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# ORBITAL SPACE SOLAR POWER OPTION FOR A LUNAR VILLAGE

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**Abstract**: The international community is increasingly interested in returning humans to the Moon and this time establishing a permanent lunar base. There are several system level constraints that will drive the location for the base, chief among which are the need for continuous power and communications with the Earth. The NASA George C. Marshall Space Flight Center (MSFC) performed a study of placing an operational space based solar power station in lunar orbit to beam energy to the lunar base, or village, eliminating the need for the base to be located at the south pole or for it to be equipped with a fission power source.

**Keywords:** Space Exploration, Moon Exploration, Space Solar Power

## 1. INTRODUCTION

One of the most significant challenges to the implementation of a continuously manned lunar base is power. During the lunar day (14 Earth days), it is conceptually simple to deploy solar arrays to generate the estimated 35 kilowatts of continuous power required. However, generating this level of power during the lunar night (also 14 Earth days) has been an extremely difficult problem to solve. Conventional solutions range from requiring that the base be located at the lunar south pole so as to take advantage of the continuous sunshine available there to developing a space-qualified nuclear reactor and power plant to generate the needed energy. There is a third option: use the soon-to-be-available Space Launch System to place a space based solar power station in lunar orbit that would beam the needed energy to the lunar base.

Several detailed studies of have been performed by NASA, universities and others looking at the lunar south pole for locating a base. The results are encouraging: by taking advantage of the moon's orbital tilt, large solar arrays can be deployed there to track the sun continuously and generate the power needed to sustain human presence. The problem with this approach is inherent to its design: it will only work at the lunar south pole. There is no other site on the Moon with geometry favorable to generating continuous solar power.

NASA has also considered the development of a compact fission reactor and power plant to generate the needed power, allowing the base to be sited anywhere on the Moon. The problem with this approach is that there are no space fission reactors available, none are being planned and the cost of developing one may be prohibitively expensive.

Using an orbiting space based solar power station to generate electrical power and beam it to a base sited anywhere on the moon should therefore be considered. The technology to collect sunlight, generate greater than the estimated 35 kilowatts of required power, and beam it to the surface using microwaves is available today. The problem with this concept in the past would have been the mass and packaging volume (for launch) required to put such a system in place in lunar orbit. This problem is potentially solved with the advent of the Space Launch System (SLS). The SLS, with its 105 mT launch capacity, it more than capable of placing such a system into lunar orbit in a single launch.

This paper will examine the potential use of an SLS-launched, space solar power system in lunar orbit as the primary power source for a first-generation, continuously-occupied lunar base and compare it with the other power generation and storage options previously considered.

## 2. THE POWER REQUIREMENTS FOR A LUNAR VILLAGE

### 2.1. Lunar Bases

The idea of a continuously occupied lunar base is not new. Before the Apollo astronauts walked on the Moon in 1969, scientists, engineers and visionaries envisioned bases, villages and even cities being built on the Moon. [1] As the reality and complexity of space travel became apparent, the ambitions for cities on the Moon waned, but the call for a permanently occupied lunar base remained high. For half a century, people have been looking at the engineering options for establishing such a base and the technological requirements for making it happen.

### 2.2 The Surface Solar Power Option

Focusing on the power system requirements, a base supporting even a small crew (<10) will require a minimum of 35 kilowatts of continuous power. The obvious technical solution to provide power for a lunar base is solar energy. Solar arrays provide the power require for our first continuously occupied base in space, the International Space Station and, with essentially the same solar flux at the Moon, we have the technology today to develop and deploy solar panels on the lunar surface large enough to provide the power required.

During the 14-earth-day lunar day, this should be an easy requirement to fulfil from just about any location on the Moon. However, the 14-earth-day lunar night will be a significant challenge. There is no current or envisioned technology that will be able to store and provide this amount of power for such a long period of time. And, without power, the base would soon become uninhabitable.

