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SSPS DEVELOPMENT ROAD MAP

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ABSTRACT

There are three candidates of SSPS (Space Solar Power Systems) currently studied in Japan for the commercial phase; microwave-type basic model, microwave-type advanced model, and laser-type model. A step-by-step road map towards the commercial model is proposed. In the near future within 7 years, we will conduct a small-scale wireless power transmission experiment at a KW level both on the ground and in space. After completion of the small-scale experiment, we will select the target model for the commercial SSPS based on trade-off studies and start a 100 KW class SSPS project in orbit. A MW class plant will be constructed in 2020's and finally we will reach the 1 GW class commercial model in 2030's. For the laser technology, other application to planetary exploration is also considered in the road map.

1. INTRODUCTION

"Energy" is one of the most important bases to support human life. 80 % of energy in our life comes from fossil fuels, burning a huge amount of oil, natural gas and coal. If we continue to consume the fossil fuel resources at the current pace, they will be completely lost within 100-200 years. Furthermore, the huge amount of consumption of fossil fuel will increase CO_2 concentrations, the primary greenhouse gas, in the atmosphere. If we continually depend on the fossil fuel, we will experience substantial degradation of life quality within this century, that leads to unprecedented confusion or tragedy in our society.

The global problem can effectively be solved in the open earth-space system, rather than in the closed earth system. There is unlimited constant solar energy in space free from the whether conditions, quite different from that on the earth. The concept of the SSPS is to utilize the space surrounding the earth to tap energy for human society. SSPS has a great potentiality for the large-scale clean energy system to replace the fossil energy plants. It is highly required to promote scientific research for the SSPS technologies and associated environmental issues.

The SSPS concept was first proposed by Peter Glaser [1] in 1968, followed by NASA/DOE studies in the 1970's [2]. Since the early investigations, various types of the SSPS have been proposed in Japan, the United States, and Europe. SSPS classification and typical examples are summarized in Fig.1. It is generally expected in the SSPS community that the commercial use starts in 2030's, however, the road map towards the commercialization has not been well

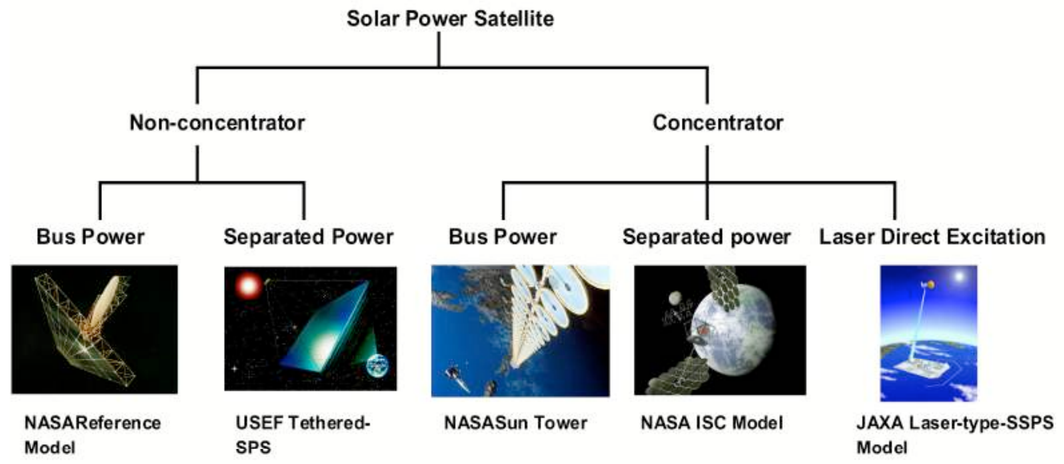

Fig.1 SSPS classification and typical examples.

established. Recently, the Japanese government decided the space development plan stating that a small scale SSPS experiment be conducted immediately after ground demonstration experiment within 5-10 years. This is the first time that the Japanese government shows its commitment to the SSPS program. Based on the new movement in Japan, we generated a road map for SSPS development to accommodate the government plan and the SSPS community's prospect.

2. JAPANESE COMMERCIAL SSPS MODELS

We have three types of commercial model in Japan; microwave-type basic model, microwave-type advanced model, and laser-type model. The basic model is the Tethered-SPS in which the power generation/transmission panel is suspended by tether wires and stabilized by gravity gradient force, which has been studied by USEF (Institute for Unmanned Space Experiment Free Flyer). The advanced model is a combination of reflective mirrors with power generation solar array and microwave transmitter. It utilizes the formation flight of reflective mirrors and power generation/transmission complex, which has been studied by JAXA. The laser-type model is a combination of focusing mirrors, a crystal laser exciter, optics, and a heat radiator, which has been studied by JAXA. The technologies required for the laser model are much more challenging than the microwave-type model.

