National Aeronautics and Space Administration

Light-driven electrochemical production of oxygen and fuel from CO_2 and sunlight for Mars ISRU

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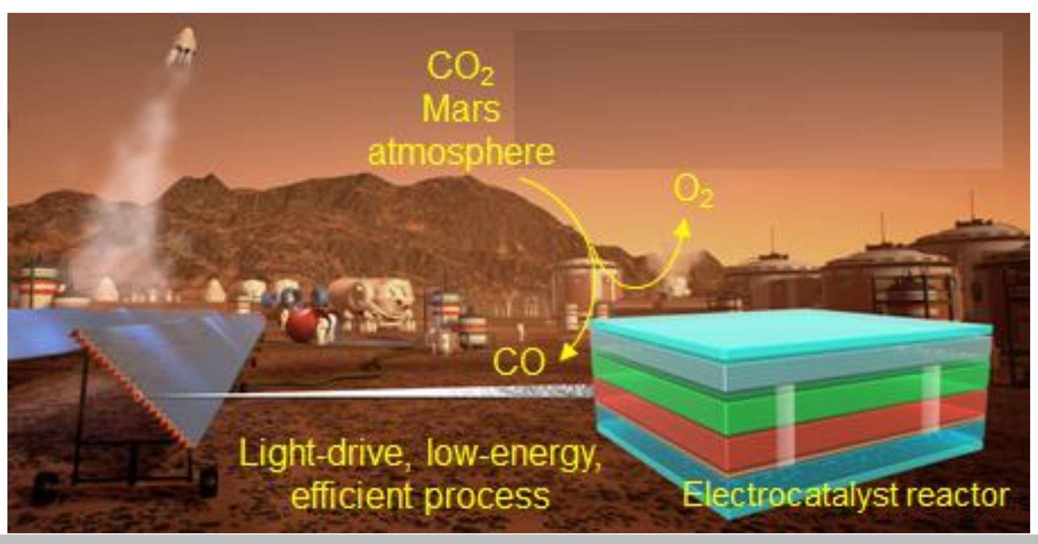
Project Objective:

Develop and evaluate low energy and low mass methods of ISRU for Mars missions. Our goal is to establish a simple, low mass, electrocatalytic technology for generation of O_2 and CO on the Mars surface at 25 °C or below.



Benefits to NASA and JPL (or significance of results):

Future Mars sample return missions and eventual human exploration of Mars would require rocket propulsion from the Martian surface. Every **1 kg of propellant made on the Mars saves 7.4-11.3 kg** launched from Earth. Production of O_2 *in situ* has considerable mass leverage as approximately **78% of propellant reactant mass is O_2**. *In situ* production of O_2 would provide a significant benefit to any mission with respect to launch mass.

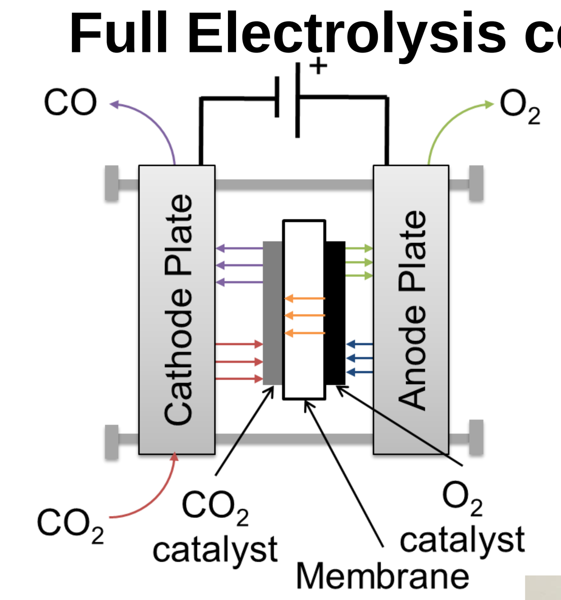
Current methods proposed in existing roadmaps require significant resources (for example, nuclear power systems) prior to implementing ISRU on Mars, due to the **high power inputs required for existing O_2-generating technologies** such as solid oxide electrolysis (SOXE). This challenging requirement could represent a major roadblock to implementing a comprehensive Mars exploration architecture.

FY19 Results:

During year 2 we fabricated and tested an electrolyzer device under Earth-like conditions, to TRL 4. This built from success in fundamental electrode research whereby work at Caltech, UCSD, Occidental and JPL identified and optimized CO_2 reduction and O_2 evolution electrocatalysts in well-performing half-cells. In March 2019 a PDR was held with subject matter experts with a delta-PDR successfully passed in May 2019. During this PDR the electrolyzer design was assessed and deemed suitable to achieve the requirements specified for TRL 4 testing including:

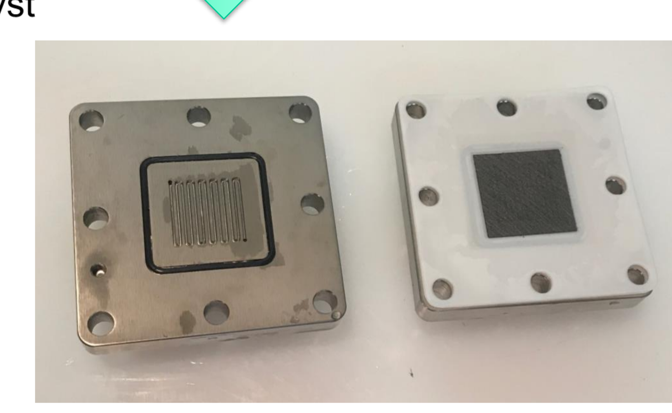
1. Electrochemical performance tests as a function of temperature, with a required minimum operating temperature of 20 °C
   i. Polarization (I-V sweeps)
   ii. Current vs. constant voltage for 24 hour operation
   iii. Coulombic efficiency measurements (half-cell only)
   iv. Outlet gas composition and flowrate
   v. Operation at Earth-atmosphere outlet pressure
2. Capable of performing CO_2 electrolysis generating O_2 gas with only inputs of carbon dioxide and electricity
   i. Current density ≥ 4mA/cm^2 at 25 °C
   ii. Minimal CO_2 and product crossover into the O_2 stream (e.g. CO_2 <350ppm, CO <9ppm)
3. Capable of operating for at least 100 hours without repair or replacement of the electrodes, solvents, or other components.
   i. ≥ 33 hours of active electrolysis which may be intermittent
4. Capable of tolerating quiescent wet storage for at least 1000 hours
5. Electrolyte water loss rate from the system during operation to be quantified and any make-up water/recapture and recycle requirements to be built into the TRL5 test plan for year 3

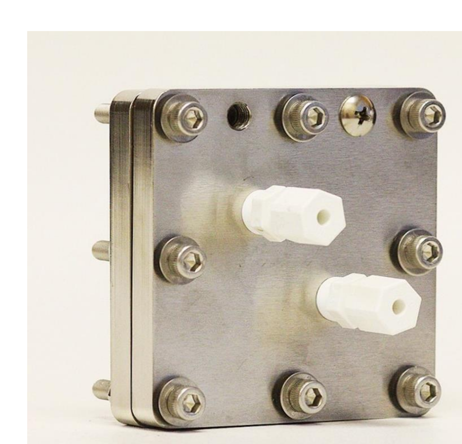
Full Electrolysis cell for testing:



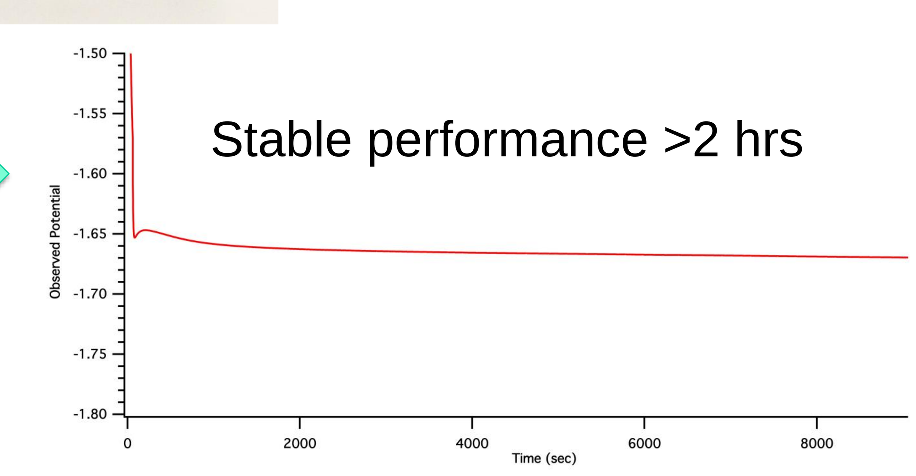
CO_2 electrolysis schematic

Titanium and 904L stainless steel flow fields/ endplates





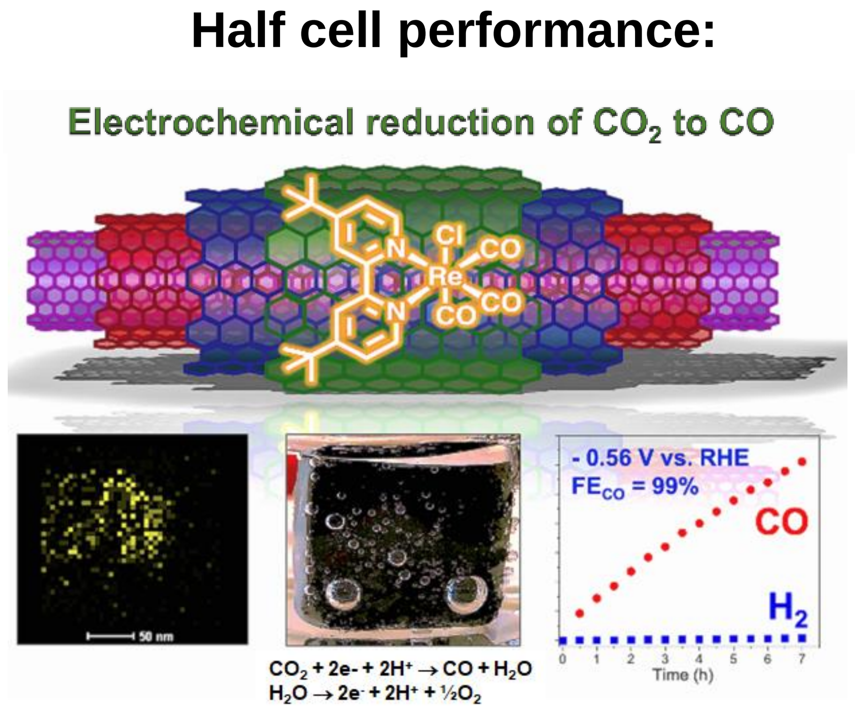
Assembled cell for testing



Stable performance >2 hrs

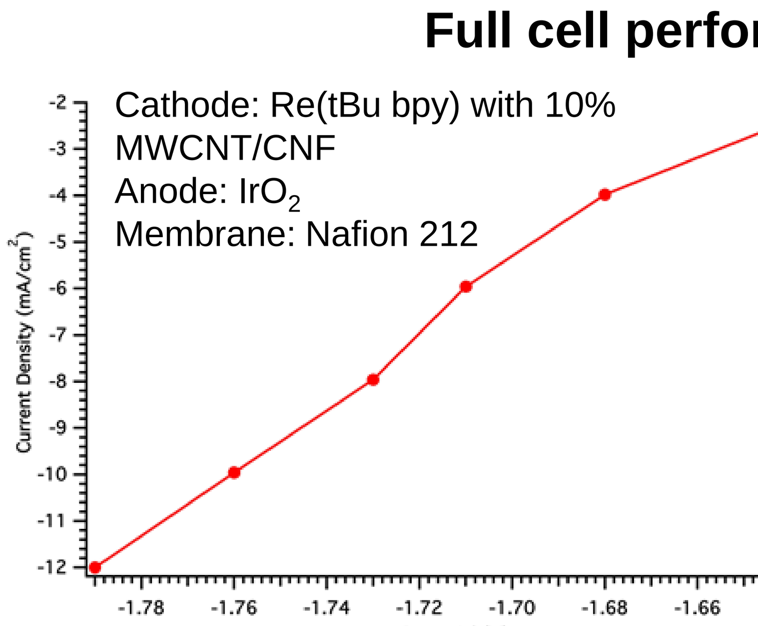
CO_2 reduction from half to full cell:

Half cell performance:



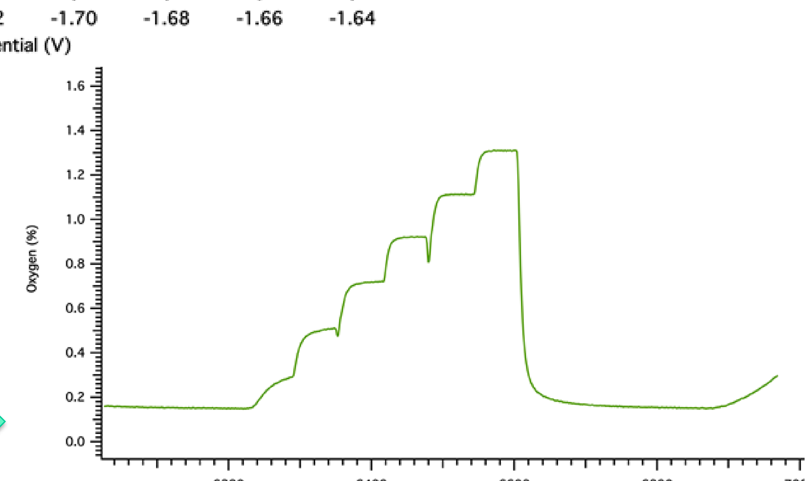
Catalysts developed in half cells were successfully transferred to full cells where performance can be quantified and compared

Full cell performance:



j (mA/cm^2) applied	E (V) observed
-1.99	-1.63
-3.98	-1.68
-5.96	-1.71
-7.96	-1.73
-9.96	-1.76
-12.0	-1.79

O_2 measurement during operation



Publications:

Almagul Zhanaidarova, Curtis E. Moore, Milan Gembicky and Clifford P. Kubiak, *Chemical Communications*, 2018, **54**, 4116-4119.

Almagul Zhanaidarova, Andrew L. Ostericher, Christopher J. Miller, Simon C. Jones and Clifford P. Kubiak, *Organometallics*, 2019, **38**, 1204-1207.

Zhanaidarova, A.; Jones, S.; Despagnet-Ayoub, E.; Pimentel, B.; Kubiak, C. Re(tBu-bpy)(CO)$_3$Cl supported on multi-walled carbon nanotubes selectively reduces CO_2 in water. Submitted to JACS.

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