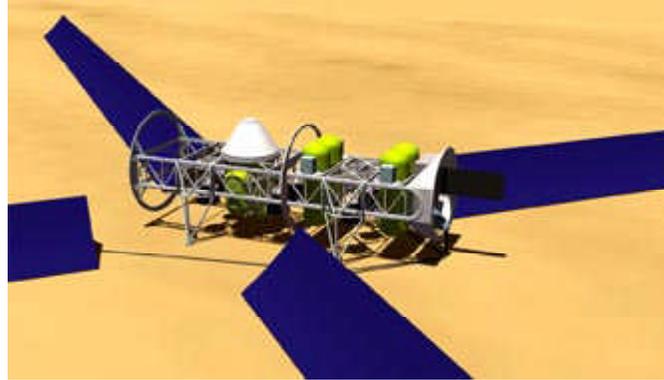


# Solar Power System Evaluated for the Human Exploration of Mars

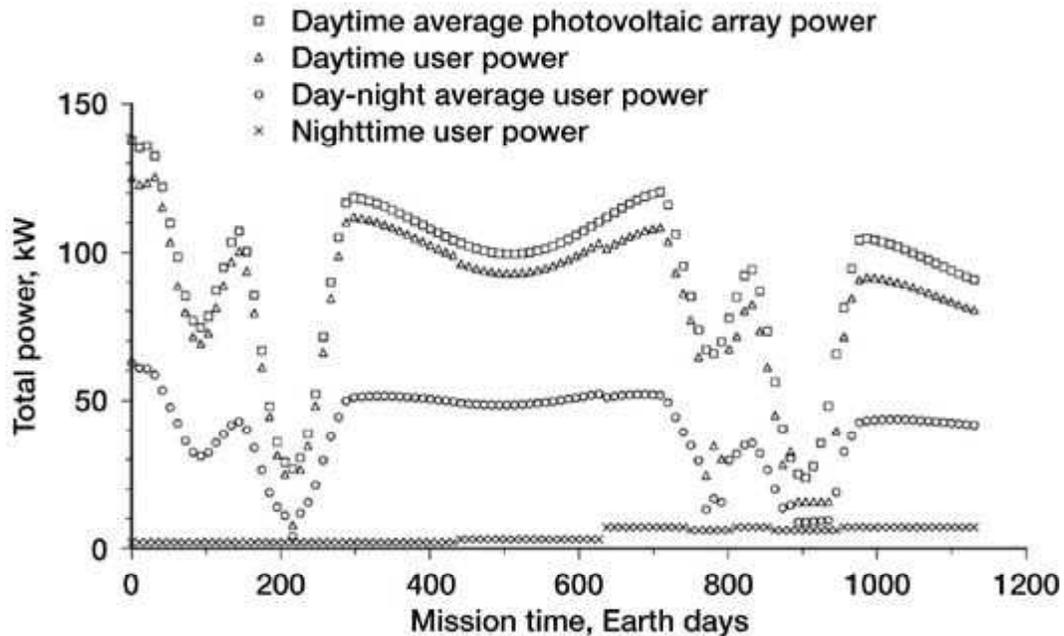


*Mars surface photovoltaic-regenerative fuel cell power system.*

The electric power system is a crucial element of any mission for the human exploration of the Martian surface. The bulk of the power generated will be delivered to crew life-support systems, extravehicular activity suits, robotic vehicles, and predeployed in situ resource utilization (ISRU) equipment. In one mission scenario, before the crew departs for Mars, the ISRU plant operates for 435 days producing liquefied methane and oxygen for ascent-stage propellants and water for crew life support. About 200 days after ISRU production is completed, the crew arrives for a 500-day surface stay. In this scenario, the power system must operate for a total of 1130 days (equivalent to 1100 Martian "sols"), providing 400 MW-hr of energy to the ISRU plant and up to 18 kW of daytime user power.

A photovoltaic power-generation system with regenerative fuel cell (RFC) energy storage has been under study at the NASA Glenn Research Center at Lewis Field (ref. 1). The conceptual power system (shown in the preceding illustration) is dominated by the 4000-m<sup>2</sup> class photovoltaic array that is deployed orthogonally as four tent structures, each approximately 5 m on a side and 100-m long. The structures are composed of composite members deployed by an articulating mast, an inflatable boom, or rover vehicles, and are subsequently anchored to the ground. Array panels consist of thin polymer membranes with thin-film solar cells. The array is divided into eight independent electrical sections with solar cell strings operating at 600 V. Energy storage is provided by regenerative fuel cells based on hydrogen-oxygen proton exchange membrane technology. Hydrogen and oxygen reactants are stored in gaseous form at 3000 psi, and the water produced is stored at 14.7 psi. The fuel cell operating temperature is maintained by a 40-m<sup>2</sup> deployable pumped-fluid loop radiator that uses water as the working fluid. The power management and distribution (PMAD) architecture features eight independent, regulated 600-Vdc channels. Power management and distribution power cables use various gauges of copper conductors with ethylene tetrafluoroethylene insulation.

To assess power system design options and sizing, we developed a dedicated Fortran code to predict detailed power system performance and estimate system mass. This code also modeled the requisite Mars surface environments: solar insolation, Sun angles, dust storms, dust deposition, and thermal and ultraviolet radiation. Using this code, trade studies were performed to assess performance and mass sensitivities to power system design parameters (photovoltaic array geometry and orientation) and mission parameters (landing date and landing site latitude, terrain slope, and dust storm activity).



*Mission power profile.*

Mission analysis cases were also run. Power results are shown in this graph for an analysis case with a September 1, 2012, landing date; 18.95° North latitude landing site; two seasonal dust storms; and tent arrays. To meet user load requirements and the ISRU energy requirement, an 8-metric ton (MT) power system and 4000-m<sup>2</sup> photovoltaic array area were required for the assumed advanced CuInS<sub>2</sub> thin-film solar cell technology. In this figure, the top curve is the average daytime photovoltaic array power, the middle curve is average daytime user load power, and the bottom curve is nighttime power. At mission day 1, daytime user power exceeds 120 kW before falling off to 80 kW at the end of the mission. Throughout the mission, nighttime user power is set to the nighttime power requirement. In this analysis, "nighttime" is defined as the 13- to 15-hr period when array power output is below the daytime power requirement. During dust storms, power system capability falls off dramatically so that by mission day 900, a daily energy balance cannot be maintained. Under these conditions, the ISRU plant is placed in standby mode, and the regenerative fuel cell energy storage is gradually discharged to meet user loads.

## References

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