Review on Solar Power Satellite System: Recent Developments

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Abstract : The concept of placing enormous solar power satellite (SPS) systems in space represents one of the new technological options that might provide large-scale, environmentally clean base load power into terrestrial markets.

The Solar Power Satellite has been hailed by proponents as the answer to future global energy security and dismissed by detractors as impractical and uneconomic. In the United States, the SPS concept was examined extensively during the late 1970s by the U.S. Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA).

More recently, the subject of space solar power (SSP) was re-examined by NASA from 1995-1997 in the "Fresh Look Study" and during 1998 in an SSP "Concept Definition Study." As a result of these efforts, in 1999-2000, NASA undertook the SSP Exploratory Research and Technology (SERT) program, which pursued preliminary strategic technology research and development to enable large, multi-megawatt SSP systems and wireless power transmission (WPT) for government missions and commercial markets (in space and terrestrial). During 2001-2002, NASA has been pursuing an SSP Concept and Technology Maturation (SCTM) program follow-up to the SERT, on identifying new, high-leverage technologies that might advance the feasibility of future SSP systems. The Solar Power Satellite emphasis upon the latest developments in the application of the technology of microwave power transmission to the SPS. The characteristics and features of the SPS as viewed at its interface with the earth's electric power system are presented.

***IndexTerms* – SPS, Transmitting Antenna, Rectenna**

I. INTRODUCTION

1.1 History of Solar Power Satellite

The first published article on the solar power satellite authored by Peter Glaser appeared in Science 1968. In the following years Glaser presented testimony on the concept to appropriate Congressional committees responsible for space technology and energy. The first group activity was a set of papers given at the International Symposium of the International Microwave Power Institute at Hague in 1970.

The first organized activity to study the technical and economic feasibility of the Solar Power satellite as a system was that of a four company team comprised of Arthur d little, Inc., Raytheon company, Grumman Aerospace corp., and Textron, Inc. The results of this six month study carried out in 1971 were sufficiently favorable to encourage the management of the four companies to jointly send a letter to the Director of NASA recommending the support and study of this concept by NASA.

NASA responded to this recommendation by first sponsoring a modestly funded study of the solar power satellite through their Lewis Research Center. Then because of the unique aspect of the microwave power transmission portion of the study, NASA sponsored a study of the overall microwave power transmission system and demonstration of microwave power transmission utilizing the Raytheon microwave power transmission laboratory and the Goldstone facility of the jet propulsion laboratory.

The oil embargo of 1973 the government had created ERDA(Energy Research and Development Agency).in 1976 ERDA was charged by the Office of management and Budget with the responsibility for evaluating the Solar Power Satellite concept as an energy option. ERDA established a task group to study the Solar Power System (SPS). This group recommended a detailed assessment of SPS covering technical feasibility, economic viability, environmental and societal acceptability and the merits of SPS. The recommendation evolved into a three year study program termed the "DOE/NASA Satellite Power System Concept Development and Evaluation Program". [5]

1.2 System Architectures

The first major attempt to conceptually design and evaluate a complete Solar Power Satellite system was by the US Department of Energy (DOE) and US National Aeronautics and Space Administration (NASA): the 1977-1980 DOE/NASA systems definition studies. The studies defined a Solar Power Satellite reference system including the satellite configuration and all of the supporting infrastructure [8]. The "completed" system would provide a generating capacity of 300 gigawatts from 60 satellites. The satellites were designed to have five gigawatt generating capacity; use photovoltaic cells for energy conversion; use wireless energy transmission at 2.45 GHz; be based at geosynchronous orbit; be assembled on-orbit with human support of automated machinery; and have a thirty-year operational life.

