Mars Oxygen and Methane System (MOMS)

Space Resources Roundtable
XXV Meeting June 3-6, 2025

SPACE RESOURCES ROUNDTABLE

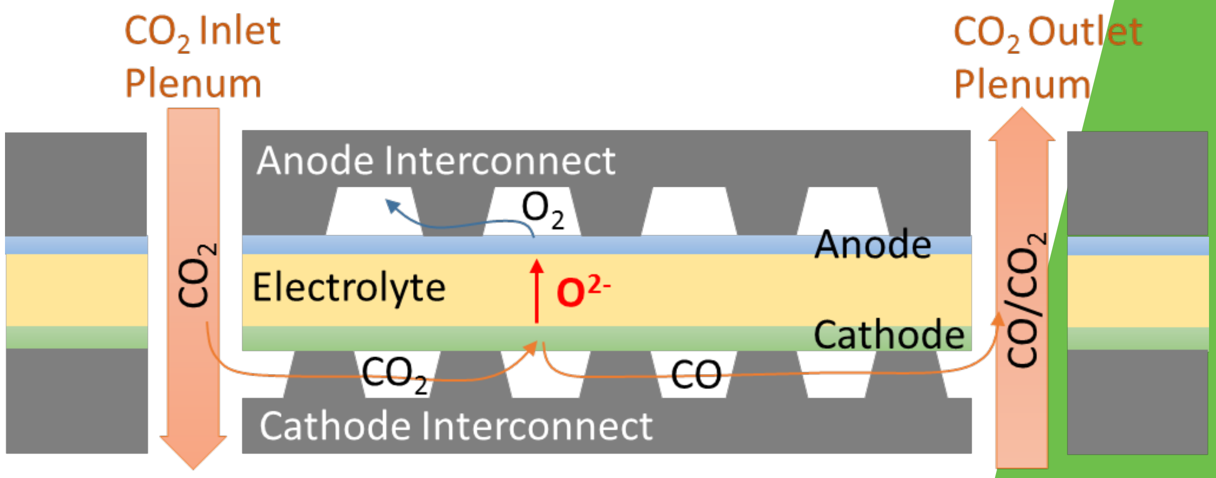
COLORADO SCHOOL OF MINES

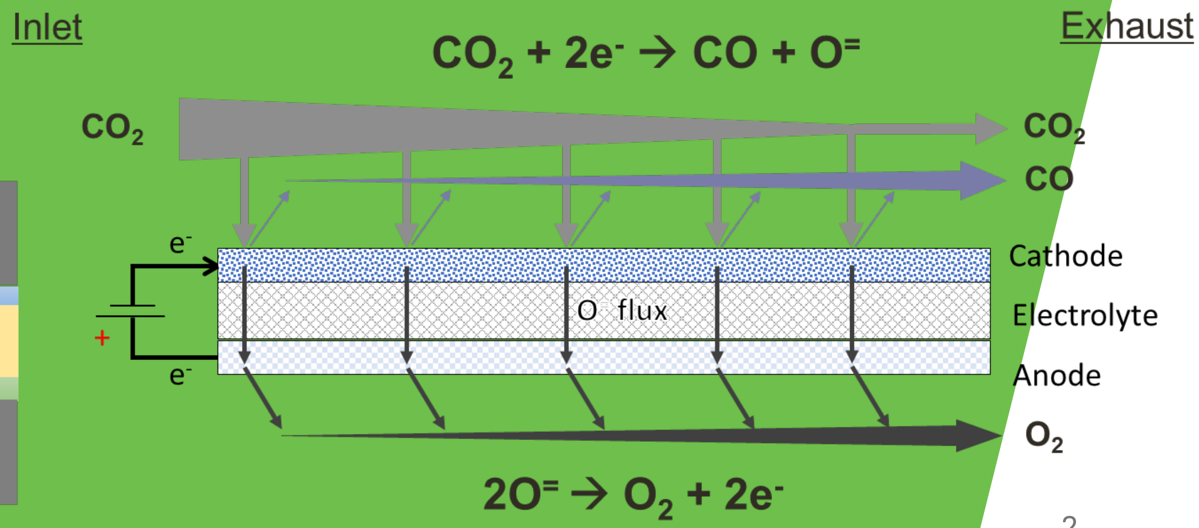
OxEon energy
Beyond Current Potential

Mars OXygen ISRU Experiment—MOXIE

Solid Oxide Electrolysis for ISRU

- CO_2 to CO and O_2 via solid oxide electrolysis cell (SOEC)
- Production of propellant and consumable oxygen from the Martian atmosphere
- ~0.5% scale prototype of expected final O_2 production rate



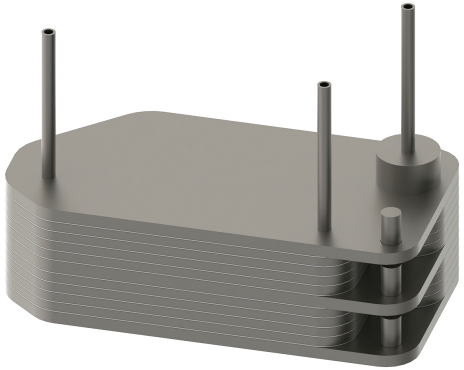


MOXIE: Program Overview

SOEC for ISRU

NASA funded flight program

- First space ISRU demonstration
  - Produced oxygen from Mars atmospheric CO_2 via SOEC device
- Operated successfully on Mars 16 times
  - Operations spanned the climatic extremes of the Martian day and seasons of the year
- All cycles performed as predicted: lab & models
  - >99.6% purity O_2 product
- Met all operational objectives



