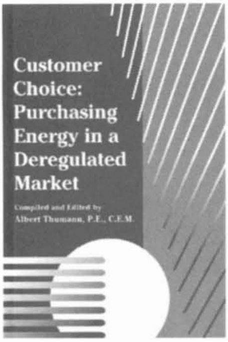


Figure 1. Cost of Power over 40 Years



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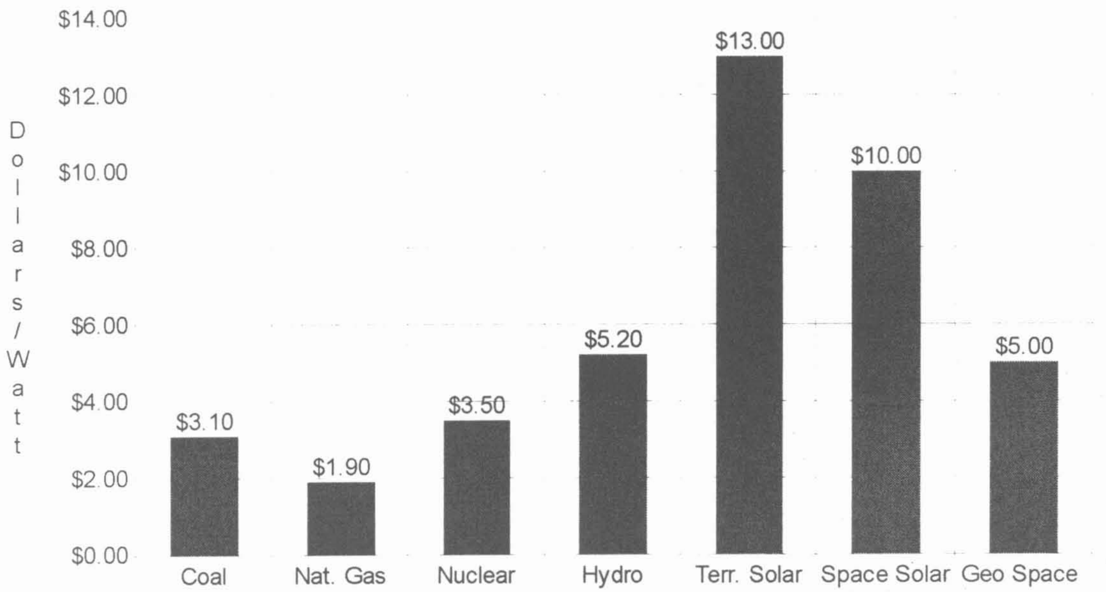

Figure 2. Capital Cost of Power Sources

costs. Very few if any hydroelectric power plants are planned because of environmental impacts and limited available sites. The well-established non-renewable fuel power plants have the lowest costs, but their environmental impacts are becoming more of a concern. When a close look at the alternatives are made, SSP becomes an attractive option.

A RESEARCH EXAMPLE

One of the SSP concepts is called "Sun Tower"; it is a gravity gradient stabilized platform concept that would be deployed in mid-earth orbit at approximately 12,000 kilometers altitude. It is modular, both to enable common carrier earth to orbit services and to enable self-assembling systems that entail little or no in space infrastucture prior to the beginning of commercial power generating.

Some research has been done on the subject on a small scale. A NASA/industry team successfully built and tested a 2kW system in NASA Lewis' Thermal Vacuum Facility in 1995. Japan has also done research, specifically in microwave power transmission. They have done experiments with powering small planes and airships by beaming microwaves up to the vehicle to provide it with power to stay in flight. An early orbital test would involve two satellites, one with a solar panel and converter, the other satellite with a microwave receiver. This will test some basic technologies such as, collection of energy, conversion to microwave, beaming accuracy and receiving the microwave signal.

CURRENT STATUS

Presently SSP is not part of NASA's strategic plan. NASA's budget has been cut for six consecutive years and is only 1/4 of 1% of the federal budget. The highest percent of the federal budget NASA received was 4% during the Apollo era. In fact, after the construction of Space Station, which starts in 1999 and will take approximately five years to complete, there is no long-term goal for NASA.

Manned Mars missions have been discussed in the aerospace community but no money has been allocated. When comparing SSP to a manned Mars mission, which do you think will get more support from the voting public? Here is an environmentally friendly renewable energy source, which could generate thousands of jobs in the aerospace field, which has suffered drastic manpower reductions, and help fill the world's clear need for more energy. A mission to Mars would most likely be sold as a scientific mission of discovery. A noble goal, but much harder for the average person to grasp.

CONGRESSIONAL INTEREST

Since the "Fresh Look Study" Congressmen Weldon and Rohrabacher have challenged NASA to follow up on the study. The House Space & Aeronautics Subcommittee have held hearings on SSP. The Fiscal year 1999 budget may include $25 million for some SSP research.

Why should NASA pursue an energy project? History has shown that government programs help pave the way for industry by doing the initial research. Once the basic technology is proven, then companies can develop the technology in a cost-effective manner. SSP could open up tremendous business opportunities and generate billions of dollars in revenue. The delegates who gathered in Kyoto to discuss global warming two years ago did not discuss SSP. With the latest information on the economics and technology, they should consider this option as part of their strategy when they meet again. We will definitely hear more on the subject in the future, as people become aware that this option exists.

FUSION RESEARCH

Let's look at fusion research for a minute. For the past forty years the US government has funded thermonuclear fusion research. Tens of billions of dollars have gone into the program during that time without a power generating fusion reactor in sight. Granted, this research is very complex and may pay off in the later half of the 21st century. SSP is much more easily tested and demonstrated. This year fusion research will get another $220 million, it doesn't take much imagination to see that amount of money would really give SSP a healthy start.

SUMMARY

1. If global warming occurs as predicted, economical and ecological consequences could be severe.

2. There will be a need to drastically reduce use of fossil fuels on a global basis.
3. Use of carbon fuels in the developing world is increasing rapidly.
4. Reducing energy use is not realistic, since energy is a requirement to increase the standard of living.
5. Increasing energy efficiency is playing a major role, but cannot offset the increase in energy usage.
6. Environmentally correct renewables can provide a significant portion of the overall capacity, but not enough to handle the base electrical load.
7. Nuclear reactors are politically non-feasible and fusion power plants are many decades away.
8. Cheap access to space is SSP's major hurdle, but will probably be remedied before 2010.
9. SSP can be built rapidly with many identical parts.
10. No energy system can prevent environmental disaster unless the problem of population increase is solved.

I am bringing this subject to AEE members' attention because it is an energy option that we might become involved in some time in the next fifteen years. Energy Engineers are known for using innovative ideas to reduce energy usage. The SSP option is an innovative idea that can provide clean energy to the next generation.

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ABOUT THE AUTHOR

Anthony V. Ferraro earned his bachelor of science in industrial

management from the Milwaukee School of Engineering. He has been a design and project engineer in the controls industry for 17 years, working on numerous commercial and industrial facilities. Has been involved in design as well as start up of many types of HVAC systems. As a Certified Energy Manager, has been involved in the performance contracting industry recommending various retrofits based on energy studies. He is a member of AEE. He is currently employed by Siemens Building Technologies, Landis Division in Cincinnati, OH.

Mr. Ferraro has several energy-related interests outside of his career. He has converted a Chevy S-10 Blazer to an electric vehicle (EV) which is used daily for commuting. Electric vehicles are approximately twice as energy efficient as internal combustion engines. The major auto makers have just begun to enter the EV market. His interest in the space program led him to do the research required for this article. He is a member of The National Space Society.

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