Fuel production on Mars with the Sabatier Electrolyzer

Duc Nguyen, Long Le, Zehua Pan, and Neal P. Sullivan

Colorado Fuel Cell Center, Mechanical Engineering Department, Colorado School of Mines, Golden, CO, USA

Presented to:
Space Resources Roundtable

Wednesday June 12, 2019

Colorado Fuel Cell Center

We are developing a solar-powered device that upgrades H_2O and CO_2 into O_2 and CH_4

Combine H_2O electrolysis for H_2 formation with Sabatier chemistry to upgrade CO_2 to CH_4 in a single device

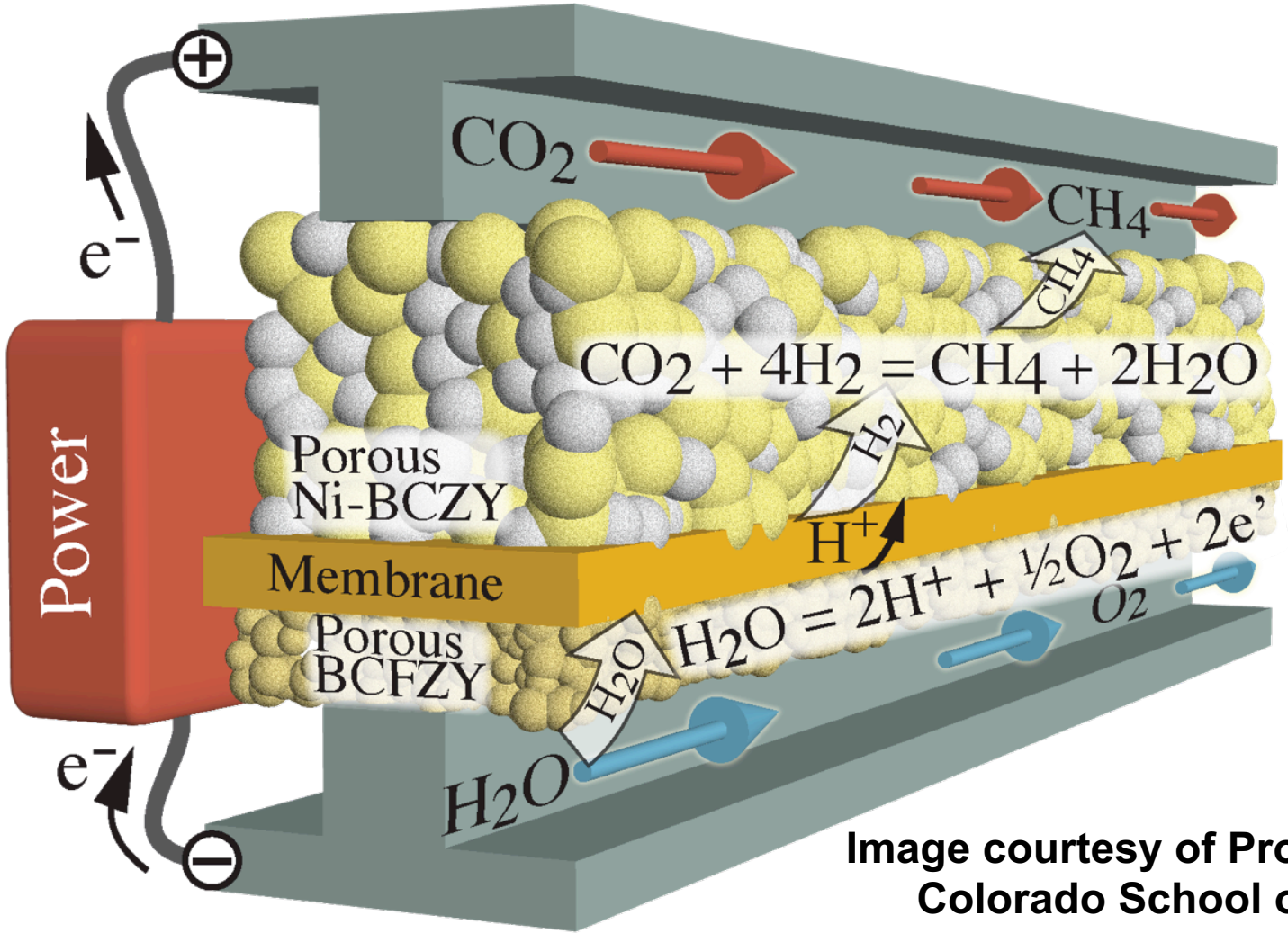
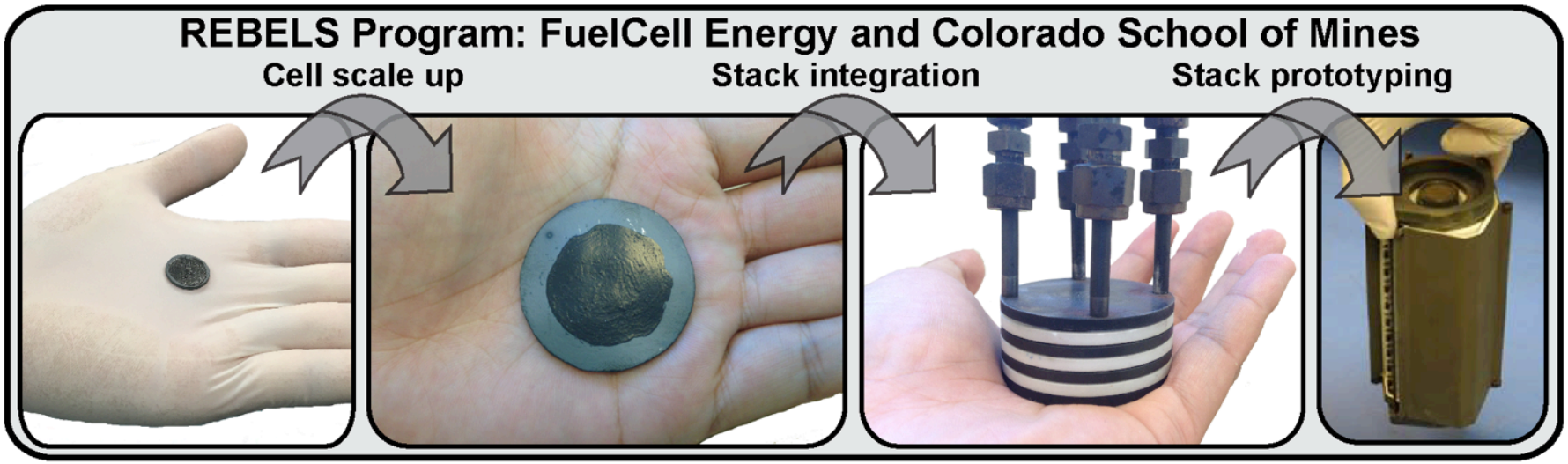