Partnerships


TIME

← THE BEST INVENTIONS OF 2023

Breathing Martian Air

NASA MOXIE

Technicians in the clean room are carefully lowering the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument into the belly of the Perseverance rover. R. Lannom—NASA/JPL-Caltech

BY JEFF WILSER

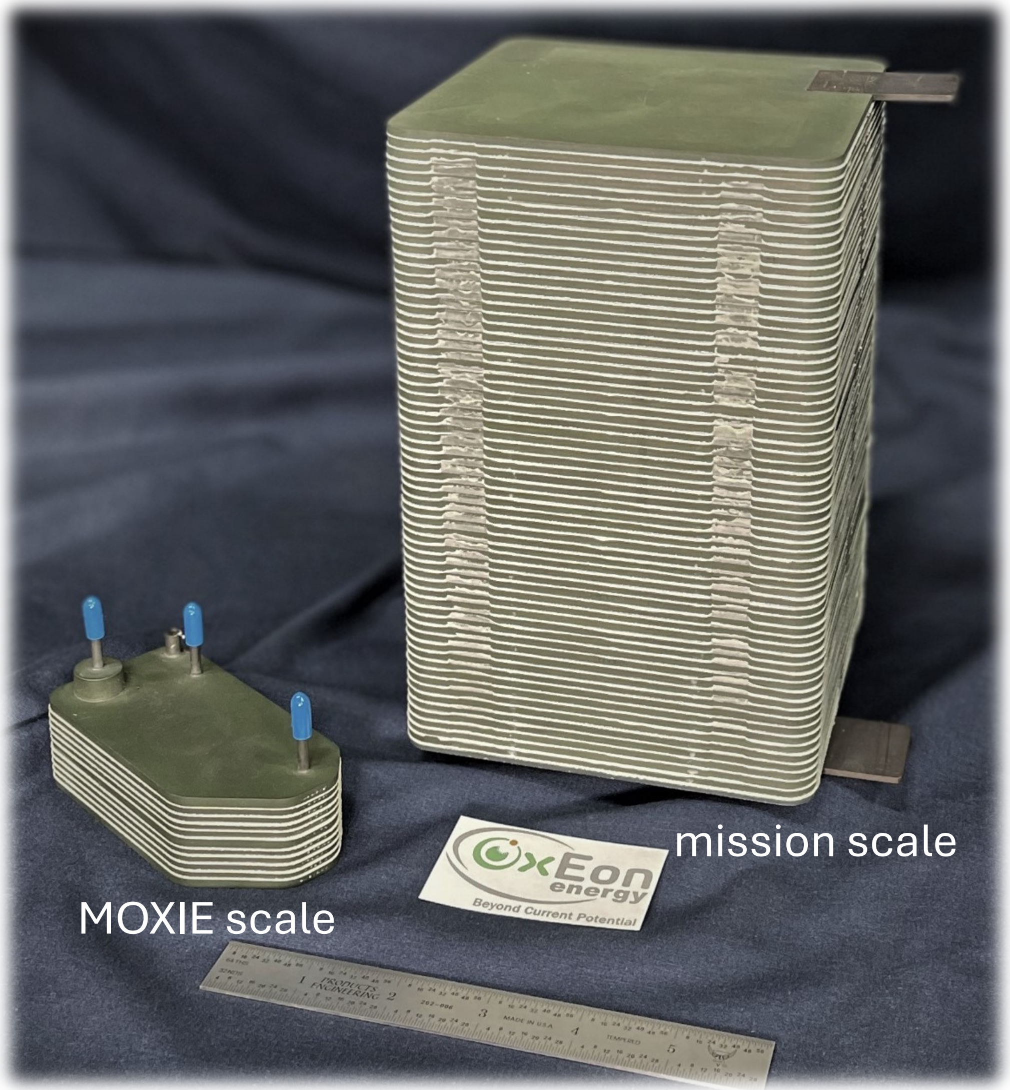
OCTOBER 24, 2023 7:00 AM EDT

Mission Scale SOEC

SOEC device scale-up

- 5x increase in cell area
  - Cell current scales with active area
- 7x increase in cells per stack
  - Total voltage scales with cells in stack
- Scaled SOEC devices have demonstrated expected production increase relative to cell area and cells/stack

- 6 mission scale stack (4 + 2 spares) would be capable of producing 30 tons propellant O_2 to fuel MAV in 19-month window from Mars landing to next launch



MOXIE capability extension

SOEC operational flexibility

Steam Electrolysis ($H_2O \rightarrow H_2 + O_2$)

- Higher productivity
- Multi-stage can achieve >99% utilization

Dry CO_2 electrolysis ($CO_2 \rightarrow CO + O_2$)