The purpose of the reference system was to be a basis for evaluating the Solar Power Satellite concept for environmental and societal impacts and as an alternative energy source. It was not a mature design to be used for manufacturing Solar Power

Satellites. The estimated non-recurring cost of $100 thousand million (for infrastructure and the first operational Solar Power Satellite system providing 5 gigawatts) contributed to the general impression of the Solar Power Satellite as an expensive program The choice of five gigawatts per satellite was arbitrary and, in fact, may be seen as unduly restrictive for worldwide acceptance of the Solar Power Satellite concept beyond the industrialized nations of the G7. Very few countries in the developing world have the necessary transmission infrastructure to distribute 5 gigawatts of power from a single location to outlying regions and would be better served by smaller, more numerous distributed ground conversion sites.

Several independent assessments were made of the DOE/ NASA study. A report by the National Research Council of the United States National Academy of Sciences [9] concluded that while solar energy from space was technically feasible, the reference system assumptions were too optimistic, especially in the areas of photovoltaic cell performance and probable launch costs. The assessment recommended further relevant research be tracked and the situation assessed from time to time, but that implementation not be pursued at that time.
Japanese interest in Space Solar Power followed closely the 1981 establishment of the Institute of Space and Astronautical Science of Japan (ISAS) within the Ministry of Education. Japan recognized the enormous cost and technical difficulty of building the DOE/NASA system and decided to concentrate on the also costly problem of developing the ground receiving system, which led to an offshore, floating rectenna design [10]. Two prototype Space Solar Power Satellite designs were developed in Japan [10] .The first was a 10 MW photovoltaic derivative of the DOE/NASA Reference System developed by the Space Technology Committee of Japan Machinery Federation [11]. The second design was for a 70 MW solar concentrator, thermal energy conversion satellite with energy storage and periodic transmission developed by ISAS and Toshiba [12].

In the early 1990s, the idea of using the Earth's largest satellite as a platform for collecting solar energy with photovoltaic materials manufactured *in situ* and beaming the power to earth was proposed as a Lunar Solar Power option [13, 14]. In this proposal, several very large, although not very efficient, solar farms would be sited strategically to provide constant power to a large aperture microwave transmitter. Because the same face of the moon is always pointed at earth, transmitted power could be beamed to earth sites either directly and periodically or continuously through satellite relays.

II. SOLAR POWER SATELLITE SYSTEM

Space-based solar power essentially consists of three elements

1. Collecting solar energy in space with reflectors or inflatable mirrors onto solar cell
2. Wireless power transmission to Earth via microwave or laser
3. Receiving power on Earth via a Rectenna, a microwave antenna

2.1 Solar Energy Conversion

Solar Photons to DC Two basic methods of converting sunlight to electricity have been studied photovoltaic (PV) conversion, and solar dynamic (SD) conversion. Most analyses of solar satellites have focused on photovoltaic conversion (commonly known as "solar cells"). Photovoltaic conversion uses semiconductor cells (*e.g.*, silicon or gallium arsenide) to directly convert photons into electrical power via a quantum mechanical mechanism.

Photovoltaic cells are not perfect in practice, as material purity and processing issues during production affect performance each has been progressively improved for some decades. Some new, thin-film approaches are less efficient (about 20% vs. 35% for best in class in each case), but are much less expensive and generally lighter. In an SPS implementation, photovoltaic cells will likely be rather different from the glass-pane protected solar cell panels familiar to many from current terrestrial use, since they will be optimized for weight, and will be designed to be tolerant to the space radiation environment (it turns out fortuitously, that thin film silicon solar panels are highly insensitive to ionizing radiation), but will not need to be encapsulated against corrosion by the elements. They do not require the structural support required for terrestrial use, where the considerable gravity and wind loading imposes structural requirements on terrestrial implementations.

2.2 Converting DC to Microwave Power

To convert the DC power to microwave for the transmission through antenna towards the earths receiving antenna, microwave oscillators like Klystrons, Magnetrons can be used. In transmission, an alternating current is created in the elements by applying a voltage at the antenna terminals, causing the elements to radiate an electromagnetic field.[3]

The DC power must be converted to microwave power at the transmitting end of the system by using microwave oven magnetron. The heat of microwave oven is the high voltage system. The nucleus of high voltage system is the magnetron tube. The magnetron is diode type electron tube, which uses the interaction of magnetic and electric field in the complex cavity to produce oscillation of very high peak power. It employs radial electric field, axial magnetic field, anode structure and a cylindrical cathode.

