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ENERGY TRANSPORTATION: THE MICROWAVE SOLUTION

1. Electromagnetic waves to carry electricity

Electricity was discovered two hundred years ago. One century ago, came the time of electromagnetic waves. It took about fifty years before some practical use could be found for electricity, first with telegraph and telephone systems, and another fifty years before electricity was used for light and energy at the end of the 19th century.

History seems to be repeating, with a development, in the first part of the 20th century, of the use of radio waves for wireless communications, first with voice broadcasting and later with television and mobile phones. Only much later, in the second part of the 20th century, electromagnetic waves began to be used for energy purposes, mainly for industrial heating and domestic kitchen microwave ovens.

Now, in the beginning of the 21st century, about one hundred years after their discovery, electromagnetic waves are eventually being considered for industrial use in **Wireless Power Transportation (WPT)** systems.

All kinds of electromagnetic waves may carry quantities of energy, but microwave beams at the industry frequency of 2.45 GHz (GigaHertz), with a wavelength of 12.2 cm are especially convenient for two main reasons :

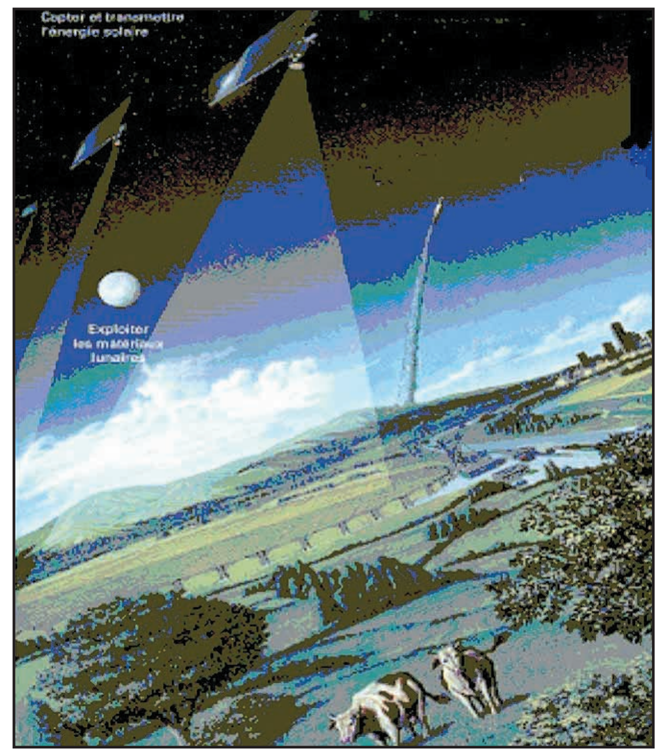
* When the wavelength is short, it is possible to form an energy beam with a small angle of aperture, and to direct most of the energy towards the collecting area with technically reasonable sizes both for the projecting system and for the collecting area ;

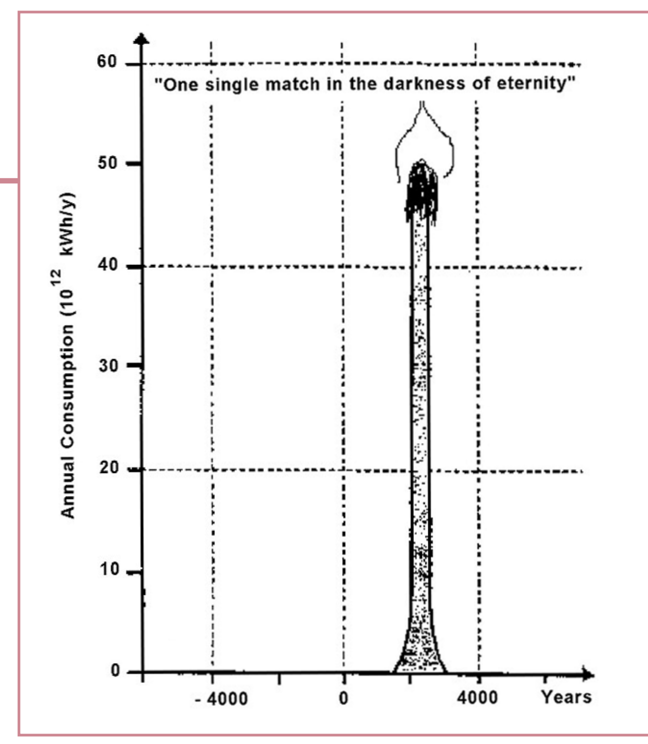
* At the frequencies of a few GigaHertz, the atmosphere remains always fairly transparent, not depending on the meteorological conditions, even in case of rain or snowfall.