Tethered-SPS is a simple, technically feasible, and practical configuration SSPS which consists of a lot of tethered unit panels. The unit panel of 100 m x 95 m is suspended by four 5-10 km tether wires extended from a bus system. The weight is about 50 MT. The important point is that the unit has the SSPS function with a power transmission capability of 2.2 MW. The essential technologies required for this concept are the deployment of the long tether of 5-10 km scale and the large panel of 100 m scale in orbit. The basic parts of theses technologies have been already demonstrated in orbit.

In the initial concept of the Tethered-SPS [3], the units are integrated to the commercial system of 1 GW by connecting each bus system to a single bus as shown in Fig.2. In the updated

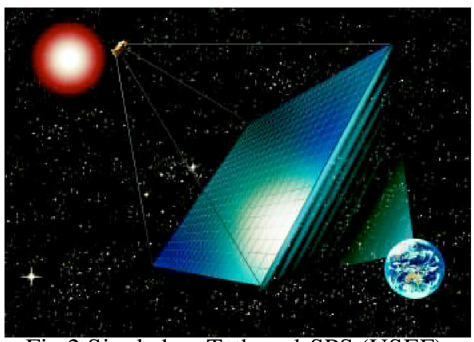

Fig.2 Single bus Tethered-SPS (USEF).

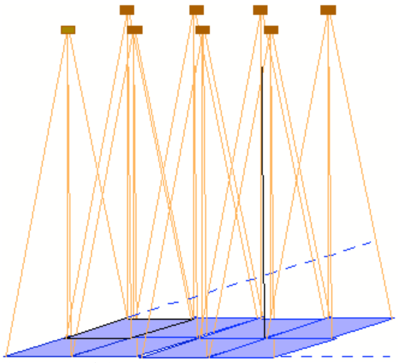

Fig.3 Multi-bus Tethered-SPS (USEF).

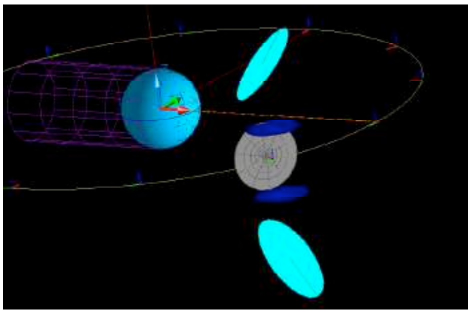

Fig.4 Formation flight model of reflective mirrors and power generation/transmission complex (JAXA).

Tethered-SPS concept [4], only power generation/transmission panels are connected, leaving each bus system unconnected as shown in Fig.3. This new configuration of separated bus system greatly enhances flexibility, expansibility, and, maintenance performance of the Tethered-SPS. Since this system has no capability to track the sun for the power generation, the total power efficiency is 36 % lower than that for the sun-pointing type SSPS even when the solar cells are attached to both sides of the panel. However, the simple configuration resolves almost all the technical difficulties in the past SSPS models.

The combination of reflective mirrors and a power generation/transmission panel has been studied in NASDA (former JAXA) since early 2000's. Two pairs of the primary mirrors and secondary mirrors are used to concentrate the sunlight onto the power generation/transmission panel. 4 movable mirrors and one power generation/transmission panel are connected using two pairs of truss beams. However, this configuration has an overheat problem at the power generation/transmission panel and one-point-failure problem at the rotating mechanism. In order to avoid these problems, the configuration has later been modified so as that the solar array panel and the microwave transmission panel are separated and the mirrors are floated free from the power generation/transmission complex using the solar pressure [5]. The conceptual model is shown in Fig.4. This model still has technical difficulties, such as light-weight structure of the free-flying mirrors, dynamics of the system, and thermal condition for the solar array panel, but it can collect the solar energy almost 100 % throughout the year.

The laser-type SSPS consists of 100 10MW modules, as shown in Fig.5. Each module has light-concentrating mirrors of 500-1000 times, a laser conversion element directly from the concentrated sunlight, an optic system to direct the laser beam to the ground receiver, and a thermal radiator. The laser exciter is a Cr doped Nd:YAG crystal, which comes from the state-of-the-art technology. The laser-type SSPS has an essential problem that the power transmission is strongly affected by the local whether and the associated technologies are not matured as compared with those for the microwave-type. However, since the laser-type has a potential advantage that the system, both

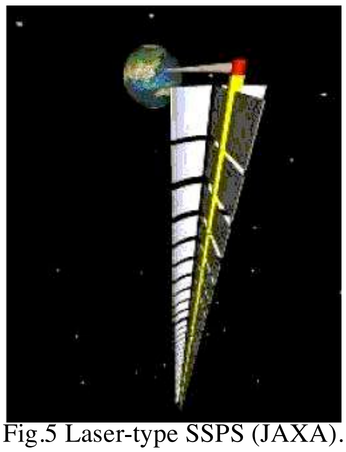

Fig.5 Laser-type SSPS (JAXA).

the space and ground segments, can be considerably smaller as compared with the microwave-type, JAXA is conducting its research as well as the microwave-type SSPS.