The cylindrical cathode is surrounded by an anode with cavities and thus a radial electric field will exist. The magnetic field due to two permanent magnets which are added above and below the tube structure is axial. The upper magnet is North Pole and lower magnet is South Pole. The electron moving through the space tends to build up a magnetic field around itself. The magnetic field on right side is weakened because the self-induced magnetic field has the effect of subtracting from the permanent magnetic field. So the electron trajectory bends in that direction resulting in a circular motion of travel to anode. This process begins with a low voltage being applied to the cathode, which causes it to heat up. The temperature rise causes the emission of more electrons. This cloud of electrons would be repelled away from the negatively charged cathode. The distance and velocity of their travel would increase with the intensity of applied voltage. Momentum is provided by negative 4000 V DC. This is produced by means of voltage double circuit. The electrons blast off from cathode like tiny rocket

As the electrons move towards their objective, they encounter the powerful magnetic field. The effect of permanent magnet tends to deflect the electrons away from the anode. Due to the combined effect of electric and magnetic field on the electron trajectory they revive to a path at almost right angle to their previous direction resulting in an expanding circular orbit around the cathode, which eventually reaches the anode. The whirling cloud of electrons forms a rotating pattern. Due to the interaction of this rotating space charge wheel with the configuration of the surface of anode, an alternating current of very high frequency is produced in the resonant cavities of the anode. The output is taken from one of these cavities through waveguide. The low cost and readily available magnetron is used in ground.

The same principle would be used but a special magnetron would be developed for space use. Because of the pulsed operation of these magnetrons they generate much spurious noise. A solar power satellite operating with 10 GW of radiated power would radiate a total power of one microwatt in a 400 Hz channel width.[4][5]

2.3 Transmitting Antenna

Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. Power beaming using microwaves has been proposed for the transmission of energy from orbiting solar power satellites to Earth and the beaming of power to spacecraft leaving orbit has been considered.

The size of the components may be dictated by the distance from transmitter to receiver distance, the wavelength and the Rayleigh Criterion or diffraction limit, used in standard radio frequency antenna design, which also applies to lasers. In addition to the Rayleigh criterion Airy's diffraction limit is also frequently used to determine an approximate spot size at an arbitrary distance from the aperture. The Rayleigh criterion dictates that any radio wave microwave or laser beam will spread and become weaker and diffuse over distance; the larger the transmitter antenna or laser aperture compared to the wavelength of radiation, the tighter the beam and the less it will spread as a function of distance (and vice versa). Smaller antennae also suffer from excessive losses due to side lobes. However, the concept of laser aperture considerably differs from an antenna. Ultimately, beam width is physically determined by diffraction due to the dish size in relation to the wavelength of the electromagnetic radiation used to make the beam. Microwave power beaming can be more efficient than lasers, and is less prone to atmospheric attenuation caused by dust or water vapor losing atmosphere to vaporize the water in contact.

Then the power levels are calculated by combining the above parameters together and adding in gain losses to antenna and due characteristics the transparency of the medium through which the radiation passes. That process is known as calculating a link budget However, the above mathematics does not account for atmospheric absorption which can be a severe damping effect on propagating energy in addition to causing severe fading and loss of Quos

2.4 Earth –Based Receiver

The Earth-based rectenna would likely consist of many short dipole antennas connected via diodes. Microwave broadcasts from the satellite would be received in the dipoles with about 85% efficiency. With a conventional microwave antenna, the reception efficiency is better, but its cost and complexity are also considerably greater. Rectennas would likely be several kilometers across.

2.5 Orbital Location

The main advantage of locating a space power station in geostationary orbit is that the antenna geometry stays constant, and so keeping the antennas lined up is simpler. Another advantage is that nearly continuous power transmission is immediately available as soon as the first space power station is placed in orbit; other space-based power stations have much longer start-up times before they are producing nearly continuous power. A collection of LEO (Low Earth Orbit) space power stations has been proposed as a precursor to GEO (Geostationary Orbit) space-based solar power.

