Photovoltaics Using In Situ Resource Utilization for HEDS

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Abstract

One of the most important elements of a human planetary base is power production. Lunar data make it clear that several types of solar-to-electric converters can be manufactured on the Moon. Materials research and processing demonstrations are suggested that can be carried out on Earth, the Space Transportation System (STS), the International Space Station (ISS), and on the Moon to advance the *in situ* production of solar-to-electric power systems on the Moon. Many of the technologies will be applicable to Mars, the silicate moons, and asteroids.

Introduction

One of the most important elements of a human planetary base is the production of electrical power. Reliable and dependable load-following power is essential for life-support, communications, transportation, and many other base functions. However, building a power system on Earth and delivering it to a planetary base significantly increases the scale of the mission. Also, the deployed power system can not be increased in capacity to allow for changing mission needs nor degradation of performance. Permanent bases on the Moon, Mars, and even the silicate moons and asteroids will be much less expensive and far more robust if the solar power systems can be made predominantly of natural planetary resources. *In situ* production of power systems is an enabling technology.

Lunar samples and geophysical measurements returned by the Apollo missions provide detailed data on the composition and physical characteristics of the lunar materials and environment. Based on this knowledge and extrapolations of terrestrial industrial experience it is clear that several types of solar-to-electric converters can be manufactured on the Moon. It is conceivable that well over 90% of a solar-to-electric power system could be made from lunar material (NASA 1982).

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Figure 1 illustrates one concept for a permanent base on the Moon that supports the construction of a power system to supply commercial solar-electric energy to Earth by low-intensity microwave beams (Criswell 1996).

Figure 1. Lunar Solar Power System

The Lunar Solar Power (LSP) System's fundamental unit is the power plot depicted in the lower right. A full system producing commercial quantities of power for use on Earth requires tens to hundreds of thousands of power plots. A power plot consists of: a microwave reflector - the upright screen; a field of solar cells - in front of the reflector; and a set of microwave transmitters - under the mound beyond the solar array. Apollo data and studies of building solar power satellites primarily from lunar materials support the concept that solar cells can be made on the Moon from lunar derived materials (NASA 1989). Manufacturing power units on the Moon, note the production machinery, from lunar materials decrease the amount of mass that must be transported to the Moon by at least a factor of 50 and potentially much more.

Studies predict that utilizing conventional processes the lunar surface could produce more than 20,000 GWe power to the Earth by microwave and generate an income exceeding 10 trillion dollars per year (Criswell and Waldron 1992). However, the predicted financial "break-even" for solar energy production is projected to require LSP Systems with power capacities as high as 10 Giga Watt electric (GWe) to 100 GWe for present construction and operating technologies. The power needs of initial scientific outposts on the Moon or Mars can be accommodated by the power output of a few tens of power plots such as depicted in Figure 1.

Photovoltaic Cell Production Challenges and Experiments

Several types of solar-to-electric converters can be manufactured on the Moon using silicon refined from lunar materials. Silicon based solar cells using bulk crystal, polycrystalline thin film, and amorphous thin film technology have been suggested. Thin film materials are inherently radiation tolerant (Landis 1990) and require only a small amount, 0.5 -25 mm, of intrinsic Silicon. The lunar vacuum, expected to be in the less than 10-9 torr, will be adequate to process photovoltaic silicon films (Landis 1989). Metals extracted from the lunar or Martian soil can be utilized as substrates (Fang 1988) and conductors.

Research should be encouraged on innovative technologies which can reduce the transport weight of the extractive and fabrication technologies used for *in situ* production of solar power systems. Growing power systems enable the expansion of lunar and Martian planetary bases. New methods of resource extraction (Curreri 1993) are possible utilizing the lunar vacuum that could greatly reduce transport weight. Research should also focus on simplifying processing procedures for example by using back contact cell design (Sinton and Swanson 1990), laser cut junction isolation (Micheels and Valdivia 1990), or ion implantation doping procedures (Bentini et al. 1982).

Conclusions

Studies show that silicon based photovoltaic systems can be produced on the Moon utilizing about 90% by weight *in situ* lunar materials. Similar processes can be utilized on Mars or the silicate moons. The utilization of *in situ* resources greatly reduces the transport weight and thus the cost of Lunar Surface Power facilities. A system could be developed that could supply all the Earth's projected energy needs and generate revenues of over 10 trillion dollars annually. However, as currently envisioned, the weight "break-even" would occur for power production scales far greater than that needed for initial lunar or Mars outposts. As part of the NASA program for the Human Exploration and Development of Space (HEDS) research should be done to prove the concepts needed to develop commercial power from the Moon and to provide innovative techniques that might reduce transport weight for the machinery required for extraction of minerals from *in situ* materials, the production of solar power systems, and for the maintenance of *in situ* planetary energy systems. Such research and development would expedite the establishment of human bases throughout the solar system.

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