Image courtesy of Prof. R.J. Kee, Colorado School of Mines

Our "Sabatier Electrolyzer" to make fuel & O_2 on Mars leverages our programs on proton-conducting ceramics

- ARPA-E REBELS: Proton conducting ceramic fuel cells (5 years)
- ARPA-E REFUEL: NH_3 synthesis with protonic ceramics (3.5 yrs)
- EERE HTWS: Proton-conducting ceramics electrolyzers (2 yrs)
- FE NETL: CO_2-to-Fuels through electrochemical catalysis (2 yrs)
- NASA NSTRF: Making fuel on Mars with protonic ceramics (2 yrs)



Colorado Fuel Cell Center

COLORADO CENTER FOR ADVANCED CERAMICS

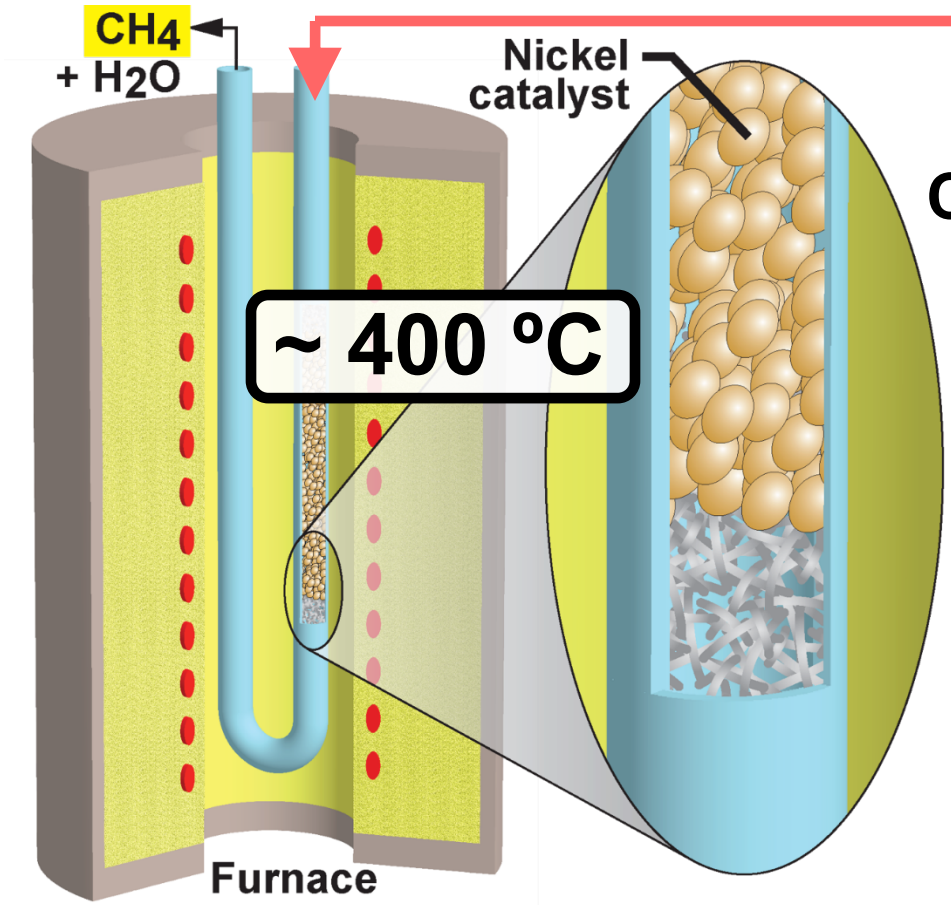
Versa Power Systems

fuelcellenergy

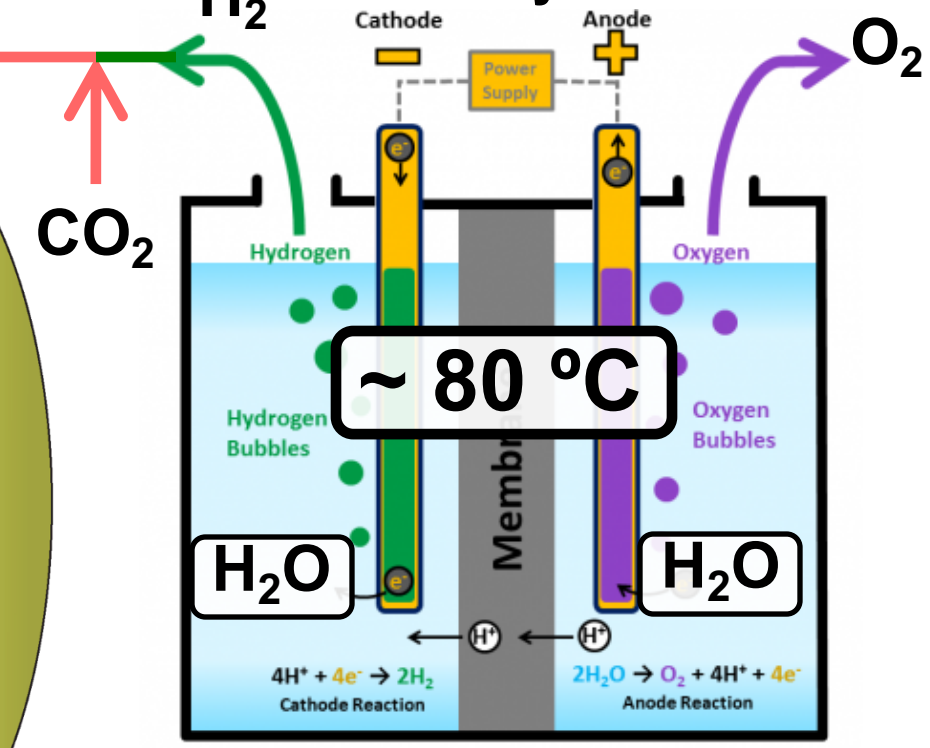
NASA's current CH_4-synthesis approach utilizes two separate devices: electrolyzer + Sabatier reactor

