International Journal of Electrical and Electronics research (IJEER)
Vol. 1, Issue 1, pp: (1-10), Month: October-December 2013, Available at: www.researchpublish.com

Wireless Power Transmission through Solar Power Satellite (SPS)

Ajay Krishnan Selucca & Jayakumar
Student
Electronics and Communication Engineering (UG)
PTR College of Engineering and Technology , Madurai.

Abstract: **The present world is developing day by day in a faster manner. This development can be a good matter for every country but the rate of requirement of the electricity also increase accordingly. Even though there are many ways for the manufacture of the electricity like Geo-Thermal energy, Nuclear energy, Thermal energy, Hydro energy, Tidal energy etc but any how they make some demerits when they are implemented . For e.g. when we go with the nuclear power plant they are subjected to the harmful radiation and the wastes which is a toxic nature to the human beings and the other living organisms. When we take thermal electric power then the initial cost is very high, that is they need large and large number of coal for the manufacture of electricity. So as the next when we go with the Hydro energy power plant then we need good construction of dams and also the presence of water without which we cannot produce the electricity. So at last without much disadvantage if we need to produce the electricity then it is with the project of SOLAR ENERGY. But the present solar energy system has some demerits such as they cannot be obtained at the night time. When the same solar energy is implemented through the SOLAR POWER SATELLITE then we can obtain the solar energy all the 24hrs for the full week even 365 days. Also the power is transmitted in the form of the microwaves and hence we can transmit the electricity to any part of the world required.**

Keywords: **Wireless power transmission, Space solar power, Microwave transmission.**

1. INTRODUCTION

A major problem facing Planet Earth is provision of an adequate supply of clean energy. It has been that we face ...three `simultaneous challenges -- population growth, resource consumption, and environmental degradation -- all converging particularly in the matter of sustainable energy supply. It is widely agreed that our current energy practices will not provide for all the world's peoples in an adequate way and still leave our Earth with a livable environment. Hence, a major task for the new century will be to develop sustainable and environmentally friendly sources of energy.

Projections of future energy needs over this new century show an increase by a factor of at least two and one Half, perhaps by as much as a factor of five. All of the scenarios from reference 3 indicate continuing use of fossil sources, nuclear, and large hydro. However, the greatest increases come from "new renewables" and all scenarios show extensive use of these sources by 2050. Indeed, the projections indicate that the amount of energy derived from new renewables by 2050 will exceed that presently provided by oil and gas combined. This would imply a major in the world energy infrastructure. It will be a Herculean task to acquire this projected amount of energy. This author asserts that there are really only a few good options for meeting the additional energy needs of the new century in an environmentally acceptable way.

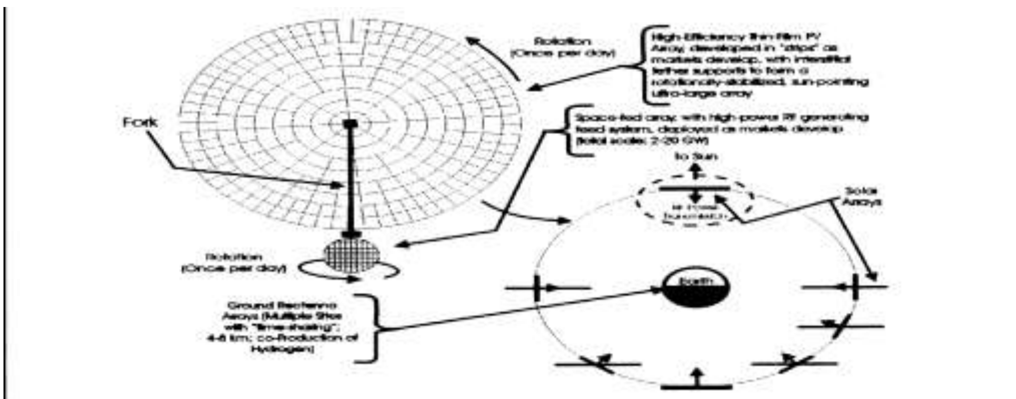
One of the so-called new renewables on which major reliance is almost certain to be placed is solar power. Solar power captured on the Earth is familiar to all. However, an alternative approach to exploiting solar power is to capture it in space and convey it to the Earth by wireless means. As with terrestrial capture, Space Solar Power (SSP) provides a source that is virtually carbon-free and sustainable. As will be described later, the power-collecting platforms would most likely operate in geosynchronous orbit where they would be illuminated 24 hours a day (except for short eclipse periods around the equinoxes). Thus, unlike systems for the terrestrial capture of solar, a space-based system would not be limited by the vagaries of the day-night cycle. Furthermore, if the transmission frequency is properly chosen, delivery of power can be carried out essentially independent of weather conditions. Thus Space Solar Power could provide the base load electricity.

