FUEL PRODUCTION ON MARS WITH THE SABATIER ELECTROLYZER Duc Nguyen, Long Le, Zehua Pan, and Neal P. Sullivan, Mechanical Engineering Department, Colorado Fuel Cell Center, Colorado School of Mines, Golden, USA 80401, dunguyen@mines.edu, nsulliva@mines.edu

Abstract: We present our development of proton-conducting ceramic materials to synthesize methane and oxygen from CO_2 and H_2O feed streams. NASA seeks such technology to enable manned missions to Mars. The CO_2 and H_2O feedstocks are in abundant supply on The Red Planet; solar power could be harnessed to convert these feedstocks into fuel to sustain human life and enable permanent bases.

NASA's current approach features a two-stage process that starts with hydrogen synthesis through solar-driven water electrolysis using polymer-electrolyte membranes (PEM) at ~ 100 ºC. Following H_2 synthesis, the product hydrogen is fed to a separate chemical reactor held at ~ 400 ºC and mixed with CO_2 drawn from the Martian atmosphere. Within this reactor, a ruthenium catalyst promotes the Sabatier reaction to form methane:

$$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$$

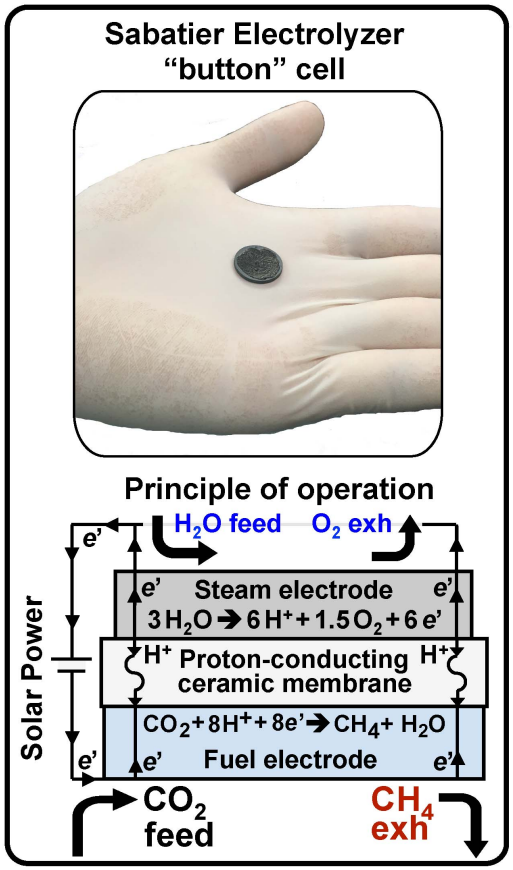
This two-stage process joining a steam electrolyzer with a Sabatier reactor results in high conversion of CO_2 and reasonable rates of methane production. However, the PEM used for water electrolysis suffers from low efficiency, resulting in an energy-intensive fuel-synthesis process.

Our work seeks to combine these two processes into a single Sabatier Electrolyzer reactor based on proton-conducting ceramic membranes. Like PEMs, ceramic membranes transport reasonable rates of hydrogen, but do so at much-higher efficiency, decreasing power requirements. Additionally, protonic ceramics operate at temperatures that are more compatible with Sabatier chemistry (~ 400 ºC). This enables integration of the catalyst with the electrolyzer, potentially simplifying the system, improving reliability, and increasing performance within a smaller package.

The Sabatier Electrolyzer concept is shown in the figure. Martian-derived H_2O and CO_2 are fed to the opposing electrodes of a protonic-ceramic electrolysis cell. The steam is electrolyzed (top), and as the product O_2 is exhausted from the cell, the product protons are driven across the protonic-ceramic membrane. These protons arrive at the fuel electrode, where they react with CO_2 to form methane and H_2O. The combination of processes can match the exothermicity of CO_2 hydrogenation with the endothermicity of H_2O electrolysis, promoting thermal balance and high efficiency.

This novel process intensification of mating water electrolysis with Sabatier chemistry brings many questions. For example, do the protons emerging from the membrane at the fuel electrode directly react with CO_2 (as shown in the figure), or do they recombine to form H_2 that subsequently reacts with CO_2 within the nickel-laden fuel electrode to form CH_4? How can we better mate the operating conditions of the protonic-ceramic electrolyzer with those needed for Sabatier chemistry? What performance can NASA expect from a protonic-ceramic Sabatier Electrolyzer, in terms of electrical efficiency, methane production per unit mass, etc.?

CSM researchers have previously demonstrated encouraging results with proton-conducting ceramics for a number of applications, including electric-power generation and fuels synthesis. In this presentation, we will review our efforts to extend development of protonic-ceramic cells to the Sabatier Electrolyzer shown in Figure 1. The cells feature a $BaCe_{0.2}Zr_{0.6}Y_{0.2}O_{3-d}$ (BCZY26) electrolyte, a Ni-BCZY26 fuel electrode support, and a $Ba-Co_{0.4}Fe_{0.4}Zr_{0.1}Y_{0.1}O_{3-d}$ (BCFZY) steam electrode. Results will be presented for CO_2 conversion and CH_4 selectivity under electrolysis operation.


Sabatier Electrolyzer
"button" cell
Principle of operation
H2O feed
O2 exh
e'
Steam electrode
3 H2O → 6 H+ + 1.5 O2 + 6 e'
H+
Proton-conducting
ceramic membrane
CO2 + 8H+ + 8e' → CH4 + H2O
Fuel electrode
Solar Power
CO2
feed
CH4
exh