Sabatier Packed-Bed Reactor

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

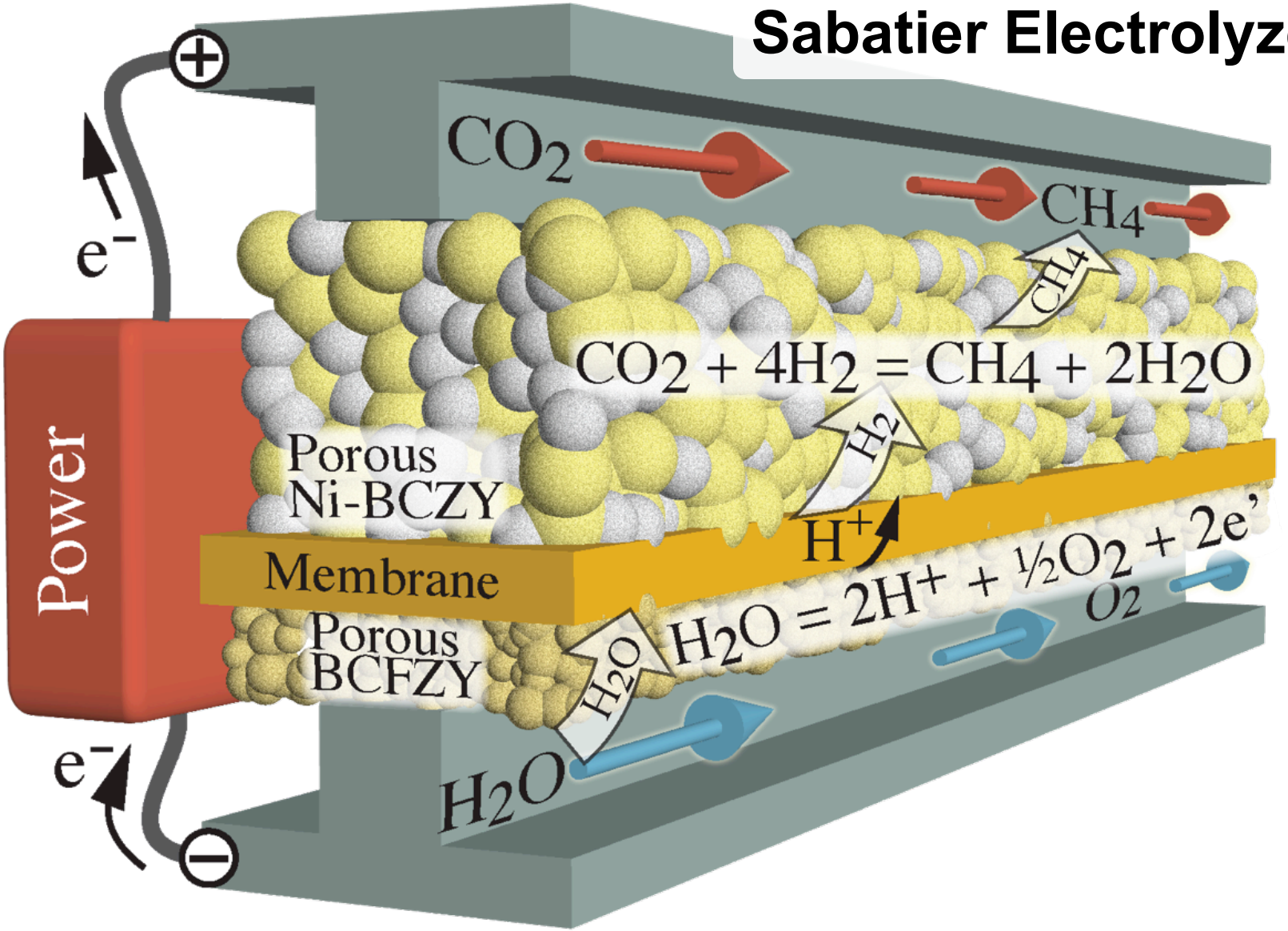


Polymer Electrolyte Membrane Electrolyzer



- Thermally incompatible
- Inefficient (~ 25%)
- Power intensive
- Heavy

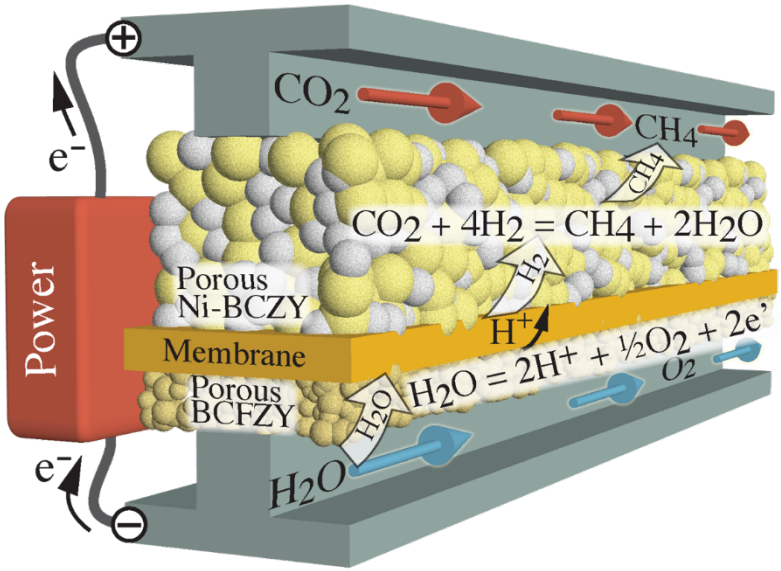
In contrast, our Sabatier Electrolyzer combines H_2 and CH_4 synthesis into a single device



Our Sabatier Electrolyzer harness the unique properties of protonic-conducting ceramic materials

Protonic-ceramic materials properties

- 400 – 500 ºC operation
- Small charge carrier (H^+)