2. WIRELESS POWER TRANSMISSION (WPT) BACKGROUND

The vision of achieving WPT on a global scale was proposed over 100 years ago when Nikola Tesla first started experiments with WPT, culminating with the construction of a tower for WPT on Long Island, New York, in the early 1900s. Tesla's objective was to develop the technology for transmitting electricity to anywhere in the world without wires. He filed several patents describing wireless power transmitters and receivers. However, his knowledge of electrical phenomena was largely empirical and he did not achieve his objective of WPT, although he was awarded patent for wireless radio in 1940.

The development of WPT was not effectively pursued until the 1960s when the U.S. Air Force funded the development of a microwave-powered helicopter platform. A successful demonstration of a microwave beam-riding helicopter was performed in 1965. This demonstration proved that a WPT system could be constructed and that effective microwave generators and receivers could be developed for efficient conversion of microwaves into DC electricity.

The growing interest in solar energy conversion methods and solar energy applications in the 1960s and the limitations for producing cost-effective base load power caused by adverse weather conditions and diurnal changes led to the solar power satellite concept in 1968 as a means to convert solar energy with solar cell arrays into electricity and feed it to a microwave generator forming part of a planar, phased-array antenna. In geosynchronous orbit, the antenna would direct a microwave beam of very low power density precisely to one or more receiving antennas at desired locations on Earth. At a receiving antenna, the microwave energy would be safely and very efficiently reconvened into electricity and then transmitted to users.



NASA: Depiction of a 5 GW "SolarDisc" SPS System Concept
FIGURE 1

The first technical session on solar power satellites (SPS) was held in 1970 at the International Microwave Power Institute Symposium at which representatives of Japan, European countries, and the former Soviet Union were present. Based on preliminary studies, a plan for an SPS program was prepared by an NSF/NASA panel in 1972 and the first feasibility study of SPS was completed for NASA/Lewis Research Center in 1974.

Shortly after the "oil shock" of October 1973, Japan staned to implement the Sunshine Plan to develop renewable energy sources. Japan's Plan included, as a long-term objective, the development of SPS. Back in the U.S. in 1975, a successful demonstration of microwave wireless power transmissions was performed at the NASA Deep Space Antenna facility at Goldstone, California. In this demonstration of point-to-point WPT, 30 kW of microwaves were beamed over a distance of one mile to a receiving antenna. Microwaves were converted directly into DC at an average efficiency of 82%, confounding critics who claimed that such high conversion efficiencies could not be achieved.

By 1976 engineering, environmental and economic analyses of several SPS concepts had been performed by NASA the office of Management and Budget, in its deliberations on the Fry 1977 budget, directed that further study of this concept be the responsibility of the Energy Research and Development Administration (ERDA), which subsequently became the Department of Energy (DoE). The SPS Concept Development and Evaluation Program (CDEP), performed by DoE/NASA and its contractors, used a NASA-developed SPS Reference System configuration as a basis for conducting environmental, societal, and comparative economic assessments, The DOE/NASA assessment team, as well as a majority of scientists, engineers, and analysts who participated in the CDEP recommended that the program be continued at a modest funding level, and SPS assessments directed at resolving or reducing significant uncertainties associated with microwave radiation effects and SPS design considerations, and to continue some promising experiments. By 1980 the CDEP was brought to its scheduled conclusion and not continued in a follow-on program, partly because the economic pressures of the oil crisis had passed, partly because of changed priorities for renewable energy development, and partly because of expectations that nuclear and eventually fusion power would meet future growth in energy demands.

A substantial body of work, both analytical and experimental, has established the technical feasibility of wireless transmission of useful amounts of power. Wireless transmission of power is similar in concept to information transmission by communications satellites, but at a higher intensity. However, because the radio frequency power beam is engineered for conversion back to electricity at very high efficiency, useful amounts of power could be transmitted at intensities less than that of sunlight. Experimental transmissions of power in amounts up to 30 kW have been accomplished over short distances (1.6 km) with conversion efficiencies in excess of 85% from incoming radio frequency power into electrical power.