Due to its axial tilt, the only location on the Moon with continuous solar power availability is the south pole. With the Sun perpetually on the horizon, a solar array gimbaled to track the Sun as the Moon slowly rotates should be relatively easy to build. Unfortunately, the lunar south pole is the only location with this continuously available solar power. This south polar preference, for the sake of power, has been known for nearly one hundred years. Robert Goddard in 1920 wrote, “The best location on the Moon [for a base] would be at the north or south pole with the [propellant] liquefier in the crater, from which the water of crystallization may not have evaporated, *and with the [solar] power plan on a summit constantly exposed to the Sun.*” (Italics mine.) [2]

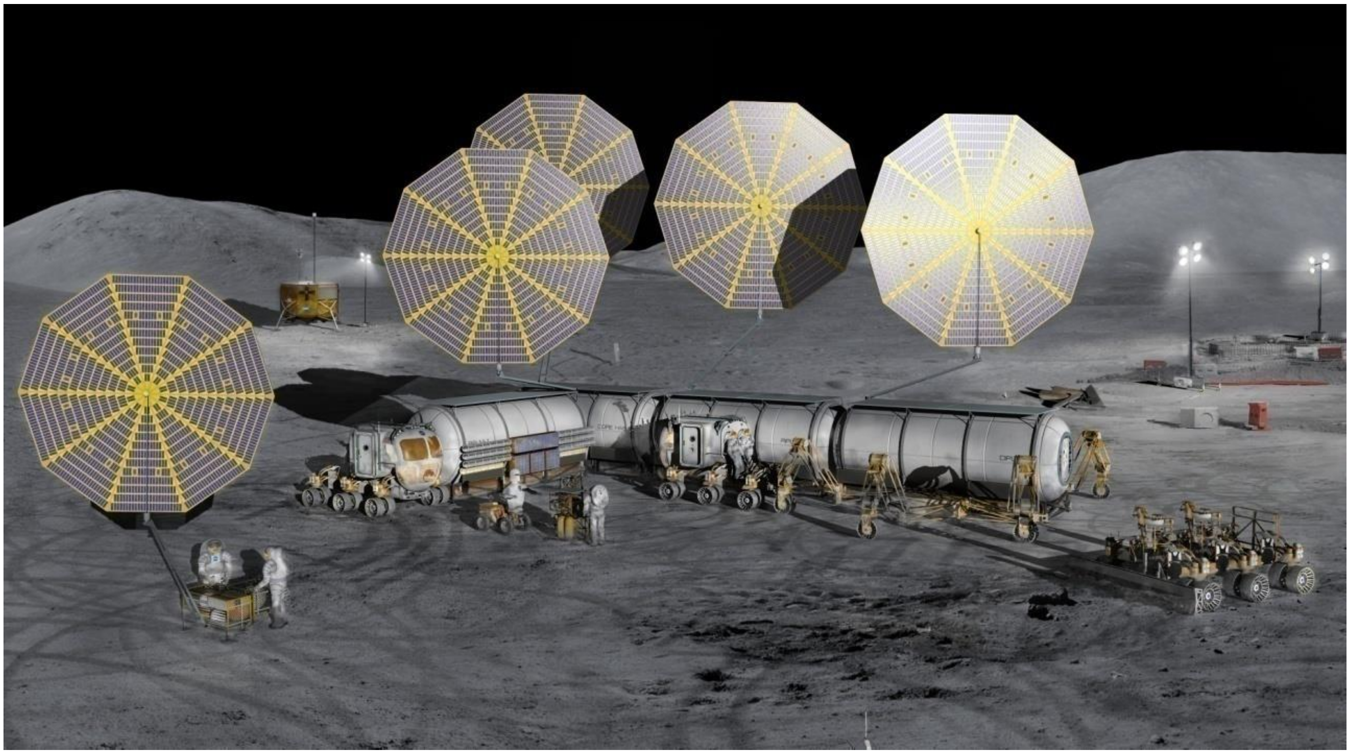

**Fig.1. Artist concept of a base at the lunar south pole with articulated solar arrays to generate power for the base. (NASA Illustration)**

There are many other regions of the Moon that are desirable for a base, for reasons other than the availability of power, and it would be best to find a power solution that would allow the village to be established anywhere on the Moon.

