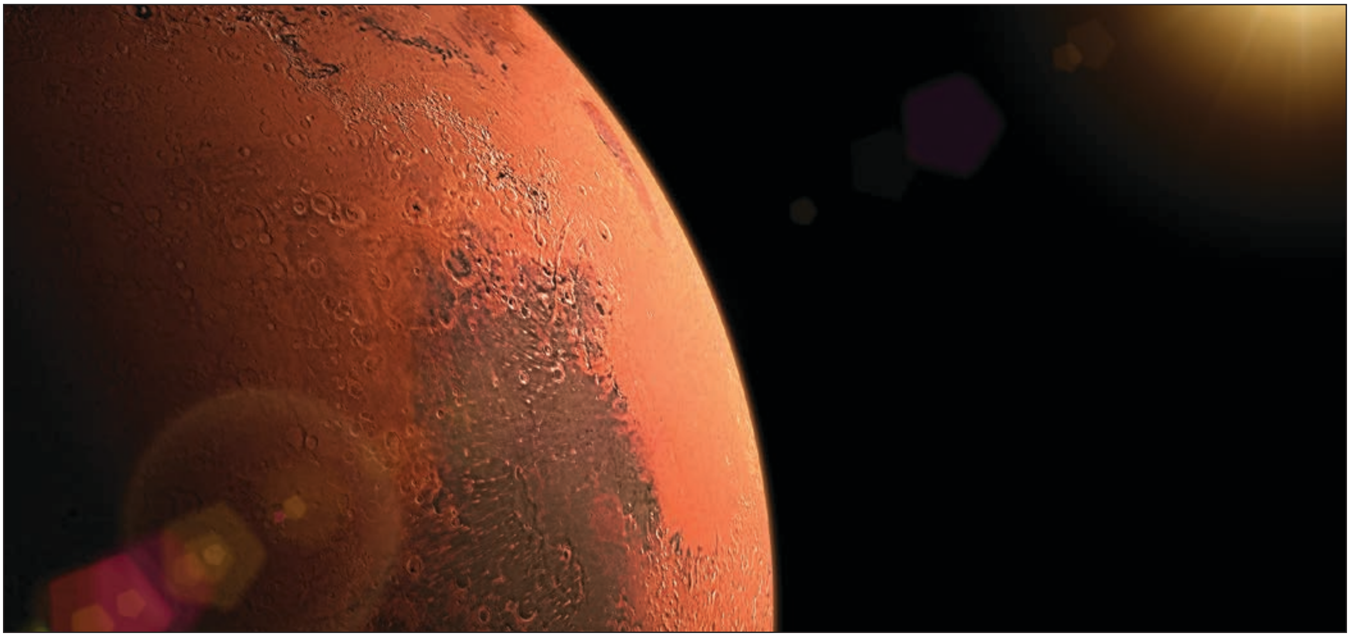
Martian Oxygen:
Creating Breathable Air with Engineered Ceramics

NASA scientists are working on advanced technologies that can one day enable human exploration of Mars—and engineered ceramics will help.



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In the 2015 film *The Martian*, based on the novel of the same title by Andy Weir, astronaut Mark Watney struggles for survival after his team is forced to evacuate Mars due to a violent dust storm—leaving him behind after mistakenly presuming he is dead. The story highlights how a manned mission to Mars will critically depend on a reliable oxygen supply. Through shrewd engineering and improvising, Watney manages to gather and create the critical supplies needed to survive on Mars until the next mission arrives: food, water, shelter, and oxygen. Watney, a botanist and mechanical engineer, plants potatoes in a modified room where he waters them by burning some of the mission's fuel supply of hydrazine with oxygen (O_2).

While the "normal" supplies of food, water and shelter were created through innovative engineering, establishing a steady oxygen supply required more specialized tools. Thankfully, the mission came equipped with the "oxygenator," which took compressed carbon dioxide (CO_2) and "passed it over a zirconia electrolysis cell to pull oxygen atoms off the CO_2."[1] While this sounds closer to science fiction than science, the truth is that NASA is implementing such a concept on its upcoming mission to Mars.