Recent studies indicate that collection and transmission of power from space could become an economically viable means of exploiting solar power within the next couple of decades. A substantial maturation of certain technologies is needed and, most importantly, the cost of launching material to space must be significantly reduced. Very active efforts are being pursued in the aerospace community to achieve both of these goals.

Two types of WPT:

1) Ground based power transmission

2) Space based power transmission

But Space-based power transmission is preferred over Ground-based power transmission. Ground is (obviously) cheaper per noontime watt but , Space gets full power 24 hours a day3X or more Watt-hours per day per peak watt. No storage required for nighttime power. Space gets full power 7 days a week no cloudy days. Space gets full power 52 weeks a year. No long winter nights, no storms, no cloudy seasons. Space delivers power where it is exactly needed. Best ground solar sites (deserts) are rarely near users. Space takes up less, well, space. Rectennas are 1/3 to 1/10 the area of ground arrays. Rectenna can share land with farming or other uses.

3. INTRODUCTION TO LARGE SPS

Since 1967, Solar Power Satellites (SPS) have proposed to collect solar energy in space and beam it down to the Earth.

With the energy crisis of the early 1970's, SPS was seriously considered as an alternative to producing electric power from fossil fuels (during the 1970s, petroleum was used to produce a significant fraction of the U.S. electric power supply).

With worldwide demand for electric power increasing as well as concern growing over urban smog and the greenhouse effect, SPS is again attracting mainstream interest.There are several advantages to SPS. Solar radiation can be more efficiently collected in space, where it is roughly three times stronger than on the surface of the Earth and it can be collected 24 hours per day (since there are no clouds or night in high Earth orbit). SPS does not use up valuable surface area on the Earth and can be beamed to areas with the highest demand at any particular time. Most of these systems would utilize photovoltaic (PV) cells similar to those on Earth-based systems (such as those used by home power systems and highway sign panels). Others would utilize reflectors and mechanical collectors similar to those used in special large-scale solar facilities in France and the California desert (Barstow). Some PV systems would also use reflective concentrators. Most of these systems collect solar energy in space and transmit it via a microwave energy beam to an Earth-based rectenna which converts the beam into electricity for use on Earth.

Microwave beams have a fairly low wavelength (lower than visible light) and do not appear to pose any danger to the Earth's atmosphere. In fact, telephone companies have been beaming microwaves through the atmosphere for over thirty years without any known problems. High launch costs, which can run roughly between $1,000 to $10,000 per pound, are the greatest barrier to the development of SPS. Most SPS proposals require launch costs of about $200 per pound to compete with your local utility company. However, growing demand for electric power could outstrip traditional production capability, driving prices up to the point where SPS would be competitive. If limits on producing electricity by burning coal (in order to reduce pollution) are enacted, SPS could become competitive even earlier.

Four basic steps involved in the conversion of solar energy to electricity and delivery are:

1.Capture solar energy in space and convert it to electricity.

2.Transform the electricity to radio frequency energy and transmit it to Earth.

3.Receive the radio frequency energy on Earth and convert it back to electricity

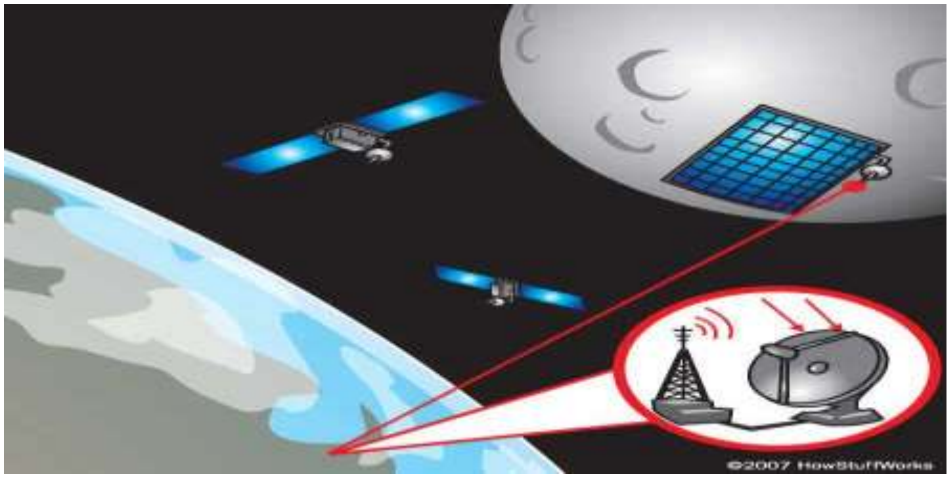
4. Provide the electricity to the utility grid.