- Efficiency can reach 75%

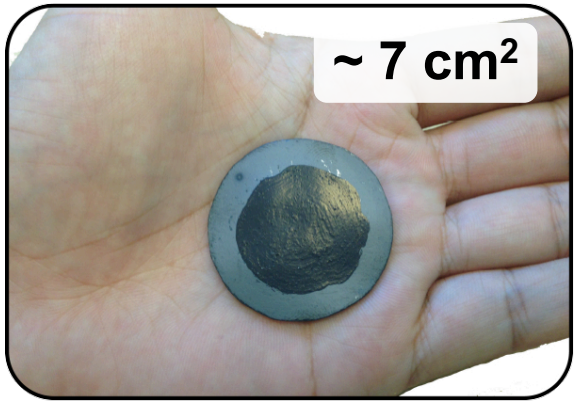


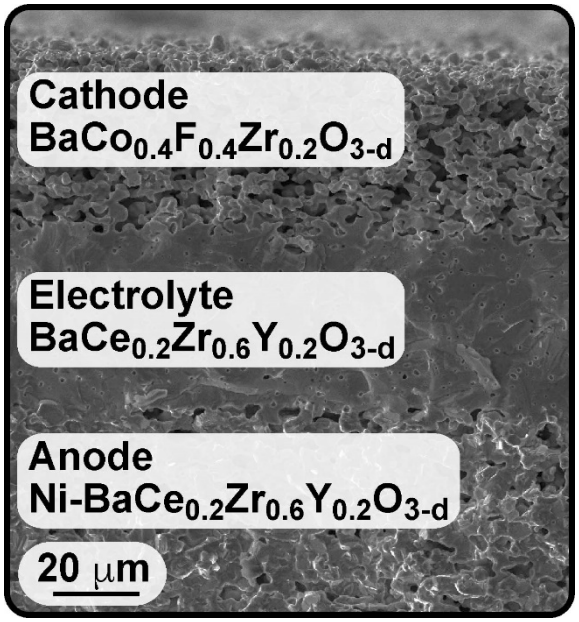
There are many fuel-synthesis questions

- Are these novel materials stable in Martian atmospheres?
  - The $BaCe_{0.4}Zr_{0.4}Y_{0.1}Yb_{0.1}O_{3-d}$ material may break down
    - Exposure to CO_2
    - Carbon deposition within the fuel electrode
    - Electrode failure during steam electrolysis
- What is the CO_2 conversion and CH_4 selectivity in this Sabatier Electrolyzer architecture?

We have developed cell-fabrication methods to increase cell size “beyond the button”

