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Low Cost Access to Space is Key to Solar Power Satellite Deployment

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Abstract

Even though the concept of Solar Power Satellites (SPS) was first proposed in 1968, development has not happened because of the massive initial investment in infrastructure required. The principal infrastructure constraint is in the transportation segment. When the space transportation costs are sufficiently low, we can count on the cost of energy from space to be as low as hydroelectric energy. There is no limit to how much energy can be generated; as long as the sun shines, a clean source of energy is available in space. With improved systems of transport, Solar Power Satellites can be the world's next energy source. This paper explores different launch systems that could be developed to provide low cost space transportation for SPS installations. Reconfiguration of a reusable two-stage-to-orbit vehicle based on the technology of the Saturn V is proposed.

Problem

Today we face the compounding problems of a world recession, passing the peak of world oil production, global warming due to carbon dioxide in the atmosphere from burning fossil fuels, and the threat of wars over Middle East oil.

The search is on for the new sources of energy required to support future economic and social development. Those sources must now pass a more strict set of criteria. They are expected to not only replace oil and coal to stop global warming, they must meet the growing global demand for energy that can be expected to rise each decade. Developing sources of renewable energy will meet some of the demand, but only Solar Power Satellites will be able to deliver the quantities envisioned. The United States currently consumes 25 percent of the world's oil usage, with only 5 percent of the population.[1] That ratio is about to dramatically change. James Michael Snead, President of the Spacefaring Institute LLC, writes that "…even if we use every source of clean energy --- terrestrial solar, wind, and geothermal --- and every source of dirty energy --- coal, oil, and nuclear --- we will run out of energy well before 2100."[2]

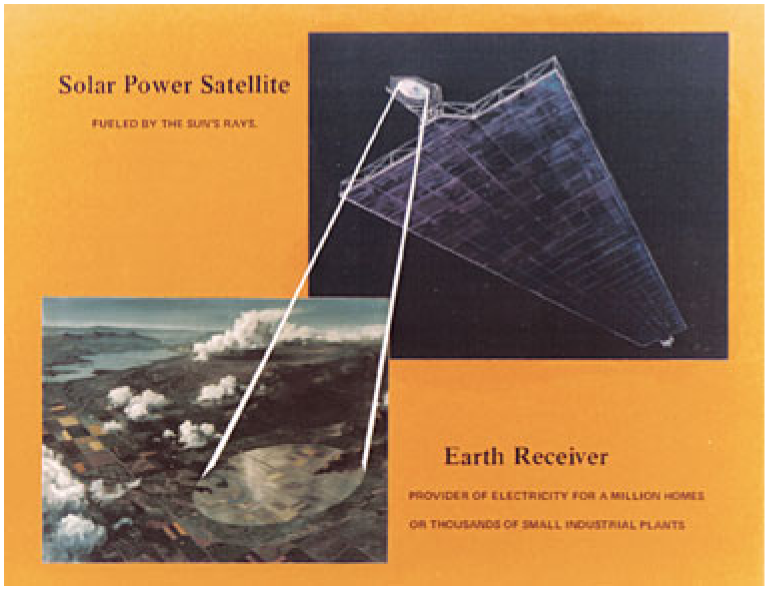
Historical Constraints

When Solar Power Satellites were first proposed in 1968, the idea was considered to be a science fiction dream. When NASA scientists did the initial investigation of the concept in the early 1970's, their reports concluded such satellites were feasible. The Arab oil embargo of 1973-74 awakened the United States to the seriousness of finding a replacement for oil as our major energy source. Solar

Power Satellite research and development was transferred to the Energy Research and Development Administration (ERDA). ERDA and all its programs were soon absorbed into a new agency at Cabinet level called the Department of Energy (DOE), under President Carter … The unfortunate feature of the new Department of Energy was that it was dominated by the former Atomic Energy Commission (AEC), the agency responsible for developing and maintaining atomic weapons. Neither ERDA nor DOE had either experience or understanding of space, and gave it little priority.

There was interest within Congress who asked that additional work be done on the concept of Solar Power Satellites. The Department of Energy formed a program office and asked NASA to act as its technical arm. DOE Program Manager Fred Koomanoff assembled a team to consider all of the ramifications of the system, including societal implications, cost comparisons and environmental impact. A complete system definition of all the elements was required, including the space transportation systems for launching the satellite hardware. NASA was given the task of contracting for the System Definition Studies. Two contractor teams were selected. The Boeing led team was selected to work under the direction of the Johnson Space Flight Center in Houston, Texas, and the Rockwell International team was under the direction of the Marshall Space Flight Center in Huntsville, Alabama.

