Scientists propose a biocatalytic reactor for detoxifying water on Mars

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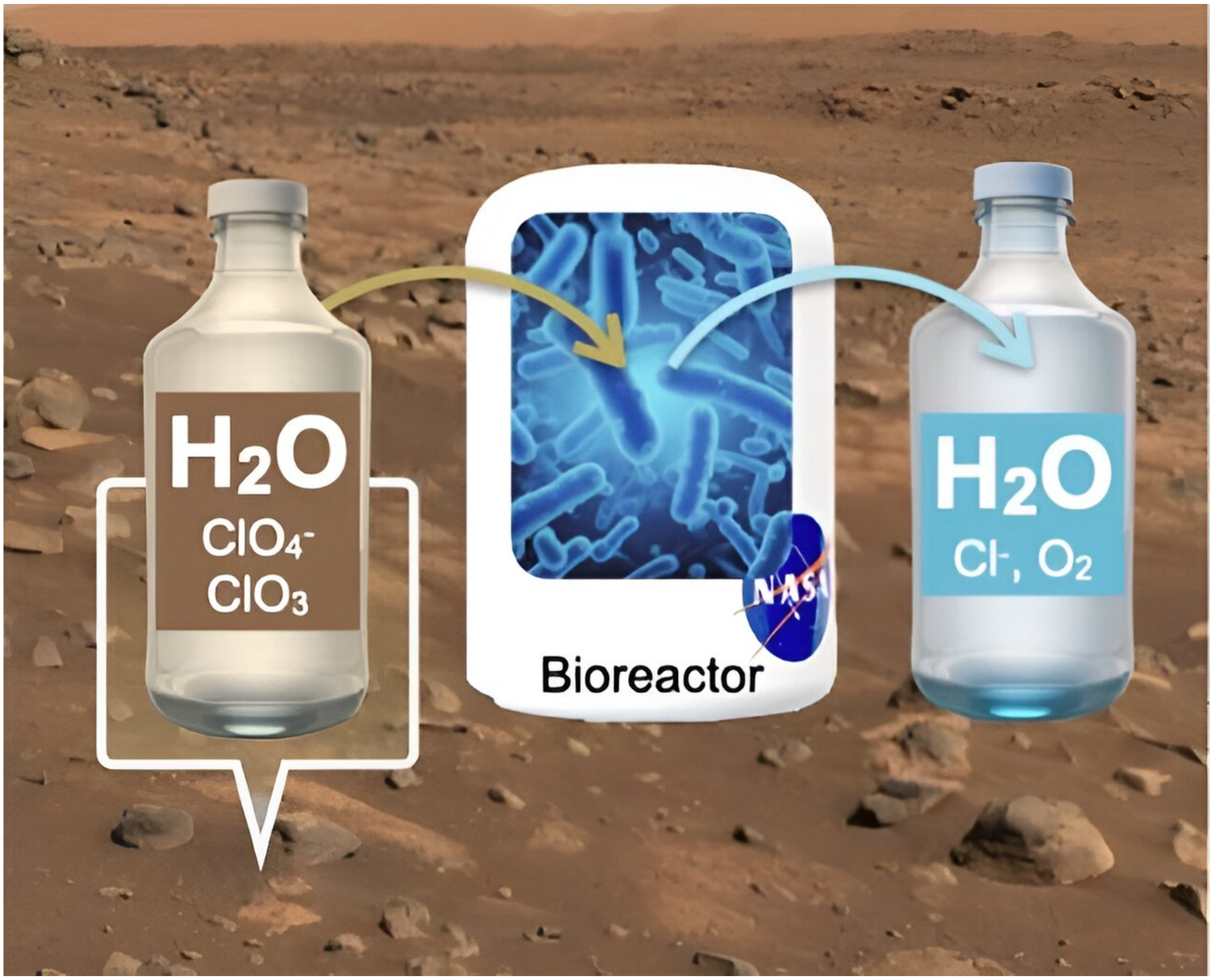

Graphic depiction of Detoxifying Mars: the biocatalytic elimination of omnipresent perchlorates. Credit: Lynn Rothschild

Mars is the next frontier of human space exploration, with NASA, China, and SpaceX all planning to send crewed missions there in the coming decades. In each case, the plans consist of establishing habitats on the surface that will enable return missions, cutting-edge research, and maybe even permanent settlements someday. While the idea of putting boots on Martian soil is exciting, a slew of challenges need to be addressed well in advance. Not the least of which is the need to locate sources of water, which consist largely of subsurface deposits of water ice.