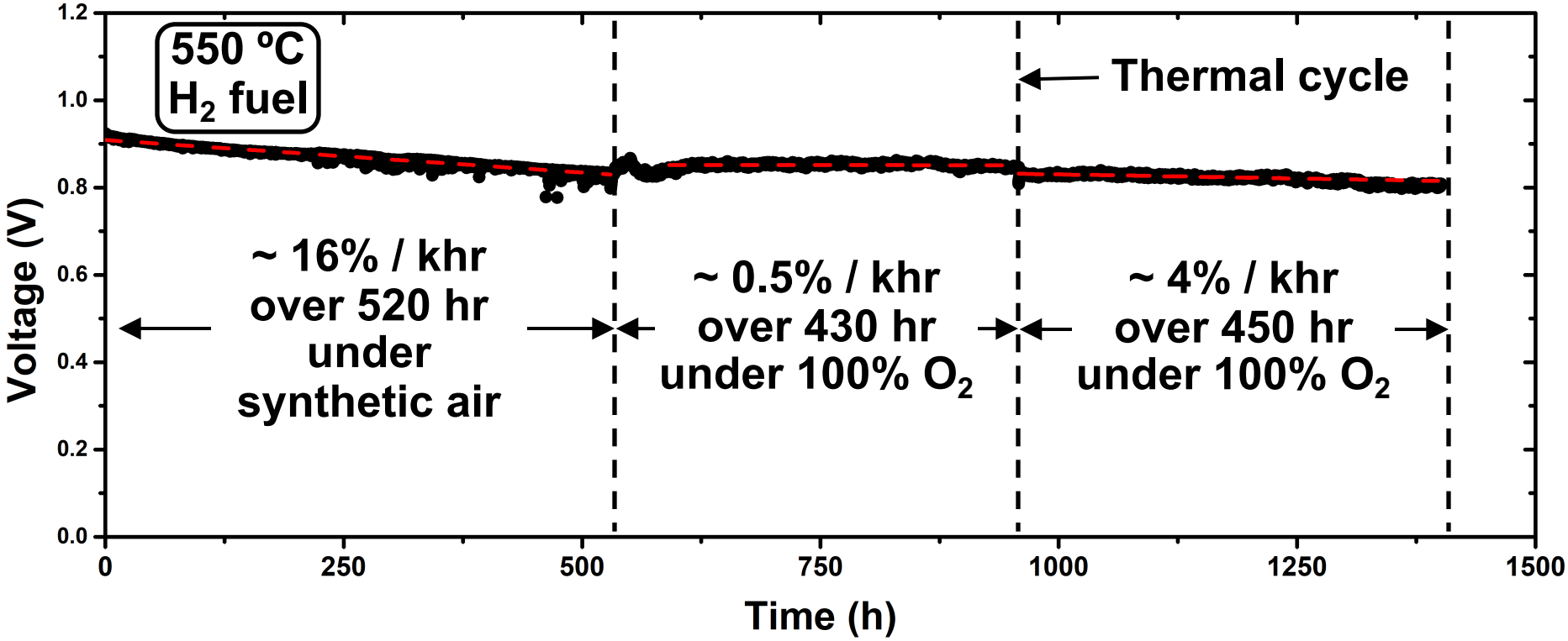
- Solid-state reactive sintering (SSRS) for both button and prototype cell fabrication
  - Simultaneous BCZY phase formation and cell fabrication
  - Single 1450 ºC sintering step combines $BaCe_{0.4}Zr_{0.4}Y_{0.1}Yb_{0.1}O_{3-d}$ calcination & cell fabrication
  - $BaCO_3$, CeO_2, ZrO_2, Y_2O_3, trace NiO
  - Manufacturing cost drastically reduced
- Prototype cells utilize dry pressing of anode and dip coating of electrolyte
  - Anode: 55% NiO : 45% BCZY26
  - Electrolyte: BCZY26, no NiO added
- $BaCo_{0.4}Fe_{0.4}Zr_{0.2}O_{3-\delta}$ cathode
  - Triple-conducting electrode (H^+, O^{2-}, *e*’)





We have shown very stable performance during electricity generation in "fuel-cell mode"

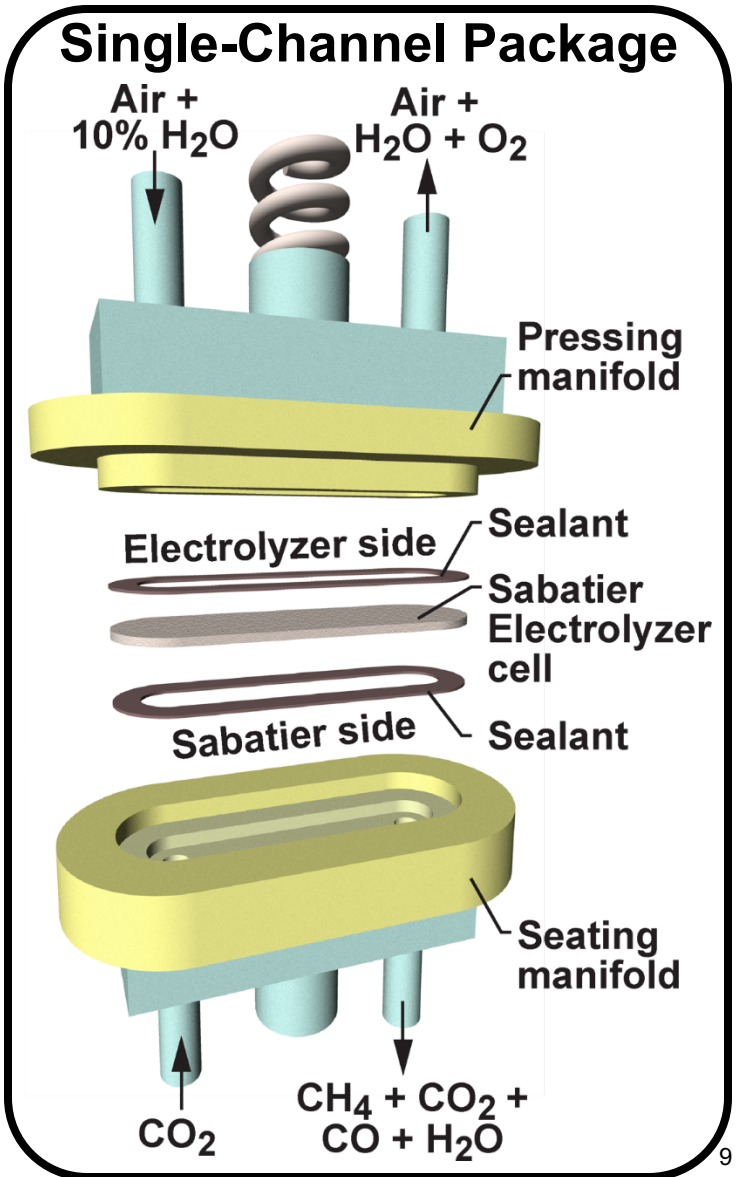
Degradation protonic-ceramic fuel cell over 1400 hours of operation



Can we reproduce this durability during methane synthesis?