3. ROAD MAP

One of the three models is expectedly realized in 2030's. The road map we are considering is shown in Fig.6. We just started development of the wireless power transmission demonstration systems on the ground at 1 KW level both for microwave and laser. The ground demonstration will be completed by the end of 2012. Based on the design of the ground demonstration system, a small scale microwave power transmission experiment in orbit will be conducted around 2015. If the technologies for the laser power transmission and the large scale panel deployment are ready for the space experiment, they will be also demonstrated in the same time frame. Small satellites and/or JEM (Japanese Experiment Module) on the International Space Station are the possible platform for the demonstration experiments. After completion of the demonstration experiments on the ground and in space, we will select the initial target of the commercial SSPS; microwave-type basic model, microwave-type advanced model, or laser-type model. The expected power cost and public acceptance will be the major trade off factors for selection. For the selected model, we will demonstrate a 100 KW class SSPS in space around 2020. All basic technologies required for the commercial SSPS will be verified at this stage. The demonstration for the commercial SSPS will be conducted using 1 or 10 MW class SSPS plant before 2030. This scenario guaranties the start of construction of the 1 GW class commercial SSPS in 2030's.

The laser power transmission technologies can also be applied to the planetary exploration. This is a branch of the main stream SSPS research in the road map. The typical examples are the energy systems for the lunar rover and lunar base. The rover to explore the permanent shaded area in the polar region that could have the water ice will be powered by the laser beam from the mother ship located at the sunlit hill. The lunar base could be powered during the two-week nighttime by the laser beam energy from the orbiting power satellite.

4. WIRELESS POWER TRANSMISSION DEMONSTRATION ON THE GROUND

In the microwave power transmission experiment, a microwave beam around 3 KW from array antenna will be transmitted

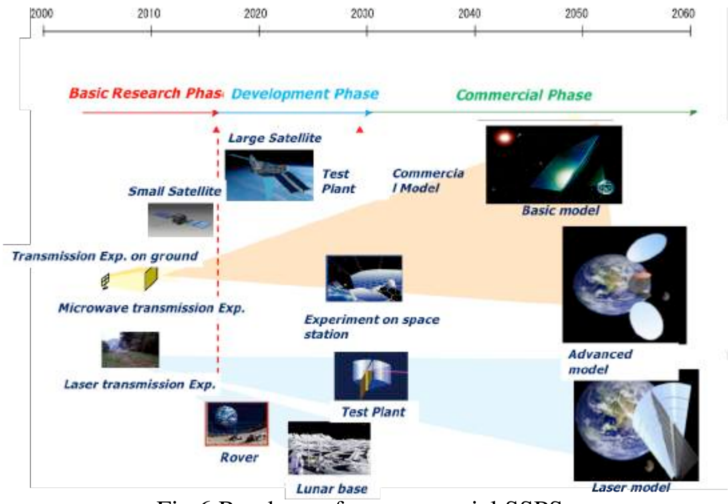

Fig.6 Road map for commercial SSPS..

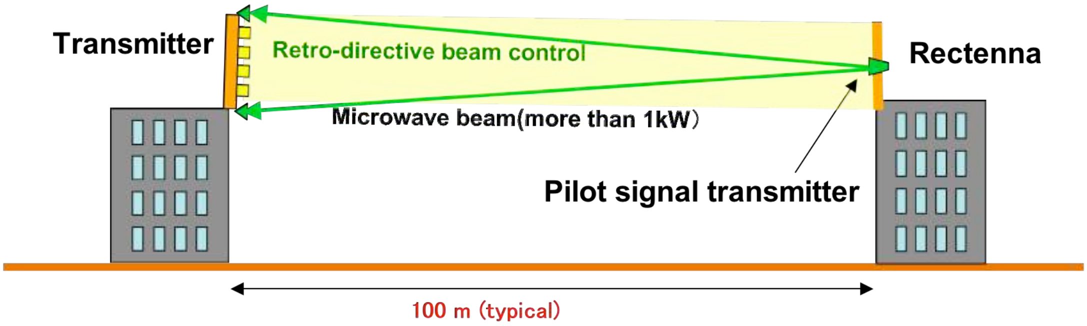

Fig.7 Microwave transmission experiment on the ground.

to a rectenna located typically at 100 m from the transmitter. The microwave beam will be precisely guided using the retro-directive beaming technology with a pilot signal from the rectenna site (Fig.7). In the laser transmission experiment, a laser beam around 1 KW directly generated by the concentrated solar light will be transmitted to a photovoltaic receiver located at 500 m apart from the transmitter as shown in Fig.8.

