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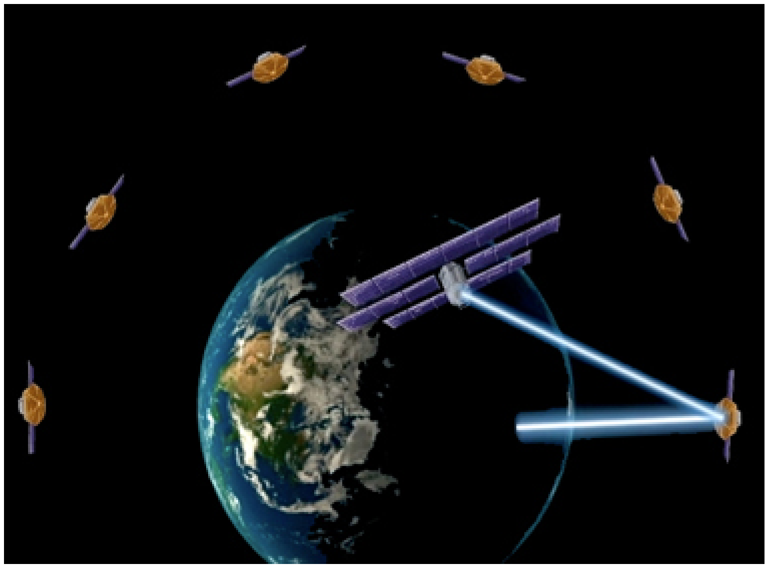

**Space Solar Power with SunSynchronous Orbits**

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## ABSTRACT

The basic problem being addressed here is the high initial cost of solar power satellite (SPS) systems. The cost is higher for GEO orbits because of the large solar array and transmitter sizes required from that distance, and the expense of lifting such a mass into the higher orbits. Aperture size is proportional to the distance the power is beamed; thus transmitter apertures can be smaller when nearer to Earth.

Decreasing the distance energy must be beamed through space means that the powersat need not be so large, or as expensive. Implementation of sunsynchronous sunsats will likely be a more complex operation, but this limitation is lessened by the cost savings resulting from the smaller mass to be delivered to lower, more accessible orbits.

The development of an economically viable space energy system on a global basis is made more attainable using satellites equipped with equatorial orbiting reflectors for the sharing of energy. The development of wireless power transmission (WPT) is critical to the emergence of sustainable private and government space ventures, including space lift, space exploration and space development. The pursuit of space-based solar power in the lower orbits will greatly expand the need for space lift capability which will help to accelerate these developments.

Space Solar Power with SunSynchronous Orbits from Space Communication Journal on Vimeo.

## TECHNICAL BRIEF

This visualization illustrates a new architecture option for low Earth orbit (LEO) space-based solar power (SBSP) using wireless power transmission (WPT) and a space power relay (SPR) to provide energy to the Earth.

Like a polar orbit, satellites in Sun-synchronous orbit (SS-O) travel from the north to the south poles as the Earth turns below it. To keep pace with the Earth's revolution around the sun, the orbital plane of a sun-synchronous orbit must precess (rotate) approximately one degree each day, eastward. Sun-synchronous orbits are typically low Earth orbits (LEO) with altitudes of 550 to 850 km.

In a “dawn-to-dusk” orbit, the satellite trails the Earth's shadow. When the sun shines on one side of the Earth, it casts a shadow on the opposite side of the Earth. Because the satellite never moves into this shadow, the sun's light is always on it and its solar panels remain in the sun. The problem with using an SS-O PowerSat is the Earth’s rotation under it. The beam time to a ground rectenna will be very short.

The solution is a Space Power Relay (SPR) in which low mass reflector satellites -placed in a 4,000km Equatorial Medium Earth Orbit (EMEO) - reflect the power transmitted from the PowerSat to the rectenna on the Earth’s surface. In the SPR architecture, these satellites act as waveguides without converting the energy to direct DC current. Since the reflectors can be small, low mass inflatable structures, the design will be both efficient and low cost.

The Model: Radarsat is an example of a satellite operating in a low sun-synchronous orbit. As it circles the globe from pole-to-pole, Radarsat orbits at an altitude of 798 kilometers above Earth's surface and at an angle of inclination of 98.6 degrees relative to the Equator. Because of its trajectory, Radarsat can rely on its dawn-to-dusk orbit to keep its solar panels facing the sun, relying on constantly generated energy from the sun instead of energy that has been previously saved into batteries.