The space-based portion will not need to support itself against gravity (other than relatively weak tidal stresses). It needs no protection from terrestrial wind or weather, but will have to cope with space hazards such as micrometers and solar flares. Two basic methods of conversion have been studied: photovoltaic (PV) and solar dynamic (SD). Most analyses of SBSP have focused on photo voltaic conversion using solar cells that directly convert sunlight into electricity. Solar dynamic uses mirrors to concentrate light on a boiler. The use of solar dynamic could reduce mass per watt. Wireless power transmission was proposed early on as a means to transfer energy from collection to the Earth's surface, using either microwave or laser radiation at a variety of frequencies.

III TRANSMISSION

3.1 Transmission of Microwave Energy

As the electromagnetic induction and electromagnetic radiation has disadvantages we are going for implementation of electrical conduction and resonant frequency methods. Of this, the resonant induction method is the most implementable due to the reasons given later. In the distant future this method could allow for elimination of many existing high tension power transmission lines and facilitate the inter connection of electric generation plants in a global scale.

The microwave source consists of microwave oven magnetron with electronics to control the output power. The output microwave power ranges from 50w to 200w at 2.45GHz. A coaxial cable connects the output of the microwave source to a coax-to-wave adaptor. This adapter is connected to a tuning waveguide ferrite circulator is connected to a tuning waveguide section to match the waveguide impedance to the antenna input impedance.

The slotted wave guide antenna consists of 8 wave guide sections with 8 slots on each section. These 64 slots radiate the power uniformly through free space to the rectifying antenna (rectenna). The slotted waveguide antenna is ideal for power transmission because of its high aperture efficiency (>95%) and high power handling capability. Microwaves are situated on the electromagnetic spectrum with frequencies ranging from 0.3to300GHz.

A pilot signal that would be sent from the rectenna on the ground. As each individual antenna panel on the satellite received the pilot signal, it would calculate the necessary phases for its microwaves and adjust accordingly. The sum of all these adjustments is a tight beam that would zing down through the atmosphere to hit the rectenna. Such phase-adjusting technologies, known as retro directive systems, have been used in small-scale antenna arrays in space, but additional work would be needed before they could coordinate several kilometers of orbital transmitters.[6]

The energy transmitted by a microwave is very diffusive in nature, such that the receiving antenna area must be very large when compared to the transmitter. Although the use of microwaves to transmit energy from space down to earth is attractive, most part of the microwaves receives significant interference due to atmosphere. Still the reare certain frequency windows in which these interactions are minimized. The frequency windows in which there is a minimum of atmospheric signal attenuation are in the range of 2.45-5.8GHz, and also 35- 38GHz; specifically we might expect losses of 2-6%, and 8-11% respectively for these two microwave signal ranges. As the microwave power is beamed towards a particular point (Point to point) using parabolic antennas (Drum antennas) the free space path loss (FSPL) is not in a considerable amount.[4] Wireless Power Transmission (using microwaves) is well proven. Experiments in the tens of kilowatts have been performed at Goldstone in California in 1975[5] [6] and more recently (1997) at Grand Bassin on Reunion Island.[3] These methods achieve distances on the order of a kilometer.

IV GROUND SEGMENT RECEPTION

4.1 SPS Receiving Array

The SPS system will require a large receiving area with a Rectenna array and the power network connected to the existing power grids on the ground. Although each rectenna element supplies only a few watts, the total received power is in the Giga watts (GW)

A Rectenna may be used to convert the microwave energy back into electricity. Rectenna conversion efficiencies exceeding 95% have been realized. The word Rectenna "is formed from rectifying circuit" and Antenna a rectifying antenna called rectenna receives the transmitted power and converts the microwave power to direct current (DC) power. The rectenna is a passive element with a rectifying diode, and is operated without any extra power source. The rectenna has a low-pass filter between the antenna and the rectifying diode to suppress re-radiation of higher harmonics. It also has an output smoothing filter. This demonstration rectenna consists of 6 rows of dipole antennas, where 8 dipoles belong to each row. Each row is connected to a rectifying circuit which consists of low pass filters and a rectifier. The rectifier is a GA-As Schottky barrier diode, that is impedance matched to the dipoles by allow pass filter. The 6 rectifying diodes are connected to the light bulbs for indicating that the power is received. The light bulbs also dissipate the received power.

