Climate Enhancing Resource Utilization Through Carbon Dioxide Valorization on Mars. A. Fertig[1], S. Sankarasubramanian[2]

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Introduction: To advance exploration of extraterrestrial bodies such as Mars, NASA has stated the need for advancement of technologies that enable sustainable surface operations while decreasing supply needs from Earth. To meet this demand, techniques focused on in-situ resource harvesting, processing, and manufacturing must be developed further. Complicating the development of this technology are the extremely harsh conditions typically experienced on the Martian surface. Extremely low temperatures (-60℃), low atmospheric pressures (7 mbar), and low gravity (3.7 m/s^2) all interfere with the operation of technology that will be required to operate over long periods of time, potentially without any direct-human contact. Major points of focus for support of manned missions to Mars include fuel production, manufacturing, support of scientific endeavors, and microbe management.

To this end, Faraday Technology, together with Dr. Sankarasubramanian at the University of Texas at San Antonio, are developing a technology capable of electrochemically producing high value materials through electrolysis of atmospheric carbon dioxide. The technology developed by Faraday will be able to operate long-term under conditions typically experienced on the Martian surface, allowing for minimization of launch mass required for exploration of Mars. The system for CO_2 electrolysis is being developed through a 2023 NASA SBIR (Small Business Innovative Research) Phase I contract (Contract #80NSSC23PB428).

Background: Faraday Technology is an electrochemical engineering company that specializes in designing state-of-the-art electrochemical processes and limited edition specialized electrochemical hardware. Faraday has 33+ years of experience in developing pulse/pulse reverse electrochemical engineering manufacturing processes and taking them to a pilot-scale for transition and implementation, serving energy, defense, aerospace, automotive, electronics and medical industries. Faraday is working with Dr. Sankarasubramanian (UTSA) who investigates electrochemical systems capable of reducing atmospheric carbon dioxide into various carbon-containing compounds, allowing for valuable insight into the design and construction of electrochemical cells capable of CO_2 electrolysis.

System Overview: The general design of the CO_2 electrolysis system is based on electrochemical flow cells, which is a matured technology that has been implemented in a variety of electrolysis and electrochemical transformation processes commercially. A 3-D CAD design of a cell developed by Faraday for use in the electrochemical production of ethanol can be found in Figure 1. The cell consists of two compartments, each containing either an anode or a cathode. The anode oxidizes water to produce oxygen gas, protons and electrons. The protons and electrons are transported to the cathode, where CO_2 is reduced to ethanol. The two compartments are separated by an ion exchange membrane which maintains charge balance in either cell by selectively allowing protons to cross from the anode to the cathode. CO_2 gas is fed into the cell at the cathode, where it is then reduced to ethanol, then fed into a storage system until it is needed.

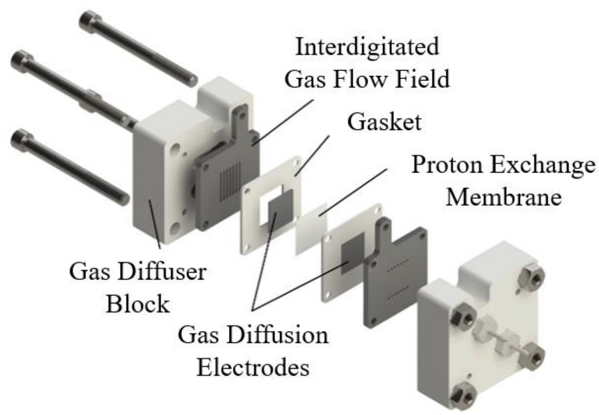

Figure 1: 3-D CAD of an electrochemical cell developed by Faraday.

ISRU. The electrochemical cell found in Figure 1 will produce ethanol using only resources found at the landing site for Martain exploration. The source of carbon for production of ethanol will come from the Martina atmosphere, which consists of over 95% CO_2 [1]. Additionally, the proton and electron source for reduction of CO_2 to ethanol will come from water harvested from the Martain surface. Recent research has found evidence of ice formations on Mars [2], which can act as a source of water for the electrochemical cell. Additionally, the existence of recurring slope lineae suggests subsurface liquid water may exist [3]. Due to the ultra-low temperature, this water must contain high concentrations of salt for the freezing point to be depressed enough to exist as a liquid. Indeed, recent evidence supports high levels of salt that may allow for liquid water to exist. However, this evidence suggests perchlorates make up a large portion of this salt [4], which introduces risk as perchlorate salts tend to create explosive mixtures with organic materials (ethanol), and high levels of oxygen (which is produced at the anode). As such, Faraday will investigate alternative electrolytes in the NASA STTR Phase II program for production of ethanol.