**2.2. The Nuclear Power Option**

Nuclear (fission) power is another option that is being considered to power the lunar village. Compact fission reactors are commonly used on Earth to power systems with similar requirements, such as submarines and aircraft carriers. While the reactor designs must, by virtue of their operating environments, be different, they are nonetheless similar in size and power generation capability and provide an existence proof the useful, small fission power reactors can be built. The reactor concept shown in Figure 2, shows a 15 metric ton power system designed to produce 50 kilowatts of continuous power at the Moon. [3]

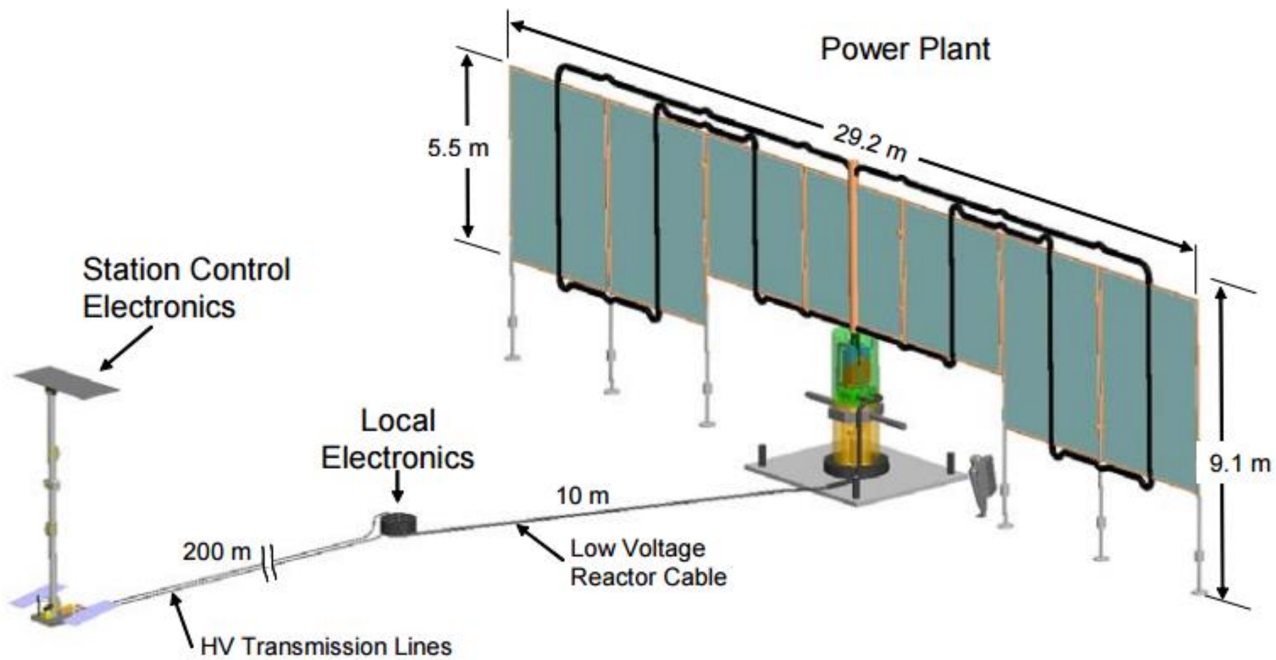


**Fig. 2. A notional layout of a lunar surface fission power plant. Shown above the astronaut are the reactor's radiators. (NASA illustration)**

The issues associated with using a nuclear system are many, and include:

1. Safety – Can the reactor be placed near the base (which needs the power) yet is safe from radiation produced by the nuclear power source. Mitigation options exist, and include placing the reactor far from the base, behind massive objects to attenuate any radiation leakage, or behind or under artificial shielding.
2. Cost – The US hasn't flown a space nuclear power system since the 1960s. [5] Recent projects to develop space nuclear power sources resulted in systems that would cost upward of $5B to develop.
3. Political – Objections to nuclear power, any nuclear power, are many and entrenched.