Using photovoltaic cells does the conversion of solar energy to electric energy. There are different types of photovoltaic cells. The single crystal silicon is one type of photovoltaic cell, which is formed by a doped wafer formed from a slice of single crystal. Though it has good efficiency it is less used due to expense factor, which comes in due to necessity of high grade of silicon. Its follower is poly crystalline silicon with moderate efficiency and reduced cost. Gallium arsenide is but most commonly used due to high efficiency in comparison to all other types. Then there are dynamic cells which use Solar concentrators to concentrate upon a mechanical heat engine (not photovoltaic). But these are expensive and involve higher maintenance. Often not suitable for small applications. But they do have high conversion efficiencies of the range 30% and above.

Developing any substantial source of energy requires the dedication of significant amounts of capital, land, technical skills, etc. The exploitation of Space Solar Power will require all of these plus some that are unique. As noted before, SSP systems will likely operate in geosynchronous orbit. This orbit is at an altitude such that the platform appears to be stationary over a specific point on the surface of the Earth. As a result, this particular orbit is highly desirable for Earth-oriented activities, for example communications, hence international control is exercised over the assignment of positions or "slots" in this orbit.

4. TRANSMISSION

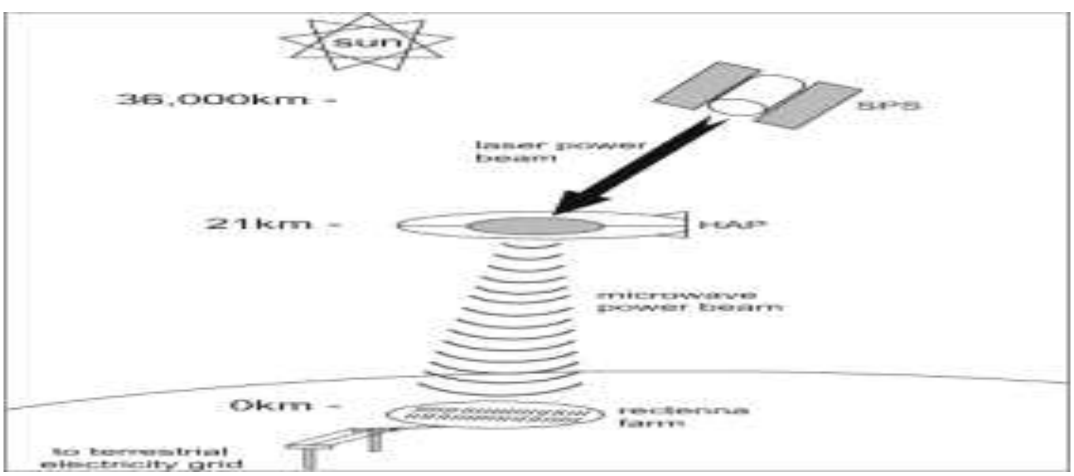
Solar power from the satellite is sent to Earth using a microwave transmitter. This transmission is transmitted to the relevant position via an antenna. The transmission is transmitted through space and atmosphere and received on earth by an antenna called the rectenna. Recent developments suggest using laser by using recently developed solid state lasers allow efficient transfer of power. A range of 10% to 20% efficiency within a few years can be attained, but further experimentation still required taking into consideration the possible hazards that it could cause to the eyes. In comparison to laser transmission microwave transmission is more developed, has high efficiency up to 85%, beams is far below the lethal levels of concentration even for a prolonged exposure. The microwave transmission designed has the power level well below the international safety standard (Frequency 2.45 GHz microwave beam).



The electric current generated from the photovoltaic cells is passed through a magnetron which converts the electric current to electromagnetic waves. This electromagnetic wave is passed through a waveguide which shapes the characteristics of the electromagnetic wave.