- Limited by CO reduction potential

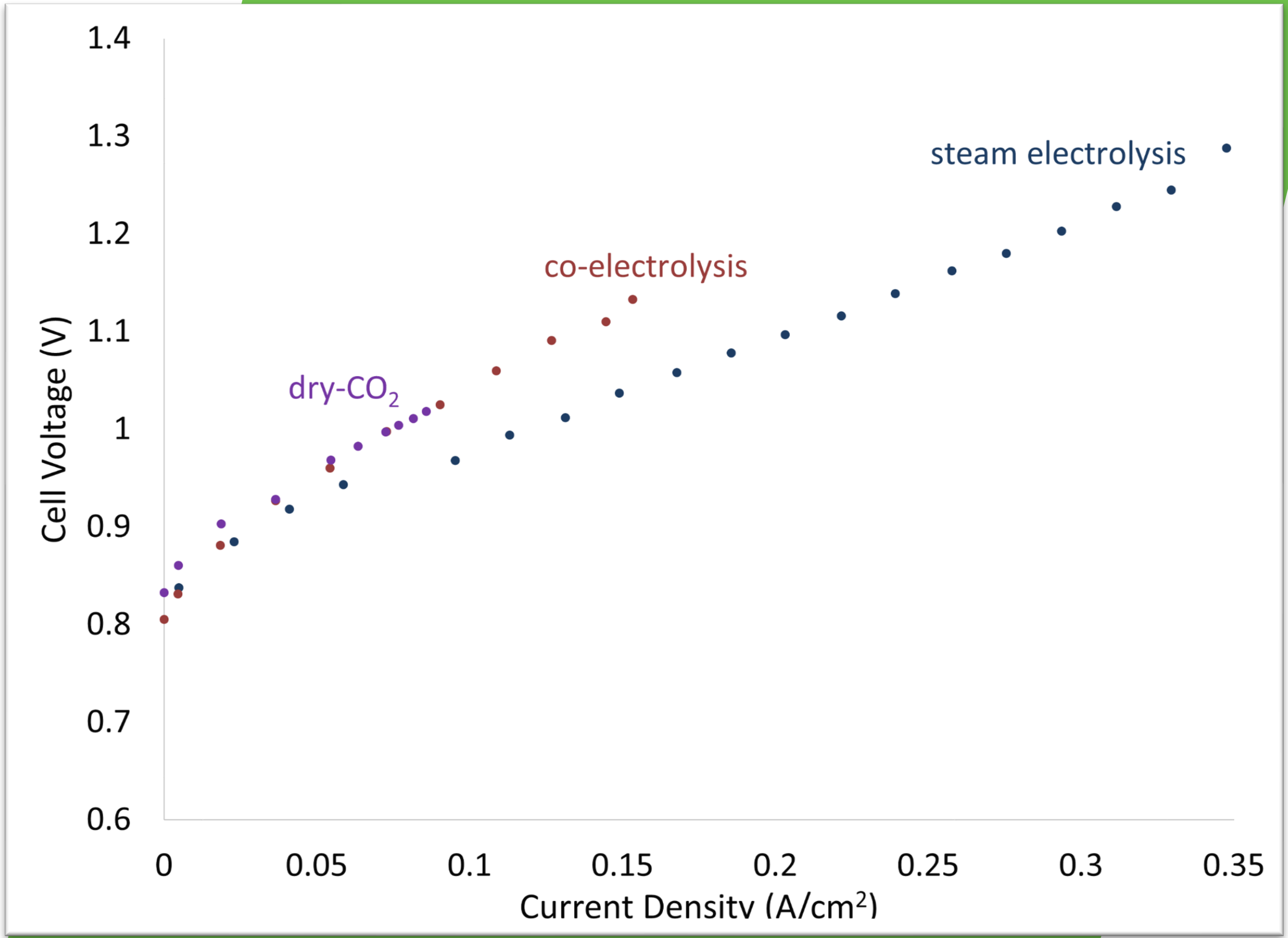
Co-electrolysis

$$(H_2O + CO_2 \rightarrow H_2 + CO + O_2)$$

- Productivity nearer dry CO_2 than steam
- Modest performance dependence on H_2O/CO_2 feed ratio

