SOLAR CELL PRODUCTION CAPACITY ON THE MARTIAN SURFACE.
A.J. Abel, A. J. Berlinger, M. Mirkovic, W. D. Collins, A. P. Arkin, and D. S. Clark

Center for the Utilization of Biological Engineering in Space (CUBES), Department of Chemical and Biomolecular Engineering, University of California, Berkeley, CA 94720, USA. Department of Bioengineering, University of California, Berkeley, CA 94720, USA. Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, CA 94720, USA. Climate and Ecosystems Sciences Division, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, USA. Department of Earth and Planetary Sciences, University of California, Berkeley, CA 94720, USA. Environmental Genomics and Systems Biology Division, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, USA. Molecular Biophysics and Integrated Bioimaging Division, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, USA

Introduction: Photovoltaic (PV) and photoelectrochemical (PEC) devices could be used to produce electricity and commodity chemicals necessary to sustain human life on Mars using in situ resources. Because life support systems require robust operation, understanding device performance is critical to determining the feasibility of solar-powered manufacturing at candidate landing sites. Solar cell device production limits are not well characterized on the Martian surface, mainly due to differences in the surface temperature and solar intensity and spectrum from typical conditions on Earth or in space. Here, we integrate relevant climate data from the Mars Climate Database [1] with a radiative transfer model, libRadtran [2], to predict spectrally-resolved solar flux across the Martian surface over the course of a Martian year. We use this result to inform detailed balance calculations for PV and PEC devices producing electricity, hydrogen, ammonia, and acetic acid. These products were selected to represent simple precursor chemicals necessary to support power systems, agriculture, and manufacturing. We determine optimal solar device performance and best-possible production rates across the Martian surface and provide design guidelines for semiconductor band gap engineering. Finally, we compare production capacity to estimated demand from established reference mission architectures to determine the solar cell array size necessary to support a six-person mission. Our results compare favorably to both established and speculative power technologies.

Methods: We use a detailed balance model [3] to calculate the power conversion efficiency of single gap and two- and three-gap tandem solar conversion devices. Power conversion efficiency is written as:

\[ \eta_{PV} = \frac{J \cdot V}{P_{sun}} \]

for a PV device, and:

\[ \eta_{PEC} = \frac{J \cdot E_{redox}}{P_{sun}} \]

for a PEC device, where \( J \) is the current density, \( V \) is the operating voltage, and \( P_{sun} \) is the solar intensity incident on the device surface. The current density, \( J \), is calculated according to the assumptions of the detailed balance model: all photons with energy greater than the absorption threshold (band gap) are absorbed, the quasi-Fermi level separation is constant and equal to \( V \) across the device (infinite carrier mobility), and only carriers recombine only via radiative recombination [4]. For PEC devices, the solar cell must achieve a minimum voltage greater than \( E_{redox} + V_0 \), where \( E_{redox} \) is the redox potential of the chemical reaction driven by the cell, and \( V_0 \) is the overvoltage losses associated with electrode kinetics and solution polarization in the electrochemical reactor.

Sunlight incident on the surface (\( P_{sun} \)) is mediated by atmospheric particles including gases, ice, and dust. Using the Mars Climate Database, we track the concentration and particle size of these species across the Martian surface for a variety of climate scenarios, including average and heavy dust conditions corresponding to a planet-wide dust storm. We calculate the wavelength-resolved optical depth, given by:

\[ \tau(\lambda) = \tau_g(\lambda) + \tau_d(\lambda) + \tau_{redox}(\lambda) \]

using libRadtran software which considers both absorption due to molecular composition and scattering events approximated by Rayleigh or Mie equations depending on the effective particle size.

Results: Figure 1 shows the and limiting efficiency of a two-gap tandem PV (a) and PEC (b) device using the average solar flux at noon at Jezero Crater over the course of an average Martian year. The PEC device is calculated assuming \( H_2 \) production from water splitting with 700 mV overvoltage, which is typical for state-of-the-art systems [5]. Optimal band gaps are 5–10% from those for terrestrial systems [4,5], emphasizing the importance of responsive design to Mars.

We determine optimal band gaps for best-possible power and chemical production by integrating device performance over the course of a Martian year, and compare this result to demand estimated from established six-person reference mission architectures. From this analysis, we show that solar cells can readily
support life support systems for human missions to Mars. For example, at Jezero Crater, we estimate that a ~2800 m² solar array (7–8 tons) would meet demand with an additional 50% tolerance for power, representing only 2–8% of the total estimated mass required for a human mission to Mars.

**Figure 1.** Power conversion efficiency for PV (A) and PEC (B) devices. The PEC device produces H₂ in a water splitting configuration with 700 mV overvoltage. We use the solar flux at noon at Jezero Crater averaged over the course of a year as the reference solar spectrum.