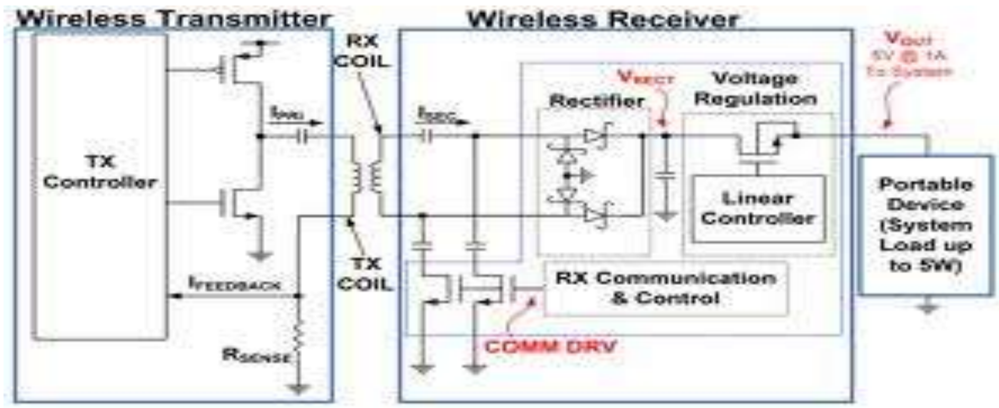
MICROWAVE	LASER
More developed	Recently developed solid state lasers allow efficient transfer of power
High efficiency up to 85%	Range of 10% to 20% efficiency within a few years
Beams are far below the lethal levels of concentration even for a prolonged exposure. Cause interference with satellite communication industry	Conform to limits on eye and skin damage

Effectiveness of Wireless Power Transmission (WPT) depends on many parameters. Only a part of WPT system is discussed below,

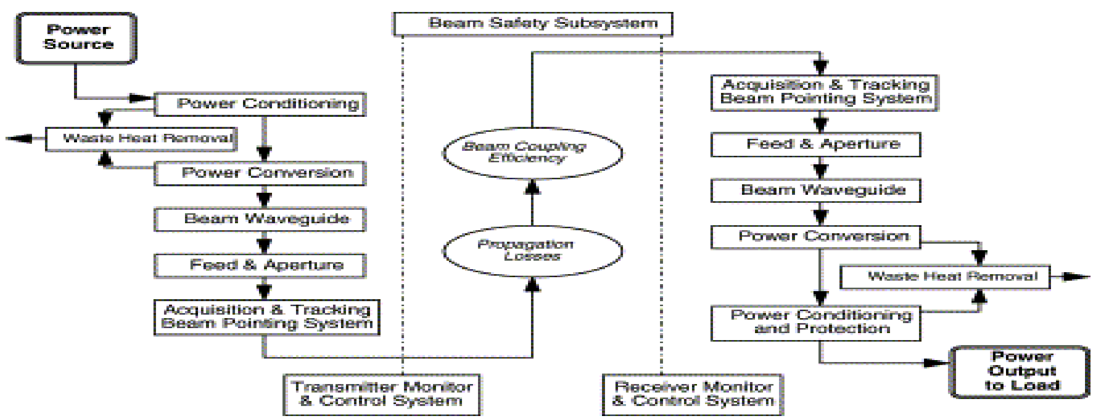


which includes radiating and receiving antennas and the environment between them. The wave beam is expanded proportionately to the propagation distance and a flow power density is increased inversely proportional to the square of this distance. However the WPT has some peculiarities, which will be mentioned here. WPT systems require transmitting almost whole power that is radiated by the transmitting side. So, the useful result is the power quantity at the receiving antenna, but not the value of field amplitude as it is usually required. Efficiency of WPT systems is the ratio of energy flow, which is intercepted by receiving antenna to the whole radiating energy.

Field distribution on the receiving antenna usually is uniform because its size is small comparatively to the width of the beam. For WPT systems this distribution isnâ„¢t uniform. It has a taper form and it depends on the field distribution on the transmitting antenna.



For increasing of the energy concentration on the receiving antenna the phase distribution on the radiating antenna has usually a spherical form with the center in the point on crossing of the receiving plate and the radiating axis. Radiating antenna of the WPT systems usually has a taper distribution of the field. This distribution allows to increase the efficiency and to decrease the field out of the receiving antenna.



The efficiency of energy transmission is expressed by the functional 2. To increase the field distribution on radiating aperture is made as a tapered distribution. High value of is supposed to be in the majority of known projects of the WPT systems. However, the effectiveness of the WPT system is defined not only by the value of. It is also determined by the rectangularity of the field distribution on the radiating aperture, the rectangular distribution factor in the theory of antennas is usually called the surface utilization factor. The meaning of these two parameters and is discrepant because to increase 2 it is necessary to have the field falling down to edges, but to increase it is necessary to have a uniform field.