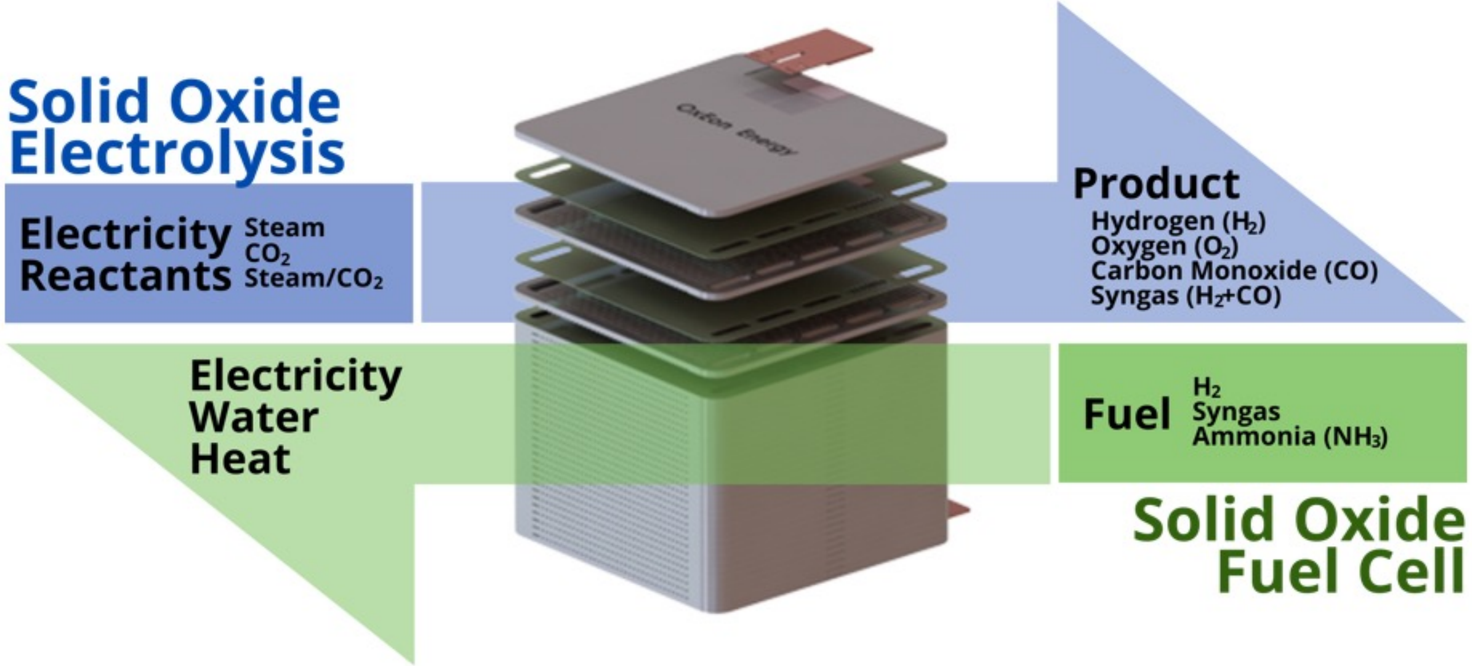
Flexibility in feed composition to SOXE demonstrated

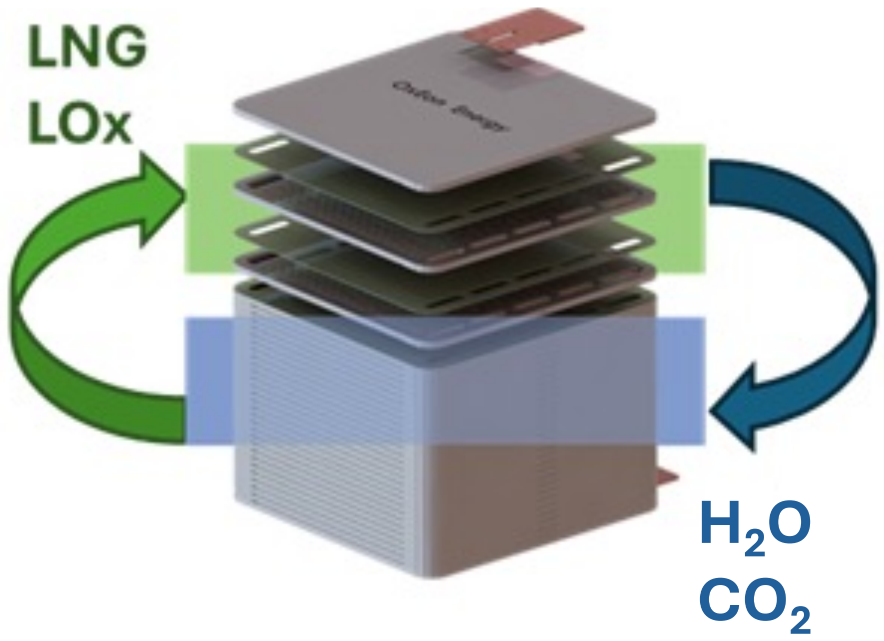
- Can vary inlet to match desired syngas composition



Same device operates in both SOEC (electrolysis) and SOFC (fuel cell) modes

- SOEC operation with dry-CO2, steam, and mixtures of steam/CO2
- SOFC operation with H2, syngas, ammonia
- Potential to alternate modes of operation based on system demands