The Earth-based receiver antenna (rectenna) is a critical part of the original SPS concept. It would consist of many short dipole antennas, connected via diodes. Microwaves broadcast from the SPS will be received in the dipoles with about 85% efficiency. With a conventional microwave antenna, the reception efficiency is still better, but the cost and complexity is also considerably greater, almost certainly prohibitively so. Rectenna would be multiple kilometers across. Crops and farm animals may be raised underneath a rectenna, as the thin wires used for support and for the dipoles will only slightly reduce sunlight, or non-arable land could be used, so such a rectenna would not be as expensive in terms of land use as might be supposed. This rectenna has a 25% collection and conversion efficiency, But rectennas have been tested with greater than90%.

V DEMONSTRATION PROJECTS

5.1 SPS 2000

The prize for most ambitious wireless power transmission demonstration proposed since Tesla's Long Island tower experiment before World War I goes to the Japanese SPS 2000 project [10, 16]. The purpose is to demonstrate a functioning solar power satellite system including the wireless transmission link and develop the ground infrastructure in several locations to provide the basis for a space solar power market.

The design calls for a gravity stabilized satellite capable of delivering 10 MW of electricity from a spherical 1100 km east-to-west equatorial orbit. The phased array antenna will be capable of steering ±30° along the orbital path (E-W) and ±16.7° perpendicular to the orbital path (N-S). This will limit the possible rectenna sites to close to the equator. In addition to being limited to an equatorial band, the receiving sites must be at least 1200 km apart to maximize the length
of time for power transmission to each individual site. Because power can only be received intermittently at any ground site (about 4 minutes out of the 108 minute orbit for a beam scan angle of 30°) energy storage is an important component of any ground site. Further limitations are placed on the power available to any site by the diurnal rotation of the Earth, since the satellite is incapable of delivering energy while in eclipse over a site during the night. With an average daily coverage of less than 30 minutes per site, 4 to 4.5 MWh of energy could be available to a site from the SPS 2000 satellite.

The satellite is in the form of a long prism. The base of the satellite is always earth facing and mounts the transmitting array. The "roof" faces of the satellite are paneled with photovoltaic cells. The phased array transmitting array is based on a dense array of low energy solid state antenna elements (the design assumes an efficiency of 60%, which has not yet been achieved, the MILAX/METS antenna solid state elements achieved 42% efficiency [17]). To assure target acquisition and tracking, a retro-directive beam at 245 MHz transmitted from each rectenna site is used. The satellite would be launched in sections and assembled on orbit.

Initial designs studies have been completed and a scale model mock-up of the satellite has been made. Several potential receiving sites, from Pacific Islands to South American Andes locations have been visited by the SPS 2000 team, with a generally enthusiastic reception.

5.2 Grand-Bassin Project

This project, planned for La Réunion will supply electricity to the remote village of Grand-Bassin [18]. During its implementation, the French led Grand-Bassin project will accomplish several goals. Most important of these is to provide an actual demonstration of point-to-point power beaming. Grand-Bassin is a small isolated mountain village on La Réunion. Set in the scenic environment of a river valley surrounded by steep cliffs, access is limited to trail or helicopter. Several tourist lodges have been established in Grand-Bassin to accommodate sightseers. Further development of the tourist potential of Grand-Bassin is hampered by the lack of electricity in the village to supply refrigeration for food and laundry for overnight guests. Several options were investigated for providing up to 10 kW of electricity to Grand-Bassin. For primarily aesthetic reasons, a microwave wireless power transmission link from the existing terminus of an electric power line was chosen.

