Solar Cell and Array Technology Development for NASA Solar Electric Propulsion Missions

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ABSTRACT

NASA is currently developing advanced solar cell and solar array technologies to support future exploration activities. These advanced photovoltaic technology development efforts are needed to enable very large (multi-hundred kilowatt) power systems that must be compatible with solar electric propulsion (SEP) missions. The technology being developed must address a wide variety of requirements and cover the necessary advances in solar cell, blanket integration, and large solar array structures that are needed for this class of missions. This paper will summarize NASA's plans for high power SEP missions, initial mission studies and power system requirements, plans for advanced photovoltaic technology development, and the status of specific cell and array technology development and testing that have already been conducted.

INTRODUCTION

One of the roles for the Photovoltaic and Power Technologies Branch at the NASA Glenn Research Center (GRC) is to develop the photovoltaic technology necessary to support the wide variety of requirements associated with solar system exploration. Working with NASA Langley Research Center, with expertise in large space structures and mechanisms, and other organizations at NASA GRC the technology necessary for very high power solar arrays is being assessed. As NASA further defines the need for new capabilities for future human space exploration missions, NASA's role is to identify and develop advanced solar cell and array technologies in support of these efforts. NASA's Human Spaceflight Architecture Team (HAT) has identified high power solar electric propulsion (SEP) systems as a critical element for future exploration activities to near Earth asteroids and similar long-range destinations because they can reduce the number of required heavy lift launches and thus substantially reduce mission costs [1]. Advanced solar arrays for these SEP elements will be required to produce power levels roughly an order of magnitude greater than those provided by current spacecraft and must possess a number of features such as autonomous deployment, low stowed volume, adequate structural stiffness, and low-cost manufacturability.

NASA MISSION REQUIREMENTS AND INITIAL STUDIES

Advanced photovoltaic technology development efforts to support this new class of missions are managed through the Space Power Systems (SPS) project in NASA's Space Technology Mission Directorate. This work aims to provide the abundant power necessary for vehicle operations, electric propulsion systems, and on location power through improvements to solar array structures and components and reductions in overall system cost. The array technology developed must be robust enough to survive the space environment while maintaining a reasonable cost. Technology development areas that can lead to cost reduction include lower manufacturing costs, innovative blanket and encapsulate materials, and modularizing cell and blanket components that are not mission specific. Additionally, developments in ground testing techniques could reduce overall array costs. Any developments made must also address a potential manufacturing issue since an array of this size would significantly distort annual U.S. solar cell production.

As a basis for this work a mission scenario is proposed that involves a piloted trip to a near Earth asteroid. The following assumptions were made concerning the mission power requirements. The basic spacecraft will be a nominal 300kW solar electric vehicle. The array will have to be designed to avoid the plume of the electric propulsion drive (see Fig. 1). The array must be capable of 400kW nominal beginning-of-life power. The operating voltage is nominally set at 300 V. The solar cell type used for the model was of the inverted metamorphic multijunction (IMM) variety. The complete mission parameters were input into a case study with the Collaborative Modeling for Parametric Assessment for Space Systems (COMPASS) group at NASA GRC [2]. The case study included the system power of 300 kW along with 15 kW for the payload and 5 kW for housekeeping. Additionally the spacecraft array would need to withstand cryogenic kickstage propulsive maneuvers of up to 0.1g steady state acceleration longitudinally, and docking event loading of up to 0.02g longitudinally and 0.01g transverse.

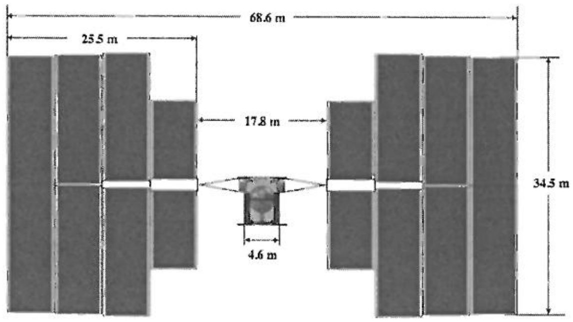

Figure 1 HAT nominal design for a 300kW SEP sized array.

The COMPASS team findings showed that with improvements in array structures and lightweight solar cells, the mission could be successfully deployed using the assumed launch technology. A key factor to reaching the mass requirements for launch was the mass savings benefit from having a 300 V spacecraft bus versus the conventional 120 V bus. A reduction in mass also occurs when cell efficiency increases but this is minor compared to overall system mass. It was shown that a lightweight cell with efficiency greater than 29% would be sufficient. An interesting finding was that solar cell costs account for over half of the recurring costs (see Fig. 2). The model assumed a rolled array structure but other designs could also work successfully and are being investigated.

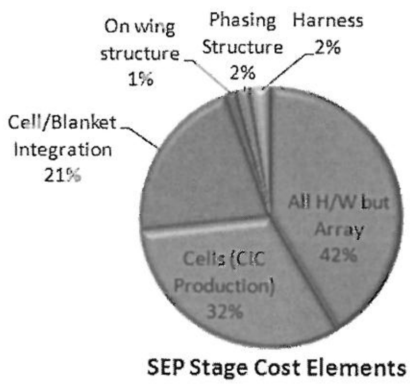

Figure 2 Flight hardware costs for a notional 300kW SEP stage as determined by COMPASS study. The cells and blanket integration account for >50% of the total cost.