5. SMALL SCALE MICROWAVE POWE TRANSMISSION EXPERIMENT IN SPACE

After completion of the ground wireless power transmission experiments, we will be ready for a small-scale demonstration experiment in orbit. For the microwave demonstration experiment, power transmission at the KW level from the low earth orbit to the ground will be conducted. The space experiment will demonstrate the beam control technology for several hundred km and verify the power beam transmission through the ionosphere without serious loss of power. There are two candidates for the initial demonstration experiment in space using a small satellite or the JEM on the International Space Station. The configuration for the microwave transmission experiment from the small satellite is shown in Fig.9. A power generation/transmission panel consisting of 4 modular panels similar to those on the ground demonstration experiment will be used to transmit 3 KW power. The experiment on the International Space Station as shown in Fig.10 will have 9 modular panels which is capable of transmitting 6 KW power to the ground Based on the results from the small-scale demonstration experiments in space and laboratory experiments, we will make a decision on the technology selection, microwave or laser, for the next phase development. In the next step, we will make a 100 KW-class SSPS demonstration experiment in orbit, and then scale up to a

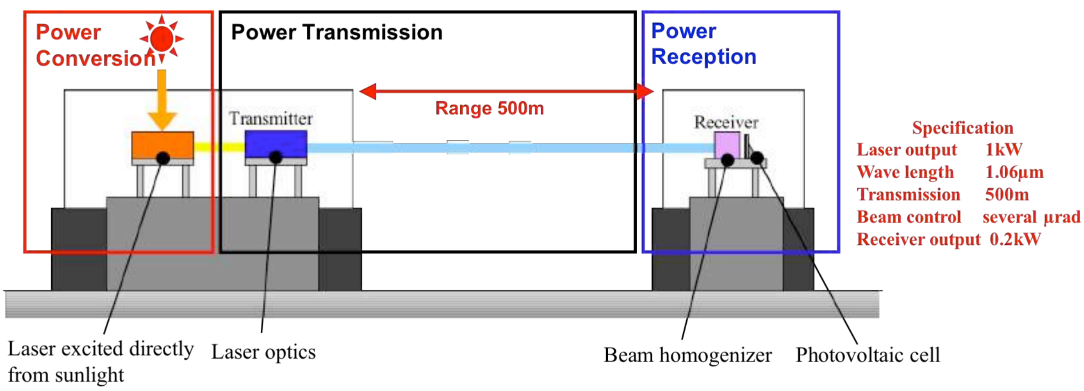

Fig.8 Laser transmission experiment on the ground.

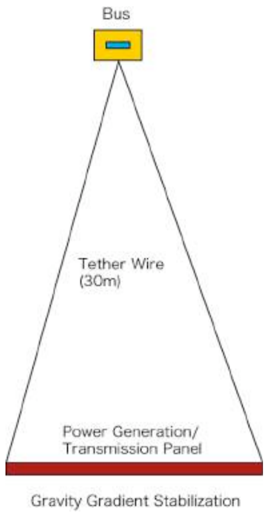

Fig.9 Configuration of the demonstration experiment using the small satellite.

10 MW-class pilot plant before 2030. This scenario will lead to realization of the first commercial model in the 2030's.

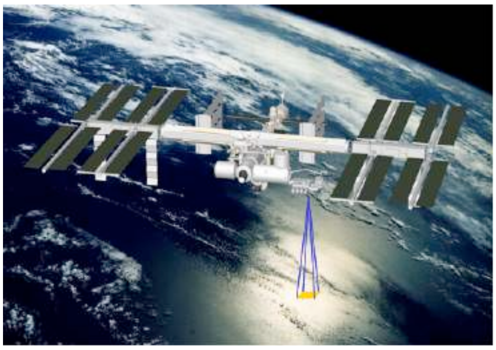

Fig.10 Configuration of the demonstration experiment using the Space Station JEM.

6. CONCLUSION

Three commercial SSPS models currently studied in Japan are introduced. As the first step towards the commercial model, a project for a ground demonstration experiment will be started soon. It will demonstrate the technologies to transmit a KW class microwave beam precisely to the rectenna located at about 100 m from the transmitter and a KW class laser beam to the receiver located at about 500 m apart from the transmitter. The technologies verified in the ground experiment will be used to conduct the next-step KW class demonstration experiment from the low earth orbit to the ground. Based on the results from the small-scale demonstration experiments in space and on the ground, we will make a decision on the technology selection, microwave or laser, for the next phase development. In the next step, we will make a 100 KW-class SSPS demonstration experiment in orbit, and then scale up to a 10 MW-class pilot plant before 2030.

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