These studies, started in 1977, reached their conclusions in the spring of 1980. The output of the satellites under examination was expected to be 5 gigawatts each. The Rockwell configuration used mirror concentrators to reduce the numbers of cells required. The Boeing configuration used a plainer array with very thin silicon cells that had an efficiency of 16.5 % and were very light and resistant to space radiation degradation due to the thinness of the cells, only 2 mils thick. The Boeing configuration was selected as the Reference System.



View of Boeing Solar Power Satellite and the earth based rectifying antenna, called a rectenna. The satellite shown is actually a double satellite of ten gigawatt ground output with two transmitters, one on each end. The planer area in space always faced the sun while the transmitter made one revolution per day to always face the rectenna on the earth.

The Boeing team also developed the design for a fully reusable two stage vertically launched winged transport system to launch the satellite hardware. This same team was the one that had also been responsible for development of the S-1C, the first stage of the Saturn V rocket, and they were the integrators of the total Saturn/Apollo vehicle. The winged vehicle configuration was chosen over a ballistic recovered configuration because of the reduced refurbishment required. Such a system would provide the low cost space transportation that was needed to achieve competitive electrical energy cost from Solar Power Satellites. The initial vehicle design was sized to launch one million pounds of payload. (see figure below) To reduce development costs, this design was later reduced to 200,000 pound payload vehicle size. Cost per pound of payload to orbit remained nearly the same.

a. Ballistic recovered two stage launch vehicle. First stage hydrocarbon fuel with hydrogen fueled upper stage. 1 million pound payload.

b. Two stage winged recovery launch vehicle. First stage uses hydrocarbon fuel and the upper stage uses hydrogen fuel. Payload is 1 million pounds. Later resized to 200,000 pound payload.

All of the technology required for the entire satellite system was well-understood and existed in 1980. The electrical cost estimates made by Boeing based on the total system definition that had been developed, showed the electric energy generated in space and delivered to the earth would be competitive with existing earth based systems.

Four major stumbling blocks arose. The first was the political opposition orchestrated by the Nuclear Fusion advocates in the Department of Energy. They had convinced President Carter … to kill the program. The second was a lack of understanding among the scientific community about how commercial production programs would be able to reduce manufacturing costs. For example, in their cost analysis of the system, evaluators looked at the laboratory cost of manufacturing solar cells, which was quite high at that time with very limited production. They then multiplied the cost of those cells by the millions that would be required for the size and number of satellites proposed, and concluded that the cost would be prohibitive. In their critiques, they reported that energy costs were too high to be competitive with terrestrial sources, which at that time were still quite cheap. Mainly, they did not understand, or did not take into consideration, how mass production could dramatically reduce production costs. The third stumbling block was the general feeling that nothing in space could be low cost: "just look at all of NASA's program cost over-runs," was a typical comment. The fourth concern was the high initial cost of space infrastructure, the up-front cost of creating a reusable transportation system.

Current Situation

The U.S. government terminated its SPS program in 1980. News of solar energy from space quickly disappeared from the media, and subsequently from public awareness. Today, the people who have heard of the concept are only vaguely aware of its potential. The author believes this situation is about to change. The reasons have to do with the need to develop renewable energy sources to replace fossil fuels, to address the effects of global warming and to find cheaper, more sustainable alternatives to oil. Also, spacefaring nations like Canada, China, India and Japan are showing real interest. These countries may be the first to develop the technologies for producing energy in space and delivering it to earth as electricity. There are startup organizations in the U.S. raising funds to do demonstrations. One of these is Solaren, a company that has a signed sales agreement with the California utility PG&E to deliver electrical energy generated in space.[3]

Some awareness is starting to surface in the media. An October 2009, Wall Street Journal article entitled, "Five Technologies That Could Change Everything," included a segment on Space Based Solar Power.[4] In the same month, The Houston Chronicle featured an article entitled, "Space-based Solar Power Can Help on Energy Needs."[5] It is a start but the understanding of space-based solar power is not yet there for the general public. Most still think of anything in space as very remote and terribly expensive.