The primary constraint imposed on the system was cost. In order to compete with photovoltaic conversion and keep overall energy costs low, the end-to-end electrical conversion and transmission system efficiency had to be at least 20%. Although the aesthetic desire was to use as small a transmitter and rectenna as possible, concern for the perceived safety of the human inhabitants and other biota argues for low energy density (maximum of 5 mW/cm2) in the beam, with an attendant loss of efficiency. An "H" dipole design is used for the rectenna. The transmitter will consist of injection locked phase and amplitude controlled magnetrons (see above, [19]) feeding a multi-focus parabolic reflector. This design consists of several parabolic reflector sectors with a common focus, a microwave analogue to the Fresnel lens. The distance of the wireless link is 700 m. The design system will utilize a rectenna aperture diameter of 17 m, with a 6m transmitter diameter to give 95% collection efficiency. Overall ac-to-ac conversion efficiency is calculated to be 57%.

A prototype system demonstration will consist of four multi-focus parabolic reflectors fed by 1 kW magnetrons transmitting over a distance of 150 m to a 180 m2 H dipole rectenna to deliver 2 kW output power.

5.3 Retro-directive Phased Array Antenna/Rectenna Demonstration

Recent and continuing work at Kobe University has led to the development of a 5.8 GHz retro directive phased array transmission system demonstrator. The antenna uses solid state amplifiers directly connected to the transmitting antenna elements to reduce cable losses and reduce weight and was derived from the antenna design used for MILAX/METS. A half frequency pilot beam (2.9 GHz) is broadcast from the rectenna. Receiving antennae for the pilot beam are integral with the transmitting antenna. The phase of the pilot beam is determined by comparison with the 5.8 GHz master oscillator. The conjugate phase is fed to phase shifters to accurately steer the beam onto the rectenna. Advantages of this system include smaller size and less mass when compared to 2.45 GHz, simple and accurate pointing control and improved efficiency of the power amplifiers. The system was first demonstrated at SPS '97 in Montreal.

5.4 SPS End to End Terrestrial Demonstration

A test project to demonstrate all the major elements of a solar power satellite on the ground has been proposed [20]. In this demonstration concept, the DC output of a photovoltaic array is used to power a transmitting array at the hundreds of kW power level. The receiving rectenna, located at a distance of 1 to 5 km from the transmitter, would convert the RF power to DC for a utility grid. The objective is to verify practical wireless power transmission and to establish the reliability of components operated over time. In addition to operation data, environmental studies could be performed to ensure the safety of the beam. Finally, it would be possible to test the concept of beam splitting (targeting multiple receivers) from the transmitting antenna.

VI HIGHLIGHTS OF SPBS

6.1 Launch Cost

One problem for the SBSP concept is the cost of space launches and the amount of material that would need to be launched. Reusable launch system are predicted to provide lower launch costs to low Earth orbit (LEO). As of November 2013, one company,Space X, is two years along on a privately funded multi-year development program for a reusable rocket launching system with the stated intention to commercialize "fully and rapidly reusable" launch technology. Space X has completed eight test flights of their low-altitude booster return prototype, Grasshopper, and one test flight of a high altitude/high velocity booster return vehicle, with a second booster return test flight planned for early 2014.

Much of the material launched need not be delivered to its eventual orbit immediately, which raises the possibility that high efficiency (but slower) engines could move SPS material from LEO to GEO at an acceptable cost. Examples include ion thrusters or nuclear propulsion. Power beaming from geostationary orbit by microwaves carries the difficulty that the required 'optical aperture' sizes are very large. For example, the 1978 NASA SPS study required a 1-km diameter transmitting antenna, and a 10 km diameter receiving rectenna, for a microwave beam at 2.45 GHz. These sizes can be somewhat decreased by using shorter wavelengths, although they have increased atmospheric absorption and even potential beam blockage by rain or water droplets. Because of the thinned array cursed, it is not possible to make a narrower beam by combining the beams of several smaller satellites. The large size of the transmitting and receiving antennas means that the minimum practical power level for an SPS will necessarily be high; small SPS systems will be possible, but uneconomic.