Herein lies another major challenge: Martian ice deposits are contaminated by toxic perchlorates, potent oxidizers that cause equipment corrosion and are hazardous to human health (even at low concentrations). To this end, crewed missions must bring special equipment to remove perchlorates from water on Mars if they intend to use it for drinking, irrigation, and manufacturing propellant. This is the purpose of Detoxifying Mars, a proposed concept selected by the NASA Innovative Advanced Concepts (NIAC) program for Phase I development.

The lead developer of this concept is Lynn Rothschild, a Senior Research Scientist at NASA's Ames Research Center (ARC) and the Research and Technology Lead for the Science and Technology Mission Directorate (STMD) at NASA HQ. As she and her colleagues noted in their proposal, the "scale of anticipated water demand on Mars highlights the shortcomings of traditional water purification approaches, which require either large amounts of consumable materials, high electrical draw, or water pretreatment."

Perchlorates (ClO_{4-}) are chemical compounds that contain the perchlorate ion, which form when chlorine compounds become oxidized. Perchlorate salts are kinetically stable, very soluble, have a low eutectic temperature (the lowest possible temperature they can achieve before freezing), and become very reactive at high temperatures. Chlorate (ClO_{3-}) salts are similar, though they are less kinetically stable than perchlorates. Perchlorates were first detected on Mars by the Wet Chemistry Laboratory (WCL) instrument on the Phoenix mission, which landed in the northern Vastitas Borealis region in May 2008.

With concentrations of about 0.5% found in these northern plain soils, scientists realized why previous attempts to find organic molecules in Martian soil had failed. In short, the perchlorate prevented mass spectrometers on the Phoenix and the famed Viking 1 and 2 landers (which explored Mars between 1976 and 1980) from detecting anything. This discovery led to renewed interest in the search for organics and astrobiology studies on Mars, leading to the Curiosity and Perseverance rovers. Since then, perchlorate (and likely chlorate) concentrations have been detected by multiple missions from both the surface and orbit.

Here on Earth, perchlorates are naturally reduced by bacteria found in hypersaline soils, which have applications for water decontamination. Unfortunately, these same bacteria are unsuitable for off-world use since they are not spaceflight-proven. Instead, Rothschild and her team envision a bioreactor that leverages synthetic biology to take advantage of (and improve upon) this natural perchlorate-reducing process. Specifically, their method relies on two key genes found in Earth-based perchlorate-reducing bacteria (pcrAB and cld).

These genes are then engineered into the spaceflight-proven Bacillus subtilis 168 bacteria strain, which will naturally convert chlorate (ClO_{-3}) and perchlorate (ClO_{4-}) into chloride (Cl^-) and oxygen gas (O_2). The oxygen gas would be immediately useable in Martian habitats or stored in tanks for extra-vehicular activities (EVAs), while the chloride could be used for various purposes, including nutrition. The process is highly sustainable, scalable, and (unlike conventional filtering systems) eliminates the need to dump the perchlorate and chlorate waste elsewhere.

With Phase I funding secured, Rothschild and her colleagues plan to test the feasibility of sending a bioreactor to Mars. The first step will be to engineer the genes PcrAB and cld into strains of B. subtilis 168 and test their perchlorate-reducing abilities. They also plan to conduct a trade study to compare the performance of their process against traditional engineering approaches, especially in terms of the mass, power, and time it takes to complete the process. The final step will consist of Rothschild and her team creating a plan to incorporate the technology into the architecture for a crewed mission to Mars.

"The system will be launched as inert, dried spores stable at room temperature for years," they state. "Upon arrival at Mars, spores will be rehydrated and grown in a bioreactor that meets planetary protection standards. Martian water will be processed by the bioreactor to accomplish perchlorate reduction. Processed water can then be used or further purified as required."

As they also indicate in their proposal, the technology will have implications for water decontamination systems and environmental restoration here on Earth:

"Development of our detoxification biotechnology will also lead to more efficient solutions to natural and particularly industrial terrestrial perchlorate contamination on Earth. It will also shine a spotlight on the potential of using life rather than only industrial solutions to address our environmental problems, which may spur further innovations for other terrestrial environmental challenges such as climate change."

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