

The Mars Oxygen ISRU Experiment (MOXIE) on the Mars 2020 Rover Michael H. Hecht,¹ and Jeffrey A. Hoffman² for the MOXIE Team. ¹MIT Haystack Observatory, Westford, MA. Email: mhecht@haystack.mit.edu. ²M.I.T. Dept. of Aeronautics and Astronautics, Cambridge, MA. Email: jhoffma1@mit.edu.

Introduction: As the only planet in the solar system other than Earth whose surface is likely to be hospitable to human explorers, Mars has been widely viewed as the next significant post-Apollo human destination. One of the many factors that distinguish such a round trip from lunar exploration is the tremendous mass of propellant that must be transported for ascent from the much deeper gravity well of the martian surface. Preliminary mission models suggest that more than 30 metric tons of oxygen will be needed as the oxidant for this ascent, representing about 78% of the propellant mass in a CH₄/O₂ propulsion system. This would translate into 400 metric tons in Earth orbit – requiring 4 to 5 heavy lift launches [1].

If the oxygen required for ascent is instead produced on Mars by In Situ Resource Utilization (ISRU) using indigenous CO₂ as a feedstock, it will eliminate the need for these expensive launches. In this scheme, the ascent vehicle, power source, and chemical processing plant is sent toward Mars ~26 months before human departure from Earth, and the oxygen tanks of the ascent vehicle are filled prior to the final decision to send the crew. Analogous systems might also support future robotic return missions.

The substantial risks of such an architecture demand an *in situ* test to evaluate the effects of actual Mars mission conditions of launch and landing, dust, wind, radiation, electrostatic charging and discharge, thermal cycles, reduced gravity, and enforced autonomy, as well as unknowns intrinsic to the first operation of a production facility of any kind on another planet.

Recently selected to fly on NASA's Mars 2020 mission, MOXIE is a 1% scale model of an oxygen processing plant that might support a human expedition sometime in the 2030s. MOXIE will produce 22g/hr of O₂ on Mars with >99.6% purity during 50 sols. More than a technology demonstration, MOXIE exercises a range of control parameters, probes performance margins, provides diagnostics of health and degradation, and exploits redundancy and modularity to explore technology options. The goal is to understand the parameters and protocols, the risks, development challenges, margins and threats, the constraints and requirements of a full-scale Mars In Situ Resource Utilization (ISRU) facility.

Technical Approach: The two major steps in O₂ production are (1) CO₂ accumulation and compression, and (2) Conversion of CO₂ to O₂.

Conversion of CO₂ to O₂. MOXIE uses a solid oxide electrolysis (SOXE) stack developed by Ceramtec, Inc. for converting CO₂ to O₂. Its working elements are stacked scandia-stabilized zirconia (ScSZ) electrolyte-supported cells with thin screen-printed electrodes, coated with a catalytic cathode on one side and an anode on the other. These are separated by expansion-matched interconnects that direct the source, exhaust, and product gases to and from their respective manifolds, as illustrated in Fig. 1. The stacks operate in the 800–850°C range.

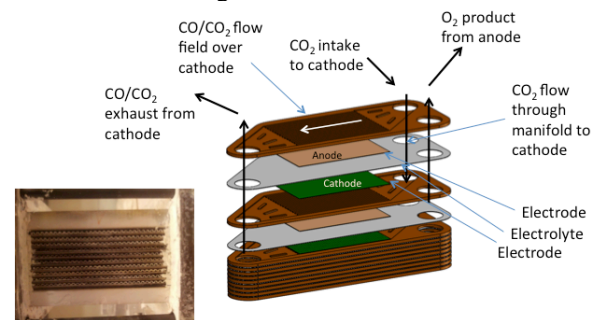


Fig 1. SOXE design and sample stack. The side view of an actual stack is shown at left.

When CO₂ flows over the catalyzed cathode surface under an applied electric potential, it is electrolyzed according to the reaction $\text{CO}_2 + 2e^- \rightleftharpoons \text{CO} + \text{O}^-$. The CO is exhausted, while the oxygen ion is electrochemically driven through the solid oxide electrolyte to the anode, where it is oxidized ($\text{O}^- \rightleftharpoons \text{O} + 2e^-$). The O atoms combine to produce the gaseous O₂ that is released from the anode cavity at a rate proportional to current, $\dot{n}_{\text{O}_2} = \frac{i}{4F}$, where F is Faraday's constant.

The reaction chemistry uniquely determines both the minimum electrical current and the minimum CO₂ flow required to produce O₂ at a given rate. For MOXIE, the reaction requires 108 W to produce 22 g/hr O₂. To this must be added ~40 W to compensate for heat loss due to convection and radiation and ~20 W to pre-heat incoming CO₂, for a total of ~168 W.

CO₂ acquisition and compression (CAC). The atmosphere of Mars varies from ~7-9 mbar in the northern hemisphere, low elevation landing sites that are likely to be selected for both Mars 2020 and an eventual human landing. This atmosphere contains about 95.5% CO₂; the remainder is largely Ar and N₂.

While both continuous-mode mechanical pumping and batch-mode cryogenic pumping are plausible both

for Mars 2020 and for eventual full-scale use, MOXIE has chosen to fly a batch-mode system that cryogenically compresses and stores CO₂ at high pressure. A fraction of the gas is continuously pumped out of the cryogenic chamber during accumulation for ventilation to prevent the buildup of residual Ar and N₂. When sufficient CO₂ is accumulated, the chamber is sealed off from the atmosphere and warmed, producing high-pressure CO₂ that is subsequently fed to the SOXE for conversion at a pressure of ~1 bar.

Extensibility to Full Scale: In a human scale Mars mission, the ISRU system would be operated continuously in a steady state without interruption for many months, adapting autonomously to atmospheric variability (temperature, pressure, dust). Such a full-scale system would produce roughly 25-30 metric tons of O₂ during the ~17-month period between arrival of the ISRU system and ascent vehicle on Mars, and the decision to launch the human crew at the next launch opportunity. This requires a production rate of approximately 2.2 kg/hr.

The SOXE architecture is a stack of cells, arranged vertically like a multi-story building. The two MOXIE stacks each utilize 11 cells. An assembly of 100 stacks, each containing 20 MOXIE-sized cells, would produce >2 kg/hr of O₂ with an energy investment of ~12 kW.

A full-size CO₂ acquisition system requires 8 kg/hr of martian atmosphere, ~0.14 m³/s at 7 mbar. This can be accomplished with a three-stage centrifugal compressor followed by a single-stage scroll compressor, for a total compressor mass of 38 kg that requires < 1.1 kW power.

Acknowledgments: MOXIE development is supported by the NASA HEOMD and STMD offices. We are particularly grateful to support from JPL and MIT, as well as our partners Ceramatec and Creare, in the preparation of the MOXIE proposal.

References: [1] Drake B. ed. (2007) Mars Design Reference Architecture 5.0, NASA/SP-2009-566-ADD.