None of these are insurmountable, but, taken together, they may prevent the use of fission power source for any near- to mid-term lunar base.

## 3. A SPACE SOLAR POWER OPTION

There is another approach to solar power they may provide a versatile, relatively low-cost alternative to surface fission power: space based solar power in lunar orbit.

NASA is developing the Space Launch System (SLS), which will fly as early as 2019. [4] The SLS will have the capability to place 70 metric tons to Low Earth Orbit (LEO) in its Block 1 configuration and upwards of 130 metric tons in Block 2. Using a single launch of the Block 1B SLS configuration, a self-contained space solar power station could be placed into lunar orbit to provide near-continuous power for a lunar base located anywhere on the Moon.

The power system would use 12 deployable solar collectors measuring approximately 14 meters by 28 meters (deployed) to focus sunlight and generate the heat used by 3 100 kilowatt Brayton Cycle engines to generate electrical power. The power would be beamed to the lunar surface using microwaves via an 85 meter diameter transmission antenna. The study assumed 200 Ghz transmitters for their higher transmission efficiency. The lunar surface rectenna would measure 200 square meters and capable of converting the microwave energy into electricity for the base.

The power station would be placed in a 3,000 kilometer lunar polar orbit that would allow a two-hour energy transmission window to the base every eight hours (figure 3).

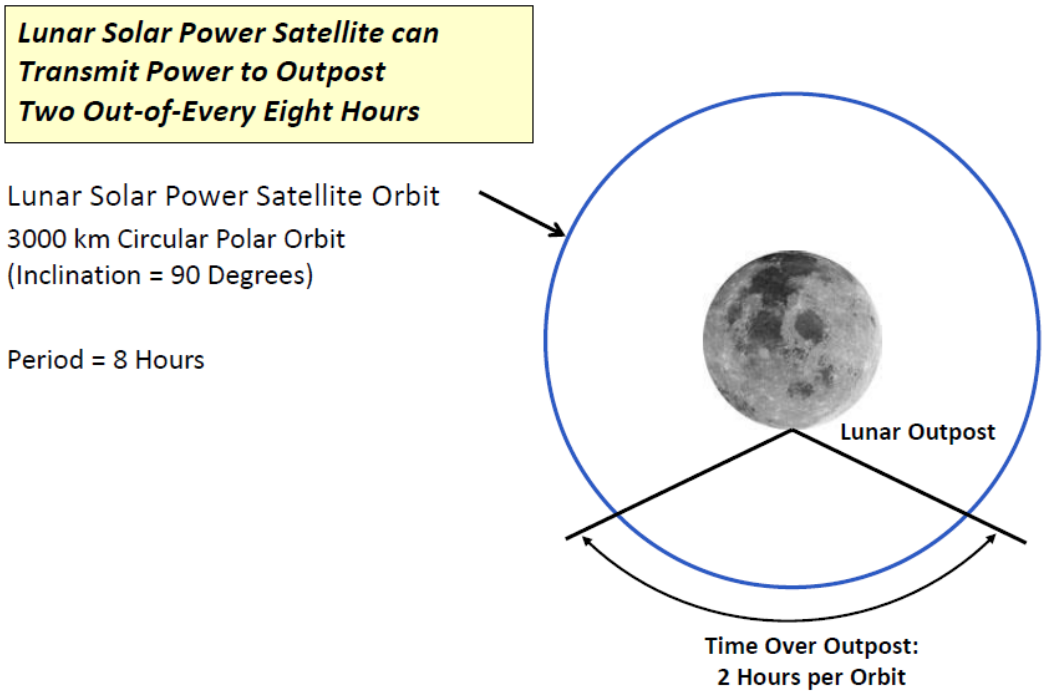


**Fig. 3. A space solar power station in a lunar polar orbit could transmit power to the Lunar Village during a 2-hour window every 8 hours.**

The power station would be folded to fit into the SLS's fairing and deployed once it reaches lunar orbit (figures 4 and 5).