To increase the effectiveness of WPT system it is necessary to increase the product 2, though the requirements for each of both multipliers are opposite. This product is named a generalize criterion! It is possible to find the way out of this contradiction if the antenna is discontinuous (discrete) one. Let us produce the field distribution in the radiating discrete antenna falling to its edges not by means of creation of non-uniform distribution of the field but with the help of irregular situation of identical sub apertures, each of them having the uniform field distribution. It is supposed that the number of these apertures is sufficiently high in order to admit the approximation of the integral optimum monotonous Gauss distribution by means of step function. The places of sub aperture disposition can be found by the differentiation of this step function. Discrete distribution of sub apertures presents non-equidistant antenna array consisting of the similar elements. Such optimization is optimal in Chebyshevâ„¢s sense since the maximum error tends to zero while the number of sub apertures is tended to infinity. So the field in the place of observerâ„¢s disposition would be similar to step and the monotonous signal source. The falling to the edge field distribution is typical for the WPT problems. For the discrete-step distributions that means the concentration of sub apertures in the center and their gradual discharge on the edges. Thus all sub apertures are similar and have the uniform distribution of the field with the equal amplitude, which may reach the maximum admissible value.

The dismemberment of continuous apertures and slight moving of them apart in the space when all of apertures are equal and uniformly feed increases their effectiveness (the generalized criterion is increased). The generalized criterion determines the quality of the WPT Systems better than usual criterion. The optimal distribution form may be reached for the large radiating apertures where dismemberment at many parts is easily realized by disposition of sub aperture clots in places, which correspond to high field intensity (first of all it concerns the center of the radiator) and relieving sub aperture density at edges of antenna. This construction allows to approach to unit the value both of coefficients 2 and as a result the effectiveness of the WPT system will be essentially increased.

For receiving these transmitted waves rectennas are set up at the Earth. An antenna comprising a mesh of dipoles and diodes for absorbing microwave energy from a transmitter and converting it into electric power. Microwaves are received with about 85% efficiency and 95% of the beam will fall on the rectenna but the rectenna is around 5km across (3.1 miles). Currently there are two different design types being looked at- Wire mesh reflector and Magic carpet. Wire mesh reflector type rectennas are built on a rigid frame above the ground and are visually transparent so that it would not interfere with plant life whereas in the magic carpet type material pegged to the ground.

5. CHALLENGES

The development and implementation of any new energy source present major challenges. And it is acknowledged that bringing about the use of Space Solar Power on the Earth may be particularly daunting because it is so different. The major challenges are perceived to be:

1. The mismatch between the time horizon for the implementation of SSP and that for the expansion of conventional energy resources.

2. The fact that space power is intrinsically global, requiring enterprise models that give every player a suitable stake and adequate safeguards.

3. The potential for concerns over reliability, safety and environmental implications.

4. The need to obtain publicly-allocated resources outside the normal purview of the energy community.

5. The prevailing mind set which tends to view the future energy infrastructure as an extrapolation of the present one.

However great the challenges, it is important to enhance global energy systems so they work for all the people of the Earth. It is asserted that a prudent course would be to give serious attention to all plausible options and prepare to implement several if needed. It is well understood that something as vast as the global energy system can change only slowly. In fact, it takes from 50 to 75 years for one source to lose dominance and be replaced by another. Even if it is recognized and agreed that a shift to different sources is needed, penetration would be slow.

The time horizon for implementing Space Solar Power will be at least a couple of decades. Current work being carried out in the US by the National Aeronautics and Space Administration (NASA) and in Japan by the Ministry of Economy, Trade and Industry (METI) indicate that demonstrations of space-to-ground transmission of power could come in the current decade and initial commercial power delivery in about 20 years. A significant contribution in terms of global energy would clearly take substantially longer. The challenge presented by this mismatch can be addressed in two ways:

1. First, governments will need to underwrite, to a major extent, the R&D needed to bring the enabling technologies to maturity. Governments have traditionally supported R&D efforts as a spur to new economic activity. Examples can be found in the development of rail and air transport systems, computers and, most recently, the internet.

2. Second, a near-term involvement by the users (the electric utilities and their suppliers) should be promoted. It is very important for these prospective users to keep abreast of progress as the technology matures.

The global scope of Space Solar Power will present another significant challenge in terms of appropriate enterprise models that give every player a suitable stake and adequate safeguards. International cooperation in the energy area is commonplace and indeed the infrastructure for energy is highly interdependent around the world. Energy acquisition, distribution, and utilization tend to involve multiple countries and far-flung networks along which various forms of energy flow. Similarly, international collaboration has been important in major space ventures of which Space Solar Power would certainly be an example.