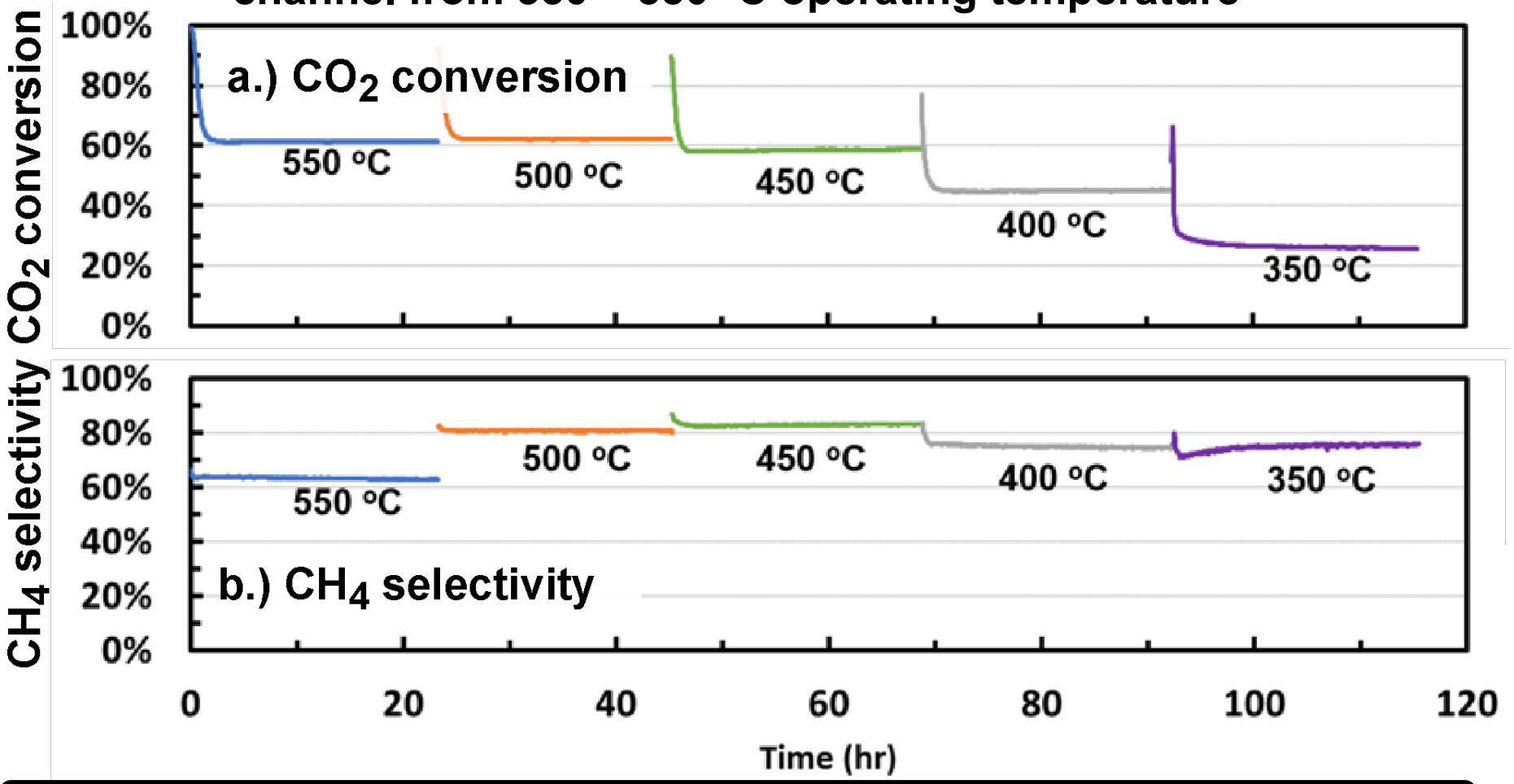
We package the Sabatier Electrolyzer to accurately quantify CO_2 conversion & CH_4 selectivity

- Single-channel package features
  - Simulates conditions within a larger-scale, multi-cell, multi-channel stack
  - Gases flow along and diffuse into catalytic cell electrode
  - Unlike packed-bed Sabatier reactor
  - Explore conversion & selectivity over wide operational space
- Operating parameters of interest
  - Temperature
  - Gas hourly space velocity
  - H_2-to-CO_2 stoichiometry
  - Fraction of electrochemically produced hydrogen



Initial studies: CO_2 conversion and CH_4 selectivity *in absence* of electrochemically produced H_2

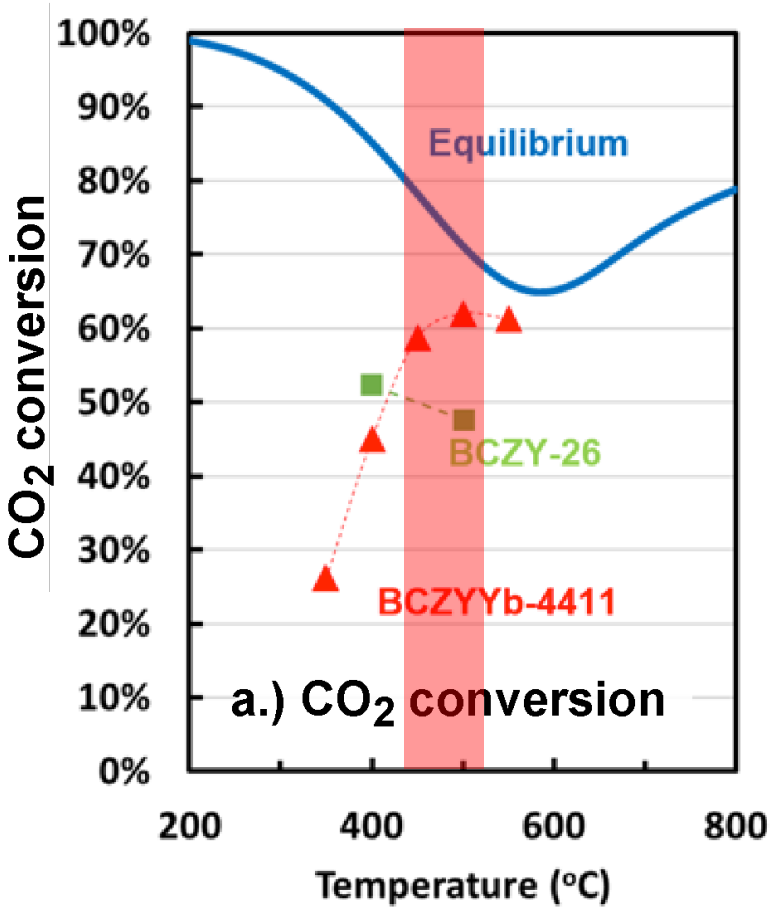
CO_2 conversion and CH_4 selectivity with H_2 and CO_2 co-fed to fuel channel from 350 – 550 °C operating temperature