By using dawn-to-dusk orbiting satellites, similar levels of power can be produced as those of PowerSats located at geostationary orbits. This was an idea proposed by Peter Glazer in 1968 (1). Moreover, by locating a PowerSat in the SS-O (550 to 850km) it would be much closer to Earth than a PowerSat on GEO (31,000km), allowing for the use of much smaller transmitters and rectennas (2, 3) and reducing the amount of mass to be transported into space.


SunSynchronous Orbits Team at the International Space Development Conference in Huntsville AL in May 2011

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**BUSINESS PLAN**

The Economics of Sun-Synchronous Satellites

A comparison of SSP concepts dating back to the 1980s shows the mass problem related to SSP satellites in GEO (4,6,12,13,14). The transmitter mass problem for GEO PowerSats can be seen below.

NASA 1980 Option 1: 1x Concentration, 16% efficient PV, 5GW, Mass 51,000,000kg, Transmitter 13,000,000kg, Power 38,000,000kg

NASA 1980 Option 2: 2x Concentration, 20% efficient PV, 5GW, Mass 34,000,000kg, Transmitter 13,000,000kg, Power 21,000,000kg

ISC 1990: 4x Concentration, 20% efficient PV, 5GW, Mass 23,500,000kg, Transmitter 13,000,000kg Power 10,500,000kg

ISC 2010: 4x Concentration, 40% efficient PV, 5GW, Mass 18,250,000kg, Transmitter 13,000,000kg, Power 5,250,000kg

Notice that even when you double the efficiency of the power system by doubling the solar concentration or doubling the PV efficiency, or both, that the transmitter mass is still the same - 13 million kilograms for a 5GW transmitter.

To move the Integrated Symmetrical Concentrator (ISC) SSP design version with a total mass of 18,250,000kg into GEO would take 1,825,000kg of ion propellant (ion propellant mass 10% of payload mass). At $5,000 per kg to place this propellant into orbit, the cost would be $9,125,000,000. This is just for the propellant for the LEO to GEO trip and does not count the SSP satellite launch costs. For a 1GW system the cost would be $1,825,000,000 just to put the propellant into orbit.

To look at this in another way, let's remove the solar power system completely and just launch the transmitter, which would have a mass as indicated above of about 13,000,000kg. To launch this mass into LEO, at $5,000 per kg, would cost $65,000,000,000. For a 1GW system the cost would be $13,000,000,000. So the total cost to launch just the transmitter and the ion propellant would be about $14,825,000,000 for a 1GW system.

You still need to launch the power system. Using the ISC 2010 at 4x Concentration and 40% efficiency the estimated mass would be 5,250,000kg x $5,000 per kg for launch is $26,250,000,000 for the 5GW system and divide this by 5 for the 1GW system and we have $5,250,000,000.

The total cost is estimated at $19,775,000,000 just for launch costs. While nuclear power might cost $16 billion to produce equivalent energy, it has the advantage of deferring half the cost to the end. SSP does not have this advantage when interest must be paid on the full amount. Clearly, launch costs need to be reduced and there are two ways to do this. First, the cost of the launch vehicle can be reduced and this has been talked about constantly since 1968. The second option is to reduce the mass placed into orbit. This is more achievable because it can be accomplished by simply moving the PowerSat closer to earth.

Comparative Benefits: In comparison with proposed alternatives, the Space Grid approach has the potential to enable radical improvement in terms of higher performance, lower cost, less mass, higher reliability, improved safety, operational simplicity and ease of manufacturing.

For SSP, the dimensioning of the RF power transmission system results from an adequate balance between the definition and sizing of the receiver system (rectenna) and the definition of the SPS transmitting system, the key driver being the transmission frequency. For an SBSP system operating in SS-O and incorporating an SPG in equatorial orbit, the addition of the space-based microwave reflector has to be taken into consideration. The much smaller transmission distances means smaller transmitters and smaller rectenna, thereby increasing the economic viability of SS-O over concepts based in GEO.

Environmental Considerations: The space grid approach integrates the issues of global warming and energy demand with the technologies for space-based solar power and space power relay. Combined these two technologies offer a potential solution to an energy hungry planet.

When one consider that there are currently plans to build 50 new coal-fired electrical plants across Europe, dozens of new coal burning plants in China and several dozen new coal and natural gas burning plants across the US, the ability to generate clean energy in space and transfer to the Earth can play a major role in reducing Global Warming by reducing or eliminating the need for new CO2 producing power plants. There are over 49000 electric power plants in the world, generating a total of 2812 GW.

Power needs during emergencies, such as the ones in Japan and New Orleans might be better met by transporting lightweight deployable rectennas to these areas. Such rectenna are simple in function yet they can provide access to large amount of energy directed it to by the Space Grid.

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