Briefly, there are several reasons for international collaboration. The most compelling are:

1. The need for increased energy supplies is a global need.
2. The impact on the environment of present energy practices is a matter of worldwide concern.
3. International coordination in energy provisioning is common today and the interdependence will only grow in the future.
4. The needed technology is widely distributed and no one country has all the capability.
5. The large scale of Space Solar Power will require international financing.
6. International regulations control critical resources, specifically slots in geosynchronous orbit and appropriate transmission frequencies.
7. Recognition of Space Solar Power as a viable and safe approach to energy will require an international consensus.

Space Solar Power is perceived as very different from all other power sources because of its wireless delivery. A significant challenge will be to allay concerns about the safety of this transmission mechanism. A substantial body of theoretical and experimental work exists and this work indicates that, for the power density levels being considered for importation of power from space, there are no troublesome effects to life forms. Since radio frequency power is non-ionizing, the only likely effects are thermal and these should be modest in view of the fact that the intensity of the transmitted beam Space Solar Power is perceived as very different from all other power sources because of its wireless delivery. A significant challenge will be to allay concerns about the safety of this transmission mechanism. A substantial body of theoretical and experimental work exists and this work indicates that, for the power density levels being considered for importation of power from space, there are no troublesome effects to life forms. Since radio frequency power is non-ionizing, the only likely effects are thermal and these should be modest in view of the fact that the intensity of the transmitted beam.

Developing any substantial source of energy requires the dedication of significant amounts of capital, land, technical skills, etc. The exploitation of Space Solar Power will require all of these plus some that are unique. As noted before, SSP systems will likely operate in geosynchronous orbit. This orbit is at an altitude such that the platform appears to be stationary over a specific point on the surface of the Earth. As a result, this particular orbit is highly desirable for Earth-oriented activities, for example communications, hence international control is exercised over the assignment of positions or "slots" in this orbit.

The changes in dominant source over time were noted in an earlier figure and we see a continuing change. Considering the relative role of the various sources over just the last century, we have seen the prominence of wood vanish and that of coal diminish greatly. At the same time, the contributions of oil and gas rose from virtually nothing to dominance, and nuclear became a significant contributor in a matter of only 25 years. Considering the changes washing over our world in almost all areas of life and the economy, can we expect anything less dramatic in the energy arena over the 21st century Today we the opportunity and the challenge to create a future that is energy-rich and sustainable, but we must be open to a departure from past and present practices and expect that the energy situation in 2100 will be very different from that of today. The prudent response is a pro-active assessment of all reasonable options and pursuit of those that appear most viable, however futuristic they may seem at present.

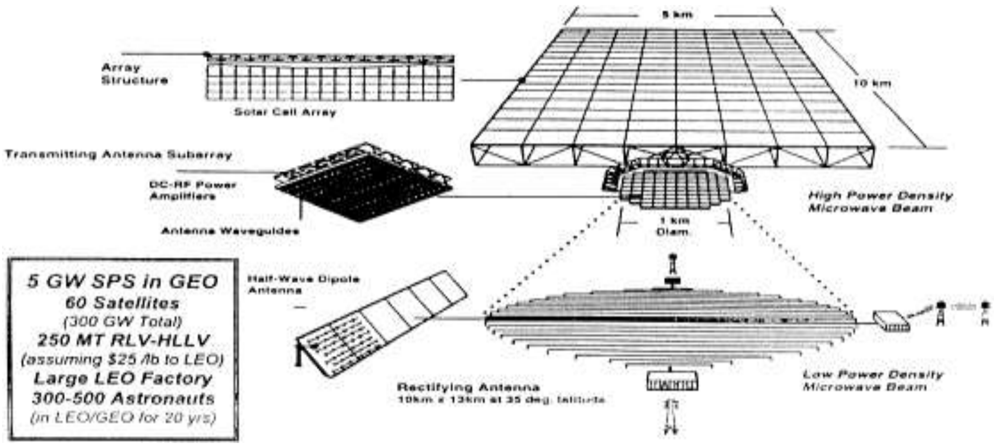
6. ADVANTAGES

1. Unlimited energy resource
2. Energy delivered anywhere in the world
3. Zero fuel cost
4. Zero CO_2 emission
5. Minimum long-range environmental impact