The Next Step in Exploring Mars

NASA scientists are working on advanced technologies that can one day enable human exploration of Mars. Set to land on Mars in 2021, NASA's Mars

2020 mission will launch a new robotic science rover with seven instruments. Each instrument was selected to help determine the potential habitability of the environment, and to search for signs of ancient Martian life. One of those instruments is the Mars Oxygen ISRU Experiment (MOXIE). The primary goal of this experiment is to determine the feasibility of using indigenous Martian natural resources (referred to as *in-situ* resource utilization, ISRU) to "enable propellant and consumable oxygen production."[2]

Delivering a sufficient, reliable supply of high-purity oxygen is a major design challenge when planning long-term manned missions. Astronauts would consume nearly a full metric ton of oxygen over the course of a three-year mission. Additionally, preliminary models estimate more than 30 metric tons of oxygen is required to escape from the deep Martian gravity well for the return trip home. Because of the immense amount of oxygen needed for both the astronauts and their return trip propellant, a Mars mission supply weight quickly becomes a major concern. Rather than transporting this large amount of oxygen more than 35 million miles from Earth to Mars, generating oxygen on-site from available resources on Mars would not only reduce the landed payload weight required to keep astronauts alive, but also allow more sustainable and in-depth exploration of Mars or other parts of our solar system.

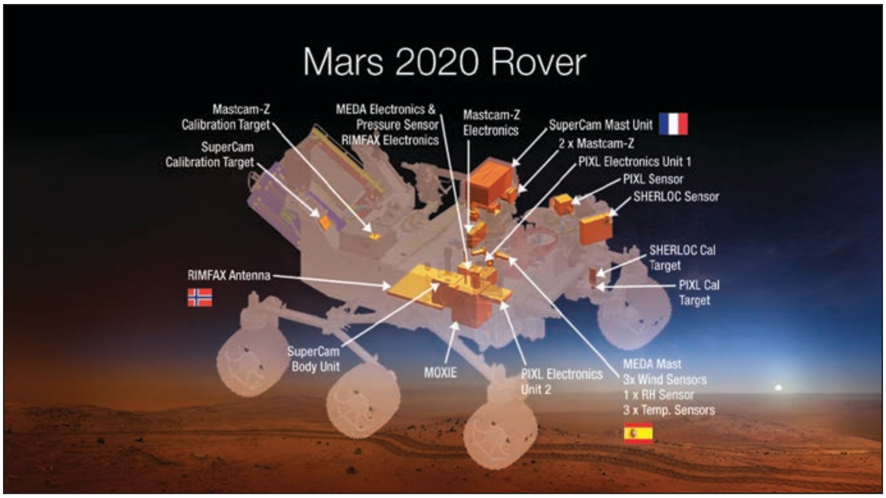

Figure 1. Illustration of planned Mars 2020 Rover incorporating seven instruments, including MOXIE. ***(Image courtesy of NASA.)***

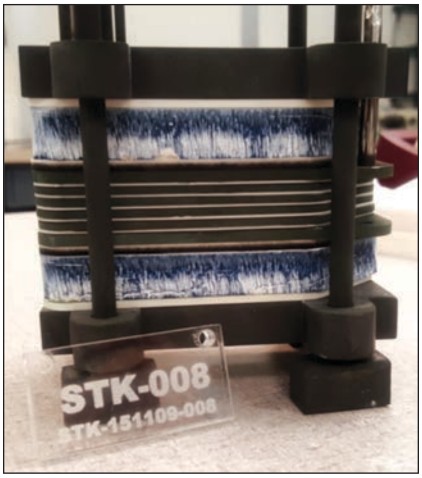

Figure 2. Prototype SOXE stack of ScSZ engineered ceramic electrolytes.