To give an idea of the scale of the problem, assuming a solar panel mass of 20 kg per kilowatt (without considering the mass of the supporting structure, antenna, or any significant mass reduction of any focusing mirrors) a 4 GW power station would weigh about 80,000 metric tons all of which would, in current circumstances, be launched from the Earth. Very lightweight designs could likely achieve 1 kg/kW, meaning 4,000 metric tons for the solar panels for the same 4 GW capacity station. This would be the equivalent of between 40 and 150 heavy lift launch vehicle (HLLV) launches to send the material to low earth orbit, where it would likely be converted into sub assembly solar arrays, which then could use high-efficiency ion-engine style rockets to (slowly) reach GEO (Geostationary orbit). With an estimated serial launch cost for shuttle-based HLLV'S of $500 million to $800 million, and launch costs for alternative HLLVs at $78 million, total launch costs would range between $11 billion (low cost HLLV, low weight panels) and $320 billion ('expensive' HLLV, heavier panels). To these costs must be added the environmental impact of heavy space launch emissions, if such costs are to be used in comparison to earth-based energy production. For comparison, the direct cost of a new coal or nuclear power plant ranges from $3 billion to $6 billion per GW (not including the full cost to the environment from CO2 emissions or storage of spent nuclear fuel, respectively); another example is the Apollo mission to the Moon cost a grand total of $24 billion (1970s' dollars), taking inflation into account, would cost $140 billion today, more expensive than the construction of the International space station.However, in 2013 based on Recent innovations, Electric Space: Space-Based Solar Power Technologies & Applications suggested a new way to reduce costs by replacing smaller satellites and in lower Orbits.

6.2 Transportation and Photovoltaic Cell Developments

Transportation of the satellite portion of the SPS system to space and the development of photovoltaic cell technology which is compatible with the cost and mass requirements of the SPS are not expanded upon in this paper. However, it is generally known that there is a very substantial program of solar photovoltaic cell development as indicated by the 1980 funding level of $140 million for the Department of Energy's photovoltaic program. In addition there is much non-government support of photovoltaic system cost to levels that will make them more competitive with other energy sources. A significant portion of these programs is devoted to research on thin-film technologies which, if electrically acceptable, will be economical to produce. It is reasonable to expect that a suitable material for the SPS application will be developed within a decade. The development of space transportation is also being supported, not only by the space shuttle program, but generically from many other programs. However, the scale of the transportation problem for the SPS is of such an order of magnitude that a second generation vehicle beyond the space shuttle will be required. A large number of such vehicles will be required and their cost represents nearly half the investment cost required for developing the SPS and tooling up for its manufacture and transporting it to orbit at the rate of two per year.[13] The cost of transportation is particularly sensitive to the mass of the satellite and therefore to recent developments which have reduced the estimated mass of the satellite.

VII CONCLUSION

The increasing global energy demand is likely to continue for many decades. New power plants of all sizes will be built. Fossils fuels will run off in another 3-4 decades. However energy independence is something only Space based solar power can deliver. Space based solar power (SBSP) concept is attractive because it is much more advantageous than ground based solar power.

It has been predicted that by 2030, the world needs 30TW power from renewable energy sources and solar energy alone has the capability of producing around 600TW. The levels of CO_2 gas emission can be minimized and brought under control. Thus the problem of global warming will be solved to a great extent.

Based on current research space based solar power should no longer be envisioned as requiring unimaginably large initial investments. Moreover, space solar power systems appear to possess many significant environmental advantages when compared to alternative approaches to meeting increasing terrestrial demands for energy including necessity of considerably less land area than terrestrial based solar power systems. Though the success of space solar power depends on successful development of key technology, it is certain the result will be worth the effort.

Space solar power can completely solve our energy problems long term. The sooner we start and the harder we work, the shorter "long term" will be.

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