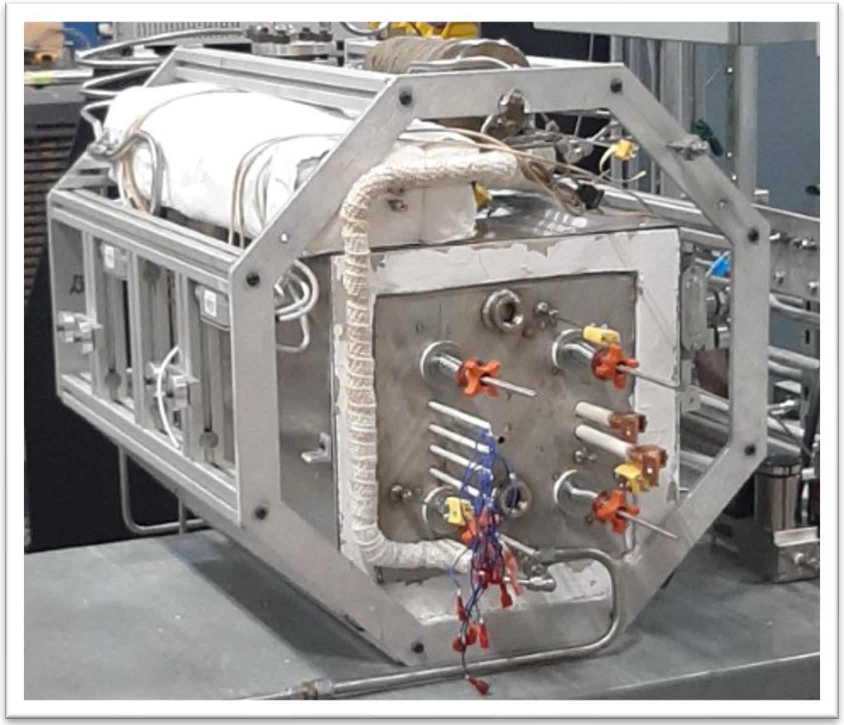


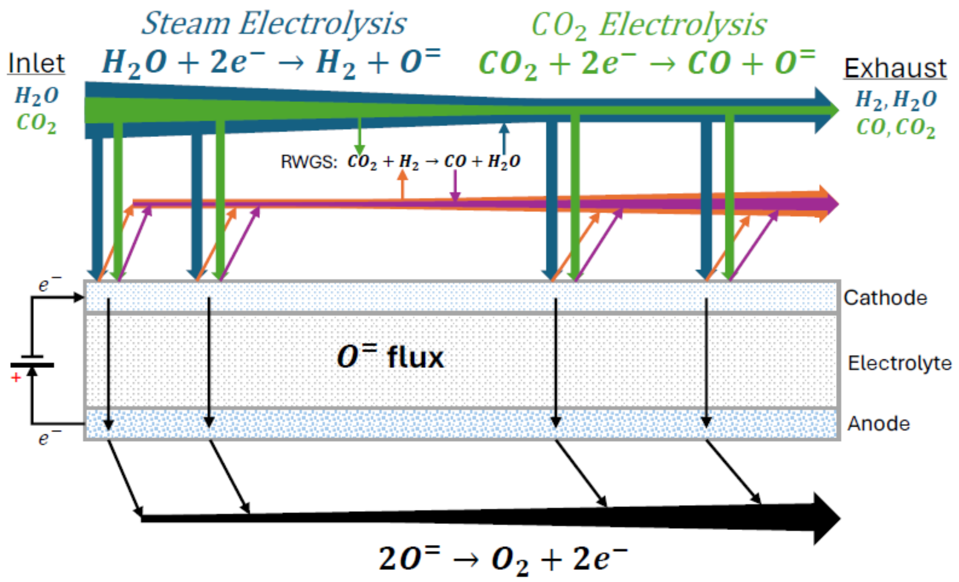


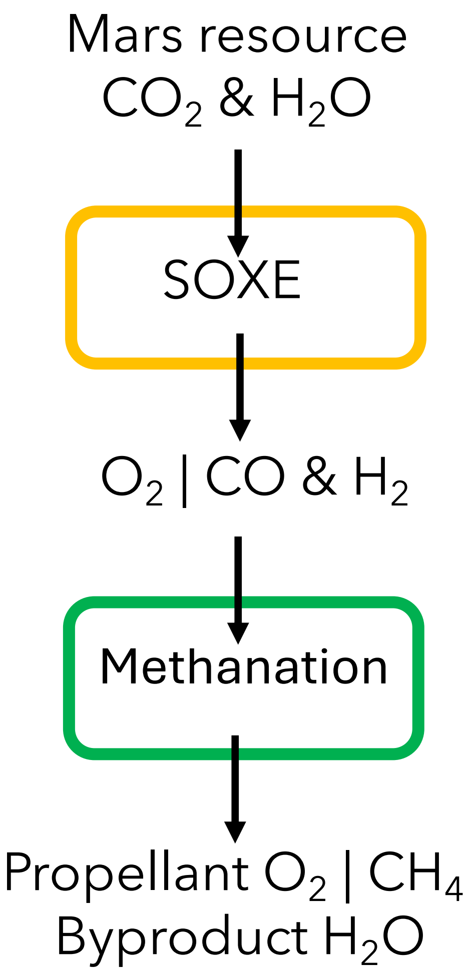
Mars Demonstration System

Mars ISRU of CO2 and H2O for propellant CH4 and O2 production

- Mission scale SOEC stack for co-electrolysis of CO_2 and H_2O to syngas with targeted composition
- Integration of SOEC with methanation reactor to convert syngas
- Prototype system test in JPL Mars chamber for TRL6