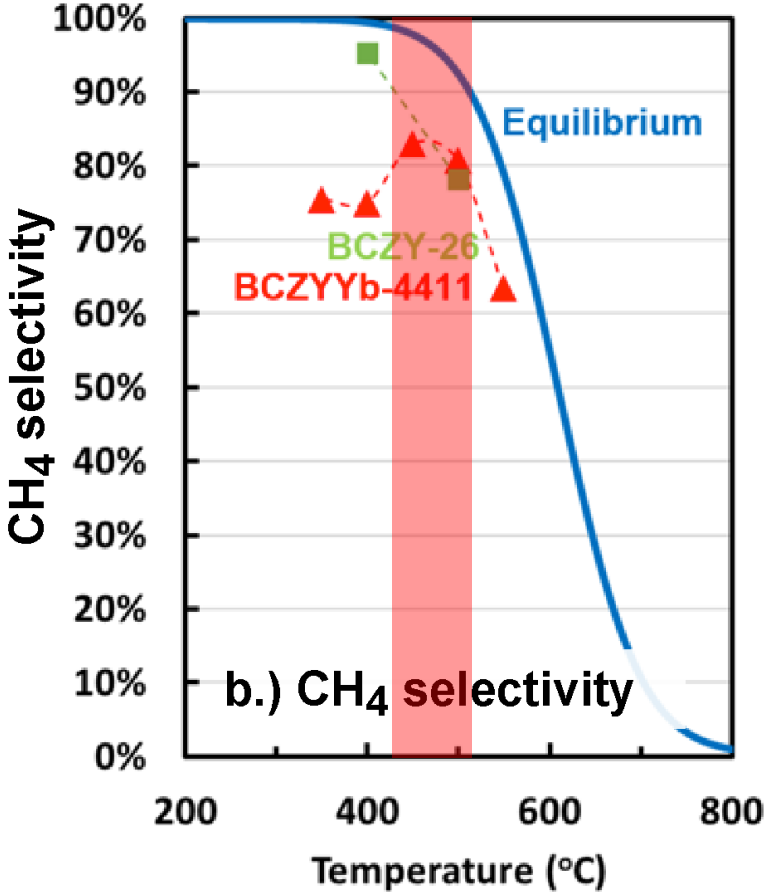
Steady results over ~ 120 hours provide confidence that materials are stable