SOLAR CELL & ARRAY TECHNOLOGY DEVELOPMENT EFFORTS

The Space Power Systems project, taking into account the results of the previous studies, has developed a plan to identify the solar cell and array technology necessary to support very high power SEP missions. These needs include the following areas of high importance. A flexible blanket assembly must be designed, developed, and validated with emphasis on modularity and affordability. Array technologies suitable for 300kW-class SEP stages must also be designed, developed, and validated. The mass savings benefits identified by operating at a high solar array bus voltage will likely require developments in cell/interconnect/coverglass (CIC) and cell/blanket technologies capable of reliable, long-lived operation within a variety of space environments. The development of these technologies would have application for a variety of missions, including 10-100kW class missions like the cryogenic propulsion stage, a deep space habitat, space exploration vehicles, and surface power systems.

The Space Power Systems project is a multiyear effort with a variety of tasks designed to either show readiness of solar array technologies or to identify areas needing additional research prior to flight. Figure 3 illustrates the

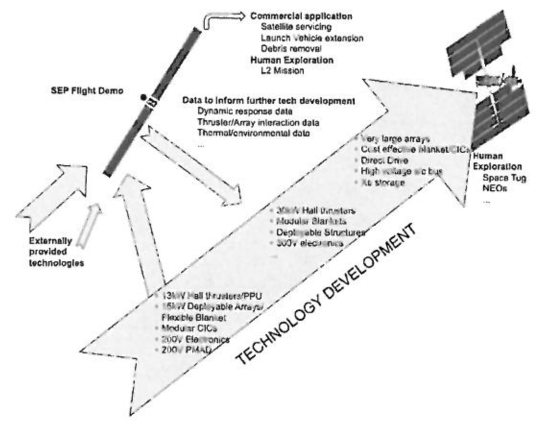

Figure 3 Power system and solar array technology development emphasis leading to operational solar electric propulsion vehicles for NASA Exploration Missions.

	Mass with Growth (Kg)			
Cell Efficiency	29%	33%	35%	37%
Battery System				
Battery Assembly-Secondary	163	163	163	163
Power Management & Distribution				
High Voltage PDU	181	181	181	181
Low Voltage PDU	62	62	62	62
DC - DC Converter	107	107	107	107
Array Regulator	373	373	373	373
Solar Array Power System				
PV Blanket	1461	1279	1160	1070
On wing structure	369	304	266	240
Phasing Structure	356	356	356	356
Harness	262	227	217	199
Power Cable and Harness Subsystem				
Spacecraft Bus Harness	280	278	278	277
Total Power System Mass (kg)	**3,614**	**3,329**	**3,163**	**3,028**
TOTAL SEP WET MASS (kg)	**46,788**	**46,361**	**46,112**	**45,909**

Table 1 Power System Metrics as a Function of Solar Cell Efficiency.

power system and solar cell/array development priorities currently identified as necessary to support a high power solar electric propulsion mission. The chart shows how the cell and array technologies being developed feed into the final SEP design, as well as how they might feed into a demonstration mission conducted prior to the operational mission. Some of the specific key requirements that are noted include flexible, low mass blanket technology for low stowed volume, modularity to reduce cost, high operational voltage solar array circuit and components, and large reliably deployable array structures. Solar cell efficiency, as it relates to reduced array size and mass, is also important. Table 1 quantitatively illustrates how solar cell efficiency affects power system metrics. While cell efficiency drives the overall size of the array, other factors such as component cost, reliability, and manufacturability are also critical to mission success and viability. As noted in the COMPASS studies referenced earlier in this abstract, the initial SEP design reference can be accomplished with a solar cell efficiency of 29%, given that the cell technology is low mass and amenable to advanced flexible blanket solar array designs.

In an effort to "jump-start" technology development in areas identified as critical, the SPS project office has initiated R&D activities in a variety of advanced solar cell and array components and systems. These R&D activities run the range from large, lightweight deployable structures to advanced cell and cell/blanket integration efforts. The goals of these individual projects are to improve overall array performance, while still focusing on cost reduction, reliability, manufacturability, and modularity. This paper will address specifics on the photovoltaic technology development activities currently being evaluated, provide results on the latest accomplishments for these efforts, discuss their potential impact on NASA mission success, and provide an update on possible future opportunities for further technology development.

SUMMARY

NASA is currently developing advanced solar cell and solar array technologies to support very large, multi-hundred kilowatt power systems for future NASA solar electric propulsion Exploration missions. Initial studies have shown that while such missions "push the envelope" of state-of-the-art space photovoltaic technology, investment in critical solar cell and array technologies can lead to a viable path for successfully developing the technologies necessary to accomplish these missions. Technology development activities are currently underway that address some of the critical issues that have been identified. This paper will summarize NASA's plans for high power SEP missions, the results of initial mission studies, power system requirements that have been identified, plans for further advanced photovoltaic technology development, and the status of specific cell and array technology development and testing that have been conducted to date.

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