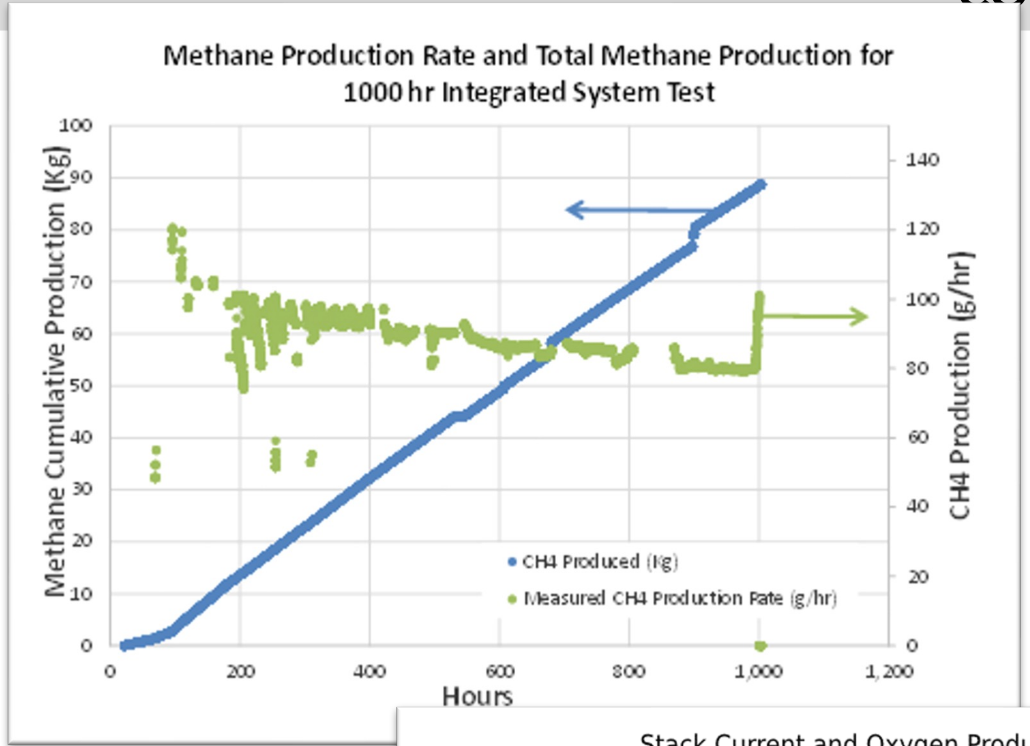
Mars Demonstration Testing

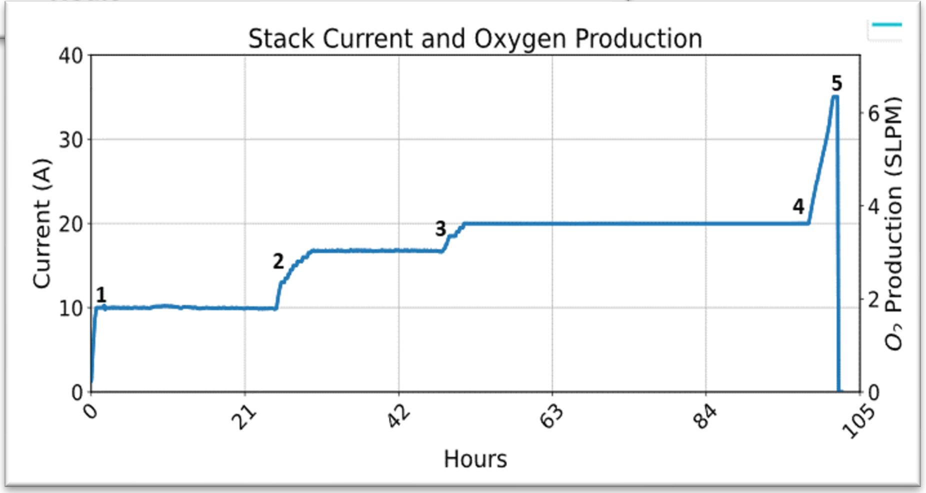
SOEC standalone test
- 1,000 hours
- Dry-CO_2, co-electrolysis, and steam electrolysis demonstrated with mission-scale stack

Methanation reactor standalone test
- 1,500 hours

Integrated system test
- Ambient conditions for 1,000 hours
- Relevant condition test in JPL Mars chamber for 100 hours

Mission Scale SOEC stack extended operation
- Three thermocycles demonstrated
- Total of 2,500 hours of operation
- Demonstrated target O_2 and CH_4 production rates, SOXE produced O_2 purity > 99.9%





MOMS–Mars Oxygen and Methane System

Mars ISRU

Key Performance Parameters								
Parameter	**Units**	**State of the Art (SOA)**	**Threshold Value**	**Project Goal**	**Current Value To Date**	**Current Value: Technical Basis of Estimate**	**Expected Exit Value**	**Exit Value: Technical Basis of Estimate**
Integrated breadboard system O_2 production rate	kg/hr	0.4 [1]	1.0	3.0	0.4	Substantiated	1.7+	OxEon SOXE stack testing adjusted for planned system size
Oxygen product pressure	bar	2 [2]	2	4	1	Nominal Operation	2+	MOXIE qual, analysis, short duration testing
Overall CO_2 to CH_4	%	55[3]	60	80	30	Nominal Operation	65	System trade-study optimization task with SOXE coking resistant materials