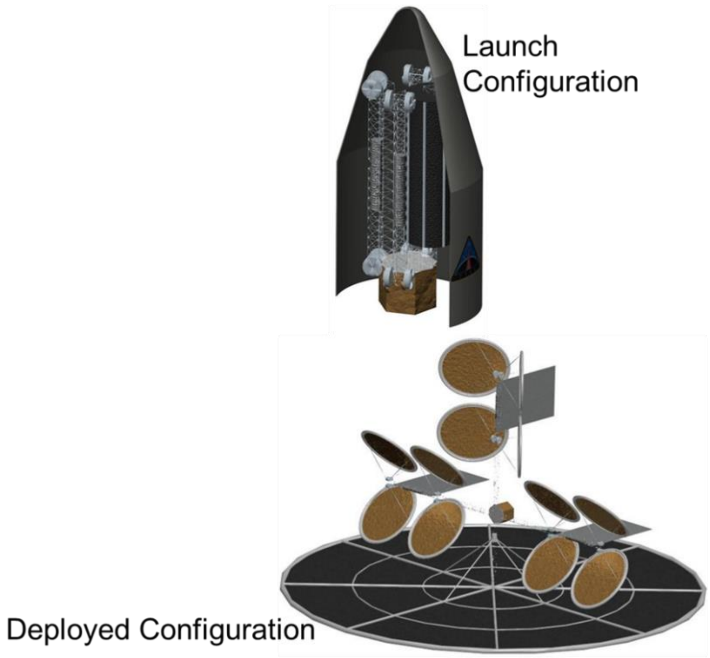


**Fig. 4. The lunar space solar power station can be stowed in the SLS launch fairing and deployed once it reaches lunar orbit. The stowed configuration is shown on top; the fully deployed configuration is on the bottom of the figure.**

The overall end-to-end power collection to power-delivered system concept is illustrated in Figure 5 and the mass breakdown for the system is listed in Table 1. The power conversion system is assumed to be a 100 kilowatt Brayton cycle engine with the state-of-the-art systems currently tested operating at under 10 kilowatts.