There are several ways to generate microwaves, also called hyperfrequencies, from various electricity sources : Magnetrons, which are used in domestic ovens and for industrial heating, are inexpensive, have an efficiency of about 90%, but they are difficult to synchronize together for phased arrays. Klystrons, commonly used in the communications industry, are efficient but expensive. Solid state is more simple, but so far the efficiency remains low.

There are a number of ways to form the microwaves into a beam and to send them in a given direction with phased array projectors ; with proper adjustment of the relative size of the projecting array and of the collecting zone, up to 90% of the energy of the beam can be collected.

In the collecting systems, the high frequency AC currents induced by the microwaves can be rectified to generate powerful DC currents which in turn can be converted to AC for distribution to the end users. In the **rectennas** (for "rectifying antennas"), the waves are rectified by semiconductor diodes. In cyclotron wave converters (CWC), the energy of microwaves is transferred to an electron beam which generates high voltage direct current.





2. Clean and sustainable baseload electricity

Fossil energies will soon be depleted. When we plot fossil energy consumption versus time, we see that the energy situation of our planet and of our civilisations is critical for the future generations. Well before the end of the new century, we shall have to turn massively to sustainable sources of controlled energy, and mainly to solar energy.

Because of the difficulty to store large quantities of electricity or to transport them over large distances, one of the favoured solutions will be to generate electricity in real time in outer space, where it can escape the night and day cycles, and to transport it near the megacities where it will be used by means of the newly developed WPT technology.

Schemes for giant Space Solar Power systems have been devised in Europe, Russia, the USA and Japan. The first SSP systems could be operational as soon as 2040 to power major urban sites in Japan. Studies have shown SSP to be the cleanest energy options for the future.

One of the most attractive features of SSP systems is their potential for a double use of the land in the collection areas, both for energy purposes and for conventional agriculture : because the operating frequency of SSP and WPT systems is not in the spectrum of direct solar radiation, there will be no significant interference with the growth of vegetation underneath the collecting arrays. For the same reason, it will be relatively easy to design aesthetically acceptable constructions for the huge rectenna arrays – between 10 and 15 kilometer in diameter for the needed tens of GigaWatts per site – and to integrate them properly in the environment and in the economy of agricultural regions near the larger cities of our planet.

Many fears and concerns have been expressed concerning the possible dangers of exposure to such huge quantities of microwave energy, but density of energy is the point to be considered : it will remain well below the energy density of sunlight, and the studies conducted so far point out that SSP will be not only clean, but also safe systems.

3. The SPS-2000 portable demonstrator

The 200 or so international researchers who are currently working on the development of Space Solar Power systems feel confident that the basic technologies are mature, and many conclusive experiments have been made already in various laboratories in several countries.

However it is a major challenge to develop and implement the technology from current lab size to the scale of something almost as large as the canal of Panama. It will have to wait until the next generations of space transportation, the development of the industrial use of space native resources, and a more acute perception of the urge to resort to the sun as our prime source of energy.

No governmental or industrial of financial institution would be today in a position to initiate major SSP projects, and a terraced approach is necessary both in terms of awareness and in terms of industrial technology development.

A co-operation between CNES, the French Space Agency, and ISAS, the Institute for Space and Astronautical Science in Japan, has resulted in the production of several models of a **functional and portable SSP demonstrator**.

Based on the design of the Japanese interim SPS-2000 concept, the model features all the essential technologies of the future Space Solar Power systems, in actual operation : an artificial sun is used to illuminate a scale model of the SPS satellite where photovoltaic arrays produce electricity. This energy is then used to generate 2.45 GHz microwaves, which are beamed from an array of projecting antennas to a display model of Planet Earth.

On the Earth model, a small but fully functional rectenna array collects the energy of the incoming beam and converts it to DC current which is eventually used to power symbolic lights on a world map.

The ISAS / CNES SSP demonstrators have already been used in a number of presentations at conventions or during meetings with government officials and representatives of international organisations, on every continent.

The self-contained "attaché-case" demonstrators have been very useful to explain the general concepts of SSP and to present both the viability and the usefulness of SSP systems. The models helped to dispel many popular fears about microwave operation. They offered a good initial support to consider the challenges of developing full scale Space Solar Power systems over the coming decades.

One of the demonstrators is operated in connection with the World Solar Programme of the UNESCO, **and presentations may be arranged upon request at the following e-mail address :**

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