Notes: Examples

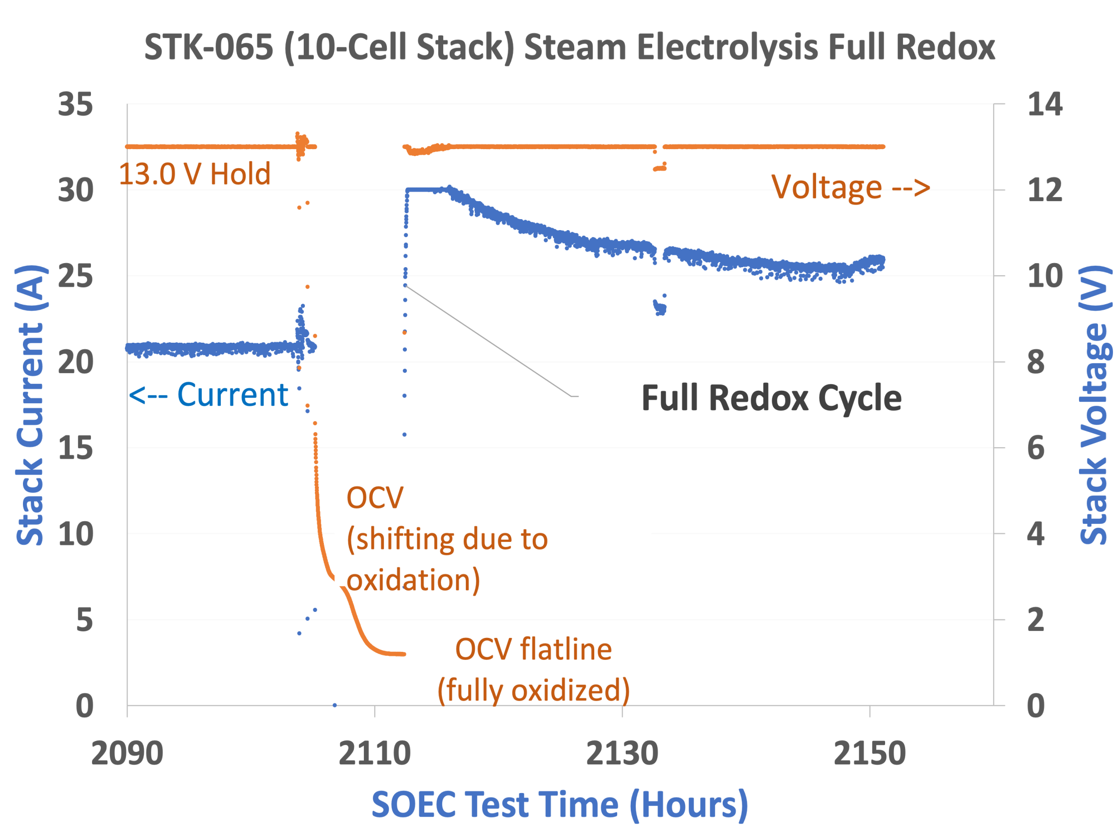
(1) SOA as demonstrated by OxEon's NASA NextSTEP-2 ISRU system is a single 65-cell SOXE stock run nominally at 20 A to produce 0.4 kg/hr O_2. Program KPPs will be achieved through a combination of scaling stack size, increasing modular SOXE unit from 1 stack to 4 stacks, and materials testing/development to increase nominal co-electrolysis operation to > 20 A.

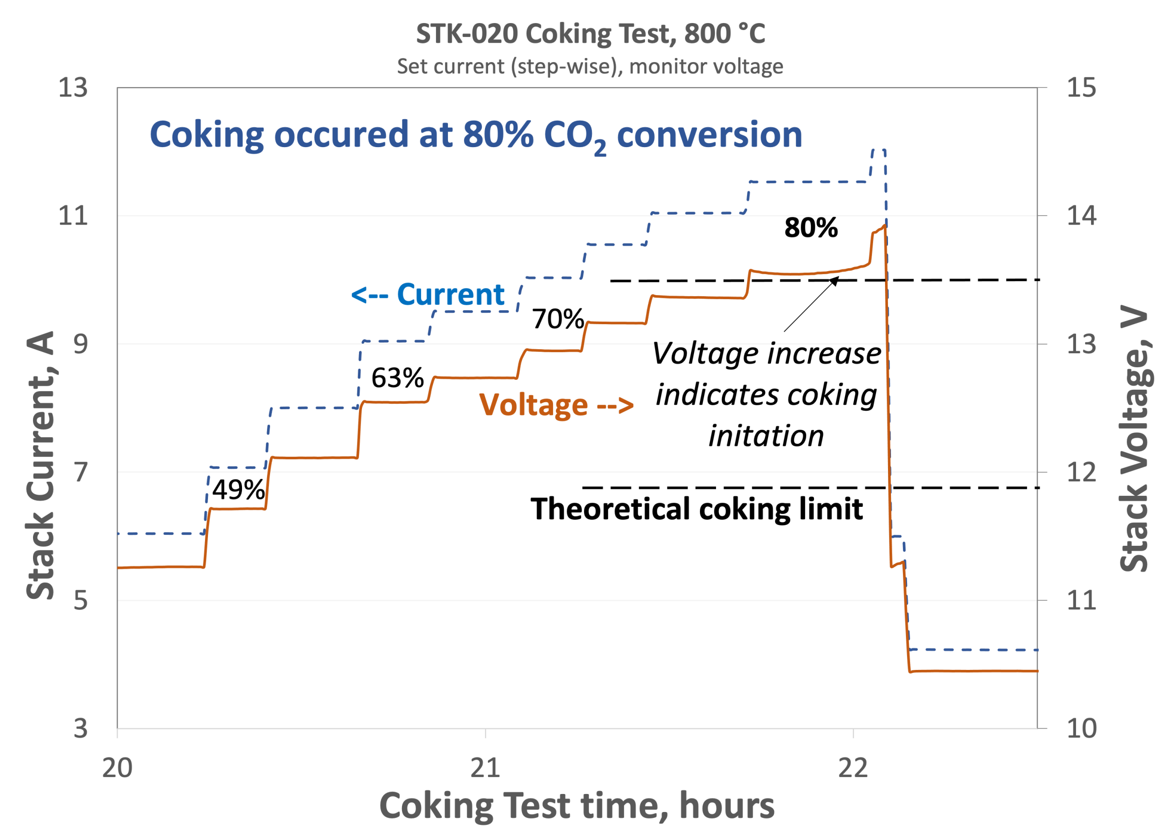
(2) SOA as demonstrated briefly by OxEon's NASA Tipping Point system during relevant condition testing. This program KPP will demonstrate SOA value for a longer duration test to verify SOXE capability for delivering oxygen product at pressure.