Phase I Testing: The initial testing in the Phase I program involved flowing gaseous carbon dioxide into the cell, where the cathode then reduced CO_2 to ethanol. The system then flowed the gaseous products out of the cell and into a gas chromatograph. This instrument allows for detection and quantification of the desired product and each side product (with appropriate calibration curves). The anode was supplied with deionized water with potassium hydroxide acting as the electrolyte. The anodically produced oxygen gas was simply vented into the atmosphere.

Testing Results. In the Phase I program, Faraday was able to demonstrate the ability to electrochemically produce ethanol using atmospheric carbon dioxide. While ethanol was successfully detected using this method, other partially reduced CO_2 products were also found. Carbon monoxide, hydrogen, methane, and methanol could each be detected; however, these products tend to be in small quantities. Optimization of the cell design and electrical current applied to the cell resulted in a maximum production rate of 2.2 grams of ethanol per hour, with a faradaic efficiency of up to 72%. Additionally, the energy efficiency for ethanol production was calculated as 0.31 grams of ethanol per watt-hour. Each of these performance parameters were over the targets for the Phase I program.

Future Work: With the success of the Phase I program, Faraday and UTSA were awarded a NASA STTR Phase II award for continuing the development of the electrochemical ethanol production system. Future work includes demonstrations of operation in simulated Martian environments, such as testing at ultra-low temperatures (below -50°C), low atmospheric pressures (7 mbar), and reduced gravity (3.7 m/s^2). Additionally, testing in the Phase II program will include designing and constructing a scaled-up version of the electrochemical cell developed in the Phase I program. The cell will be required to produce approximately 10 times as much ethanol per hour, and as such, will need to be able to process the appropriate amount of CO_2 to meet this rate. Faraday will test a larger surface area cell (Figure 2), along with initial testing of a stacked version of the cell, in which multiple individual cells are combined to form a single, multi-cell system. Work in Phase II will focus on transitioning the technology from the bench-top scale system tested in Phase I, toward the full-scale system that would be installed onto the surface of Mars for the electrolysis of atmospheric carbon dioxide into ethanol for use by astronauts on the Martian surface.

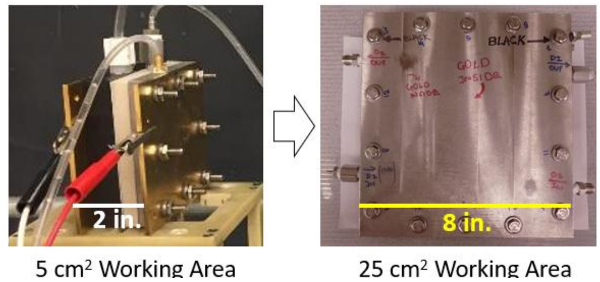

Figure 2: Scaling up electrochemical cell for larger volume CO_2 electrolysis.

Conclusion: During the NASA Phase I STTR program, Faraday Technology and UTSA were able to successfully demonstrate the ability to electrolyze atmospheric carbon dioxide into ethanol using an electrochemical cell developed by Faraday. The system was found to be able to produce over 2 grams of ethanol per hour, with a Faradaic efficiency of up to 72%. The results demonstrated in this program prove that utilization of atmospheric carbon dioxide on the Martian surface is a viable technology, and Faraday will continue to develop and transition the technology to reach the demands for exploration of the Martain surface.

References: [1] https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html. [2] Khuller A. R. and Christensen P. R. (2021) *JGR Planets*, e2020JE006539. [3] Ojha L. Chojnacki M. et al. *Nature Geoscience*, 8, 829-832. [4] Rzymski P. Schulze-Makuch D. et al. *Icarus*, 421, 116246.