The technology has evolved. Solar cell costs have come down and performance options have improved, particularly with the development of the thin filmed cells printed on metal foil. These cells are very light weight, low cost and have a long life potential in the radiation environment of geosynchronous orbit. Potential for use by the military, for supplying space based solar energy to advanced bases from small satellites using lasers, has created a new advocate for the concept.[6] Also the potential of using very high frequency wireless power transmission opens the option of much smaller output satellites. Such an approach would reduce the cost of the first-generation commercial satellites and demonstrations.

The barrier to their development is still the lack of a low-cost space transportation system for launching the satellite hardware. Without a reusable launch system there is little hope to deploying a significant capability to generate competitive cost electric energy from space. The problem is not technology; it is the up-front investment money and understanding of what is required. In the 21st century, NASA's goals and approaches are no longer compatible with those of a commercial development program such as Solar Power Satellites.

Proposed Solution

There have been many suggestions on how to jump-start the SPS program. In my testimony before the House Sub-Committee on Space and Aeronautics on

September 7, 2000, I proposed a government/industry partnership program starting with eight critical steps. It is still a valid approach to getting the program under way. These are:

1. Assign a lead agency within the government. The Department of Energy is the logical lead agency with NASA providing the primary technology support.
2. Fund a Ground Test Program to demonstrate the satellite functions of power generation, the wireless power transmission system, and integration of the energy into a utility grid. This program would also demonstrate the capability of relay satellite power transmission.
3. Obtain frequency allocation for wireless power transmission.
4. Pass commercial space tax incentive bills, like the Zero Gravity, Zero Tax bill.
5. Incorporate testing for solar power satellite technology into the plans for the International Space Station.
6. Continue technology development for reusable space transportation systems.
7. Consider the implementation of loan guarantees for commercial development of reusable space transportation systems.
8. Commit to the purchase of the first operational Solar Power Satellite.

The Aerospace Technology Working Group released a paper on February 20, 2009, titled: **Sustainable Space Exploration and Space Development A United Strategic Vision**.[7] One of the key elements of this paper was the recommendation that a new agency be established entitled the Department of Space. Such a department would be positioned at Cabinet level and would be responsible for guiding the commercial development of space. This agency would also absorb NASA in its reduced role for space exploration and technology development. This paper laid out a plan to provide the kind of government leadership and oversight that is needed to develop Solar Power Satellites.

In the rest of this paper, I am going to focus on the specifics of developing a space transportation system based on reusable vehicles, an approach that will finally make the deployment of Solar Power Satellites commercially viable. The first step is to look at what has occurred in the past and see what has happened, and why it happened. To make the right choices for the future developing the right kind of system, we need to understand what is different now.

All of the early launch systems starting with the launch vehicle for Sputnik were expendable rockets. In the early days, there wasn't much choice. To reach orbit, launch systems had to be made as light as possible to achieve orbital velocity. There was nothing left over for adding recovery systems that would allow reuse. As time went on, systems got more efficient, but overall program cost became a key decision maker. To minimize cost, payload was reduced. The added cost of development for a reusable system was traded against the number of flights required. The other element was that many of the payloads needed to go to high orbits that made the recovery of the upper stages difficult and costly. As a result, the market was not large enough to justify the cost of a reusable system. The optimum manageable design was always to build a highly efficient expendable system. Once the commercial satellite providers managed to become profitable using expendable rockets, the launch vehicle builders had no real incentive to develop reusable systems.

As the Saturn/Apollo Program was winding down, NASA stepped forward with a bold plan that could have led to a new era of space development. It was the plan for a Space Shuttle. NASA's criteria was for a fully reusable two-stage winged vehicle that would burn liquid hydrogen and oxygen as the propellants in both stages. This vehicle would have a payload of 65 thousand pounds, a payload bay 65 feet long by 15 feet in diameter and have a maximum lift off weight of 3½ million pounds.

The problem was the level of technology available in 1970. The two criteria that were the biggest stumbling blocks were: 1) the maximum gross lift-off weight and 2) the need to use hydrogen as the booster fuel. The use of hydrogen fuel dictated a much larger vehicle than would be required with a hydrocarbon fuel booster. The gross lift-off criterion was incompatible with hydrocarbon fuel and the size of a hydrogen fueled booster. None of the biding contractors could meet the lift-off criteria.

As design manager for the Boeing Space Shuttle Definition Studies, I came up with the idea to carry the liquid oxygen in the wing of the booster. This sufficiently reduced the size of the booster so that we could meet the lift-off weight limit. This configuration was submitted in the joint Boeing/Lockheed proposal for the future Space Shuttle. The NASA evaluators unfortunately found the idea impractical and the Boeing/Lockheed team was eliminated from the competition. At the same time, Grumman, who was bidding alone, submitted a proposal that had the booster burn a hydrocarbon fuel using a winged version of the Boeing S-1C, … The Administrator of NASA liked that idea and Boeing was asked to become Grumman's partner for an alternative approach to the Space Shuttle design.