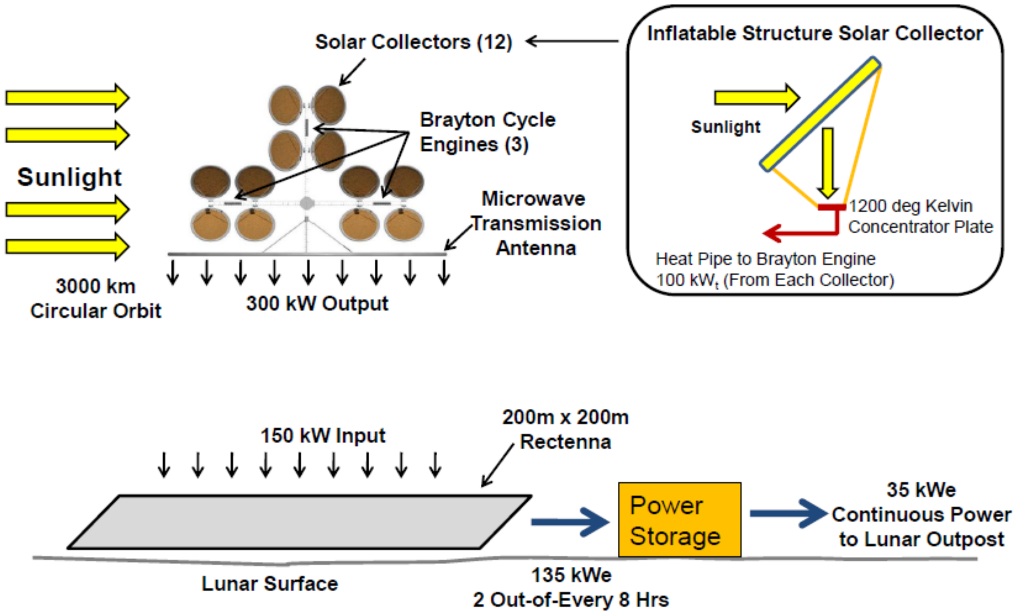


**Fig. 5. A lunar space solar power station would convert sunlight to microwaves for beaming to the lunar surface where the microwaves are then converted back into electricity for use at the lunar base.**

**Table 1. The high level mass budget for the solar power satellite system, including a 30% contingency.**

| System | Qty | Mass (kg) | Power (kW) | Area ($M^2$) | Mass Total (kg) | Mass w 30 % Cont. (kg) |
|---|---|---|---|---|---|---|
| **Thermal** | | | | | | |
| Brayton engine | 3 | 600 | 400 kW ea | 1 per truss | 1800 | 2340 |
| Heat pipes | 3 | 270 | 100 kW ea | 4 per truss | 810 | 1053 |
| Radiators Brayton | 3 | 3165 | | 161 $m^2$ ea | 9495 | 12343.5 |
| | | | | | | |
| Radiators PMAD | 0 | 0 | | | 0 | 0 |
| Radiators ACS | 0 | 0 | | | 0 | 0 |
| | | 4035 | | | | |
| **PowMan&Dist (PMAD)** | | | | | | |
| Collector | 12 | 100 | | | 1200 | 1560 |
| Collector plate | 12 | 10 | | | 120 | 156 |
| | | 110 | | | | |
| Solar panel (SP) | 0 | 0 | | | 0 | 0 |
| Power cables | 3 | 130 | | | 390 | 507 |
| Battery | 2 | 50 | | | 100 | 130 |
| μwave convertor | 1 | 7500 | | | 7500 | 9750 |
| Transmitter antenna | 1 | 5550 | | 84 m dia | 5550 | 7215 |
| Antenna deployment | 1 | 400 | | | 400 | 520 |
| | | 13450 | | | | |
| **Attitude Cont Sys (ACS)** | | | | | | |
| CMGs | 4 | 100 | | | 400 | 520 |
| Propulsion | 1 | 350 | | | 350 | 455 |
| **Comm & Data Sys (CDS)** | 1 | 100 | | | 100 | 130 |
| | | | | | | |
| **Structures** | | | | | | |
| Solar trusses | 3 | 930 | | | 2790 | 3627 |
| Bus | 1 | 2400 | | | 2400 | 3120 |
| | | | | | | |
| **Totals** | | | | | **33405** | **43426.5** |

## 4. CONCLUSIONS

There is no doubt that humanity will one day soon establish a permanently inhabited lunar base. The question is only a matter of time and, of course, money. There are many technical issues to be resolved to make the base possible and viable, chief among which is power. Given the length of the solar night, lunar surface based solar power will not be sufficient to meet the power needs of the base unless it is located near the lunar south pole. Nuclear fission power could meet the power demands of the base and allow it to be emplaced anywhere lunar surface. While the nuclear solution is certainly physically possible, it will be expensive and politically sensitive. Another option, one that takes advantage of the soon-to-be-demonstrated SLS rocket, will make it possible to deploy into lunar orbit a space solar power station that could meet the power needs of the lunar base not matter where it is located on the lunar surface and do so affordably.

## ACKNOWLEDGEMENTS

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