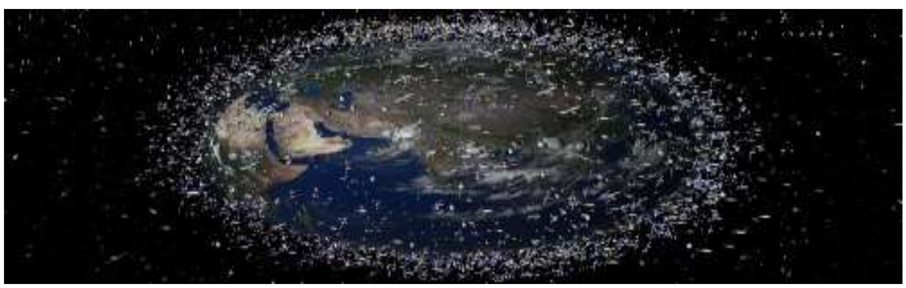
6. Solar radiation can be more efficiently collected in space

7. DISADVANTAGES

1. Launch costs
2. Capital cost even given cheap launchers



3. Would require a network of hundreds of satellites



4. Possible health hazards
5. The size of the antennas and rectennas
6. Geosynchronous satellites would take up large sections of space
7. Interference with communication satellites

8. EVOLVING WPT MARKETS

Markets that will be made accessible with WPT will have a profound influence on global business activities and industry competitiveness. The following are examples of the future commercial opportunities of WPT:

1. Roadway powered electric vehicles for charging electric batteries with WPT from microwave generators embedded

in the roadway while a vehicle is traveling at highway speed, thus eliminating stops to exchange or recharge batteries greatly extending travel range.

2. High-altitude, long-endurance aircraft maintained at a desired location for weeks or months at 20 km for communications and surveillance instead of satellites, at greatly reduced costs.

3. Power relay satellites to access remote energy sources by uncoupling primary electricity generation from terrestrial transmission lines (15). Power is transmitted from distant sites to geosynchronous orbit and then reflected to a receiver on Earth in a desired location.

4. Solar power satellites in low-Earth or geosynchronous orbit or on the Moon to supply terrestrial power demands on a global scale.

9. CONCLUSION

There is little doubt that the supply of energy must be increased dramatically in coming decades. Furthermore, it appears almost certain that there will be a shift toward renewable sources and that solar will be a major contributor. It is asserted that if the energy system of the world is to work for all its people and be adequately robust, there should be several options to develop in the pursuit of and expanded supply. While the option of Space Solar Power may seem futuristic at present, it is technologically feasible and, given appropriate conditions, can become economically viable. It is asserted that it should be among those options actively pursued over coming decades. The challenges to the implementation of Space Solar Power are significant, but then no major expansion of energy supply will be easy. These challenges need to be tackled vigorously by the space, energy and other communities.

Finally, it should be emphasized that if we fail to develop sustainable and clean energy sources and try to limp along by extrapolating present practices, the result is very likely to be thwarted development of economic opportunities for many of the Earth's people and, almost certainly, adverse changes to the planetary environment.

The resolve of the synthesis problem of the WPT shows that WPT efficiency may be improved by using special current discontinuous distribution on the antenna. Here we have three possibilities:

1. To use a discontinuous equidistant array with the quasi Gauss distribution.

2. To use a discontinuous non-equidistant array with the uniform distribution.

All of these methods are original and they have been modeled only in the frame of International Science and Technology Center Project. The possibility of decrease of the wave beam expansion permits to make the WPT systems less expensive. Such approach to the problem of the continuous radiators and of the real antennas, which can be created, is new.

10. REFERENCE

[1] P.E. Glaser Ã‚Â«Method and Apparatus for Converting Solar radiation toElectrical PowerÃ‚Â», U.S. Patent 3 781 647, 1973.

[2] R. Bryan Erb, "Space-Based Solar Power - How Soon and How Much", 49th Congress of the International Astronautical Federation, Paper IAF-98-R.2.02, Melbourne, Australia, September 28 - October 2, 1998.

[3] WEC/IIASA, Global Energy Perspectives, Nakicenovic, Nebojsa, et al, Cambridge University Press, 1998.

[4] P. E. Glaser, "An overview of the solar power satellite option," IEEE Transactions on Microwave Theory and Techniques, vol. 40, no. 6, pp. 1230-1238, June 1992.

[5] W. C. Brown and E. E. Eves, "Beamed microwave power transmission and its application to space," IEEE Transactions on Microwave Theory and Techniques, vol. 40, no. 6, June 1992.

[6] World Energy Council, "Energy for Tomorrowâ„¢s World - Acting Now", WEC Statement 2000, http://www.worldenergy.org/ http://www.nspri.com/