The Grumman/Boeing team considered a large number of alternate configurations, including all types of boosters including the stage-and-a-half that ultimately became the Space Shuttle, and the fly-back S-1C. I was made design manager of the fly-back S-1C that we called the RS-1C. (See image) Various configurations were eliminated. NASA did not always agree, especially with our recommendation that the troublesome stage-and-a half configuration be dropped. We also proposed to modify the two flight certified S-1C's in bonded storage at Michoud. There were enough spare F-1 engines left over from the Saturn/Apollo Program that some 400 flights could have been supported, with proper refurbishment.

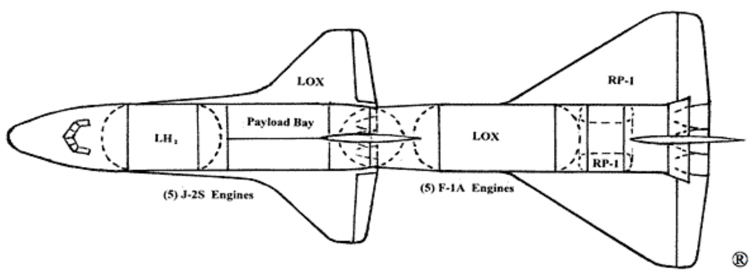
At the final review meeting, the Grumman/Boeing team recommended the RS-1C and the Grumman H-33 orbiter. Politics dictated that both be rejected. Had they been selected there would not have been any work for the NASA Huntsville Center and no work in Utah for the Senator from Utah who was Chairman of the Space Committee. The Director of NASA in charge throughout the Saturn/Apollo era had retired.

Now close to 40 years later, the U.S. has had two fatal accidents on Space Shuttle flights, each mission costs a small fortune to fly, and now the entire fleet is slated to be retired in 2010. The question is: What can we do today to develop a reusable space transportation system with a minimum of developmental costs?

My proposal is to reach back 40 years to the technology we understand, update it with modern knowledge and materials and incorporate what is learned into a fully reusable vehicle that applies the known principles of low cost transportation systems. Those principles are high usage, low maintenance, reasonably sized payloads, and ease of loading and unloading. When a transportation system reaches maturity with these characteristics, the cost of operating the system can be expected to be between three and five times the cost of fuel. With today's systems, the cost is over a thousand times.

The configuration I propose is shown below. The design is based on the Saturn V technology, the largest and most successful rocket vehicle ever flown. I would stay with the 33-feet diameter for both stages, with the mounting nose to tail. The booster would have a rotating dome on its nose. When mated (while on their wheels), the dome would be rotated to provide room for the orbiter engine bells. The joined vehicle would then be raised to the vertical with a gantry, fueled and launched. After separation, the dome would rotate to form the booster nose. The majority of the hydrocarbon fuel would be carried in the wing with the remainder in a short torus tank in the aft body. The fly-back jet engines could be located either aft around the body or forward on the body. The booster engines would be F-1A engines. These were certified back in the Saturn/Apollo era at 1.8 pounds of thrust, but never flew. The 5-engine arrangement is the same as S-1C, but there is room to go to six engines. The booster would be all metal for heat sink re-entry with a staging velocity in the neighborhood of 7,000 feet per second.[8]

The orbiter has basically the same plan form as the Space Shuttle Orbiter. It would have five J-2S engines (up grades of the Saturn S-II stage engines planned for the Aries upper stages.) The wing would be sized to carry the liquid oxygen and the hydrogen would be in a body tank forward of the payload bay. The payload bay would be sized to accept 8 to 10 lightweight standard sized shipping containers. (8'x 8' x 40')



Reusable Launch System Based on Saturn V Technology
Same Diameter, 33 feet   Same engines, Updated
Approximate Payload is 100,000 pounds
(click image for larger view)

Significance

With the development of a fully reusable launch vehicle designed for commercial use, by people that understand commercial operations, Solar Power Satellite hardware can be launched at low enough cost that the satellites will provide competitively priced electricity to the earth. Such an event would be the beginning of the new era of energy from space that would bring economic growth to the world while at the same time stopping the addition of carbon dioxide to our atmosphere.

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