Tradeoffs between Sabatier kinetics and limits of thermodynamics is evident

CO_2 conversion

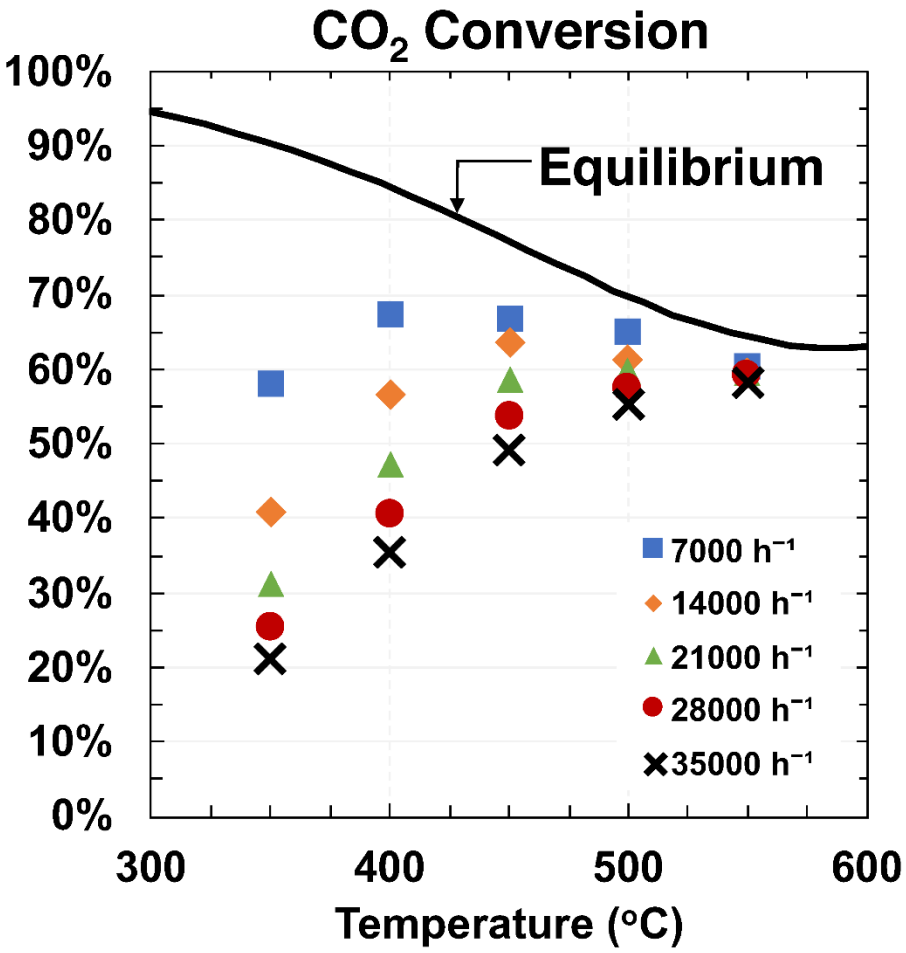


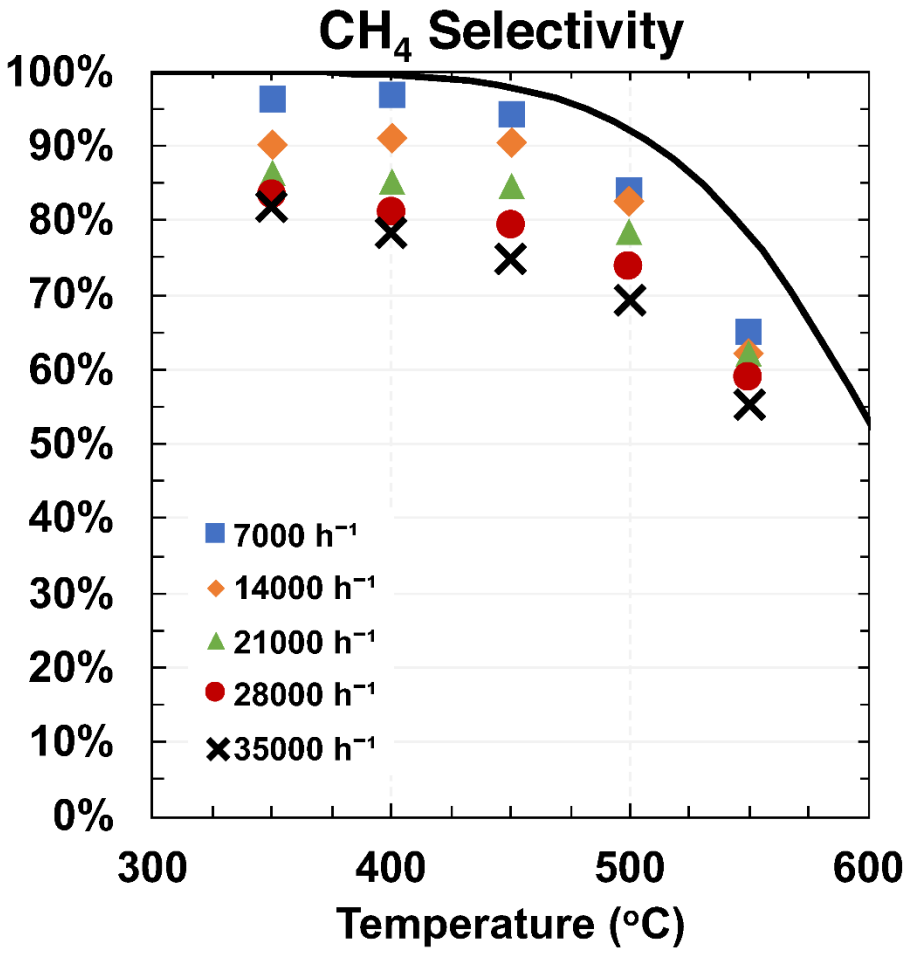
CH_4 selectivity



Ideal operating temperature appears to be near 450 – 500 °C

As expected, higher CO_2 conversion & CH_4 selectivity are found with lower Gas Hourly Space Velocity





Reasonable conversion and selectivity at 14,000 hr $^{-1}$, 450 ºC

In summary, CSM has demonstrated encouraging preliminary results with the Sabatier Electrolyzer

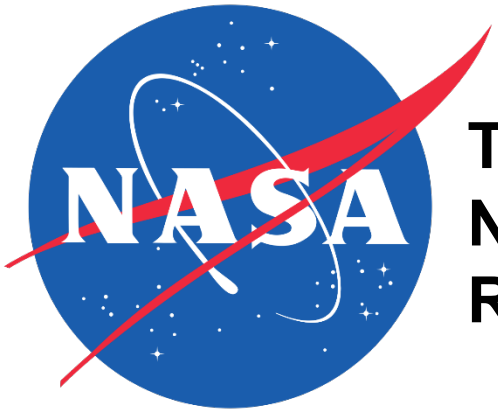
- Stability of proton-conducting ceramics in high CO_2 is evident
  - Over 100 hours of continuous operation with no performance degradation
- Encouraging CO_2 conversion and CH_4 selectivity demonstrated
  - All tests to date reflect the zero-electrolysis "bound"
  - CO_2 conversion over 60% at 450 ºC
  - CH_4 selectivity over 80% at 450 ºC
- Gas Hourly Space Velocity can dramatically alter performance
  - Reasonable CO_2 conversion and CH_4 selectivity at 14,000 hr^{-1}

Going forward

- Explore the other "bound" of Sabatier Electrolyzer
  - All hydrogen produced through electrolysis of H_2O
- Execute energy efficiency and mass analyses
  - Compare results with current state-of-the-art

Acknowledgements

U.S. National Aeronautics and Space Administration (NASA)



This work is supported by a NASA Space Technology Research Fellowship

Thank you for your kind attention!

Colorado Fuel Cell Center