Using Engineered Ceramics

Unlike Earth, the Mars atmosphere is predominantly carbon dioxide—approximately 95% CO_2, with the remainder largely argon and nitrogen. MOXIE uses a solid oxide electrolysis (SOXE) stack* to produce oxygen from the CO_2-rich Martian "air." These custom-engineered stacks are comprised of scandia-stabilized zirconia (ScSZ) electrolytes with ceramic anodes and cermet (ceramic-metallic composite) cathodes on opposite sides.

As compressed CO_2 flows through the powered SOXE stack, electrolysis breaks out oxygen ions. Using the solid electrolysis system is important for three reasons: efficiency, durability and stability. Solid oxide electrolysis consumes much less electric energy than other processes, minimizing the consumption of the limited power in space missions. In fact, the SOXE stack operates near the theoretical efficiency limit. Other electrolysis systems use liquid electrolytes to conduct the ions to the anode. However, this system needs to remain stable in the harsh Mars environment (e.g., extreme cold, low gravity and dusty atmosphere). These conditions especially influence liquid electrolytes, as their phases and volumes are dramatically affected by external temperatures. In addition, dust contamination will decrease the effectiveness of the electrolyte.

On the other hand, the solid-state ceramic will be able prevent the contamination due to its hard surface and exhibit excellent volume and phase control, remaining solid even at the maximum operating temperature. To meet the strenuous demands of a Mars mission, the durable ScSZ ceramic electrolyte is a superior choice for electrolysis over a liquid system. The effect of environmental conditions on the performance of SOXE cermet electrodes is somewhat unknown, and the MOXIE results will provide information to build robust, large-scale devices for human exploration.

Electrolysis essentially takes free electrons and uses them to replace one of the double bonds to oxygen. Once an oxygen ion is freed up, it is directed through the electrolyte into the anode. The anode then "oxidizes" the ion, thereby creating O_2. At the same time, the leftover CO is exhausted along with any unprocessed CO_2. The oxygen flow will then be analyzed for purity and output rate.

The MOXIE technology demonstrates what could ultimately become a Mars-based oxygen processing plant to support future human missions. The experiment will be conducted across the seasons of the Martian year (approximately 687 Earth days) to evaluate its performance and resilience through the variety of environmental challenges.

Preparing for Human Exploration

All seven instruments on the Mars 2020 mission are designed to further its four goals: look for habitability, search for biosignatures, obtain and cache samples, and create preparations for human exploration. While many of the instruments will capture and analyze data on

**Developed by CoorsTek company Ceramatec.*

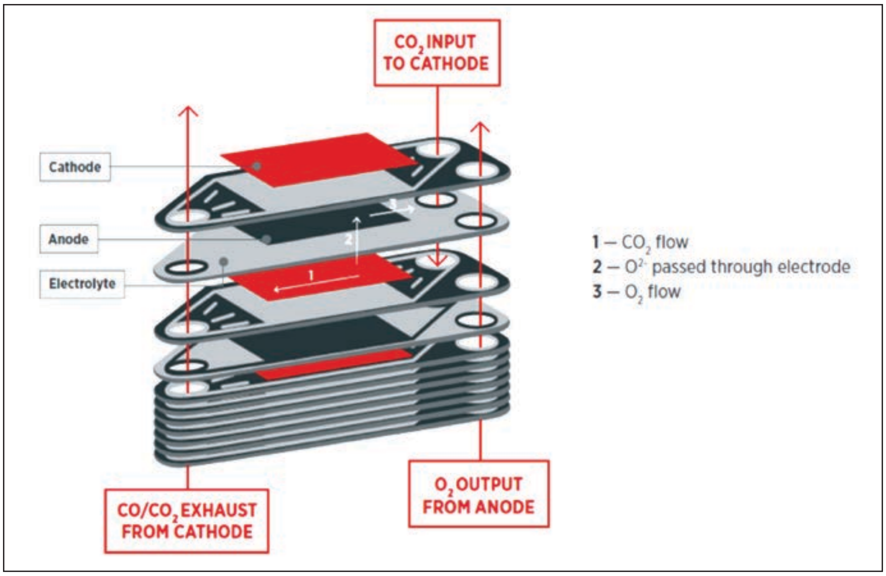

Figure 3. Schematic of electrolysis using SOXE stack.

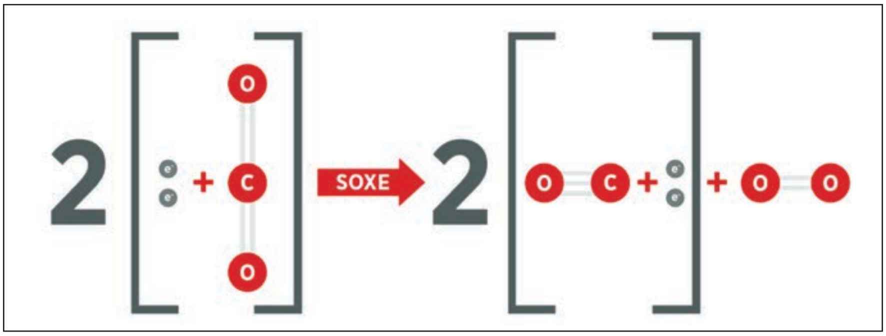

Figure 4. The process of solid oxide electrolysis converts CO_2 to O_2.

the Martian environment, MOXIE's purpose is to actively use and change that environment. This will drive the goal of preparing for human exploration through proving both the science behind the experiment and the feasibility of using *in-situ* resources to supply the necessary amounts of oxygen. Factors for a successful mission will include durability of the vital system, ensuring the energy consumption matches anticipated values, and that production levels and purity meet what would be needed for human exploration.

Beyond the 2020 mission, SOXE technology could be used for expanding the concept of space exploration. Because the conversion of CO_2 uses Mars atmosphere instead of transported O_2, future manned and unmanned missions may have the potential of reduced payload, cost, and complexity. While having hospitable air is an intuitive requirement for manned missions, the ability to produce oxygen from the atmosphere will allow on-site fuel production. Using the produced oxygen, those missions could land on and explore Mars, and then return to Earth or continue exploring other sections of the solar system.

A New Frontier

With success, the MOXIE project will not only prove the science behind *The Martian*, but also shape the vision of what long-term space exploration missions could look like. This technology uses the concept behind solid oxide electrolysis to take energy and break the bonds in CO_2 to free up an isolated oxygen ion—meaning a CO_2-rich atmosphere on Mars can be used to create oxygen, eliminating a heavy part of the mission's payload.

Due to the potential need for high production volume and the vitality of having a constant oxygen supply, MOXIE focuses on the use of solid engineered ceramic ScSZ electrolytes over other methods for superior efficiency, durability, and stability, which are critical to flight qualify this ISRU concept. The inherent durability of a scandia-stabilized zirconia electrolyte comes from its ceramic nature. As with most ceramics, the ScSZ is very hard and resists wear better than most metals. These properties are vital for the mission, as the secondary nature of the project is to analyze how the system stands up to surface operations in the severe Martian environment. On top of its durability, SOXE has the advantage of working in a solid state throughout the whole process. MOXIE's electrolysis cells will not have the inherent problems of controlling the phase and volume that stem from using liquid electrolytes.

By testing and proving the concept behind MOXIE, NASA hopes to verify that SOXE can be used as a viable source of oxygen on Mars, and to understand how dust will affect any surface operations. These two elements will be vital for human exploration of Mars. By eliminating the need to shuttle in oxygen for astronauts and for return flight fuel, future manned missions will be able to include better equipment and dramatically extend the potential scope of missions. MOXIE will help open a new frontier for space travel and exploration. CI

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Acknowledgements:

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1. Weir, Andy, *The Martian*, The Crown Publishing Group, Random House, New York, N.Y., 2013, p. 231.
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