(3) SOA as demonstrated by OxEon's NASA NextSTEP-2 ISRU system during briefly at the end of test when stack current was pushed above theoretical coking limit.

NASA SBIR Phase II Material Development

- Goal to develop a redox tolerant cathode material set to eliminate the risk associated with a recycle loop
- Material set appears to provide coking tolerance to allow for higher conversion of the stack CO_2 feeds





Materials Development–anode

MOMS materials development (current effort)

MOMS

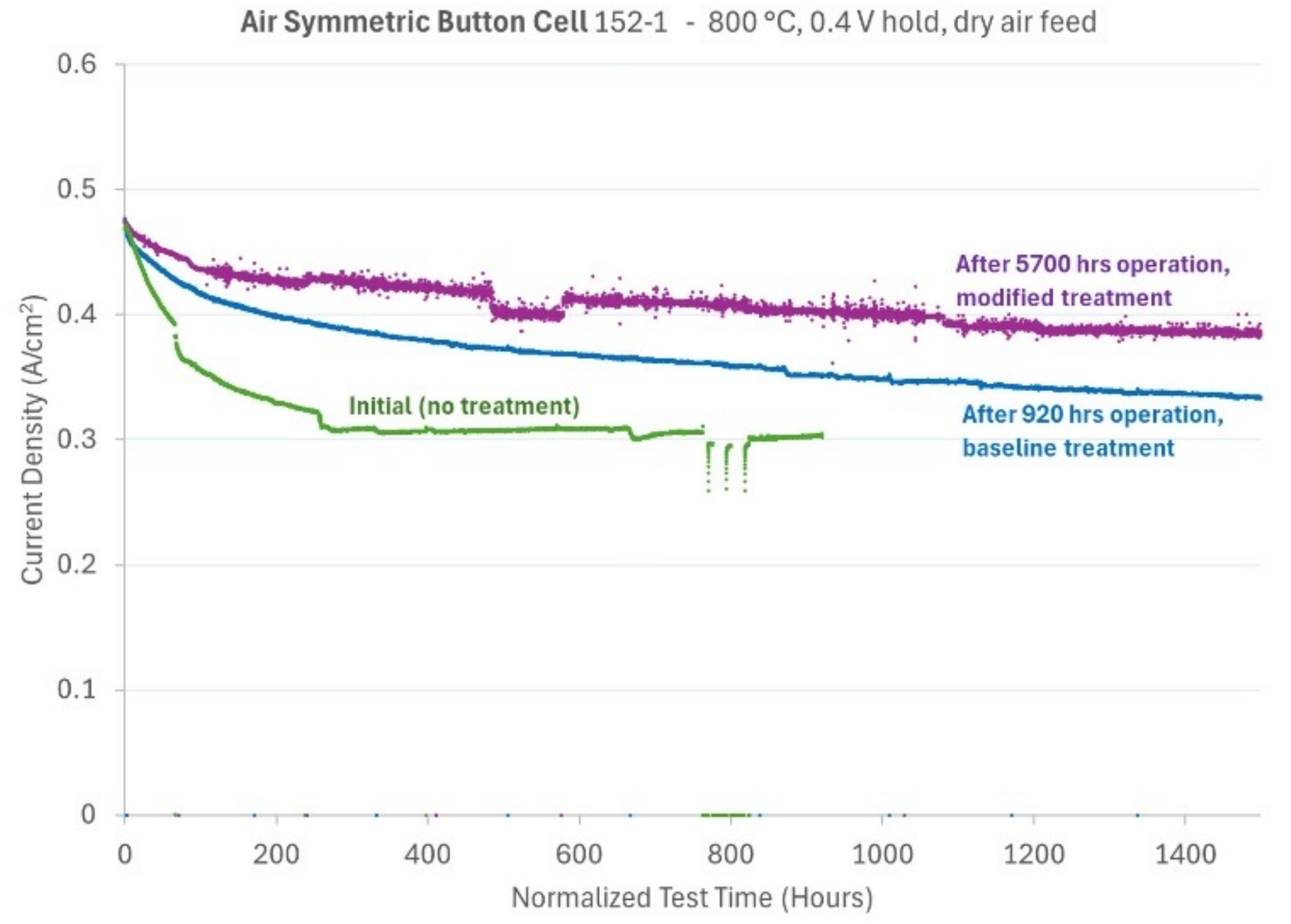
Air side improvements

- Improved procedure for air side barrier layer has resulted in better coverage and density

- **Air side treatments for improved stability**

Plot shows the same button cell for:

- Initial 920 hours performance with no treatment
- Catalyst infiltration returns cell to full performance with improved stability, run for an additional 5000 hours
- Catalyst stabilizer returns cell again to full performance with improved stability compared to first two runs



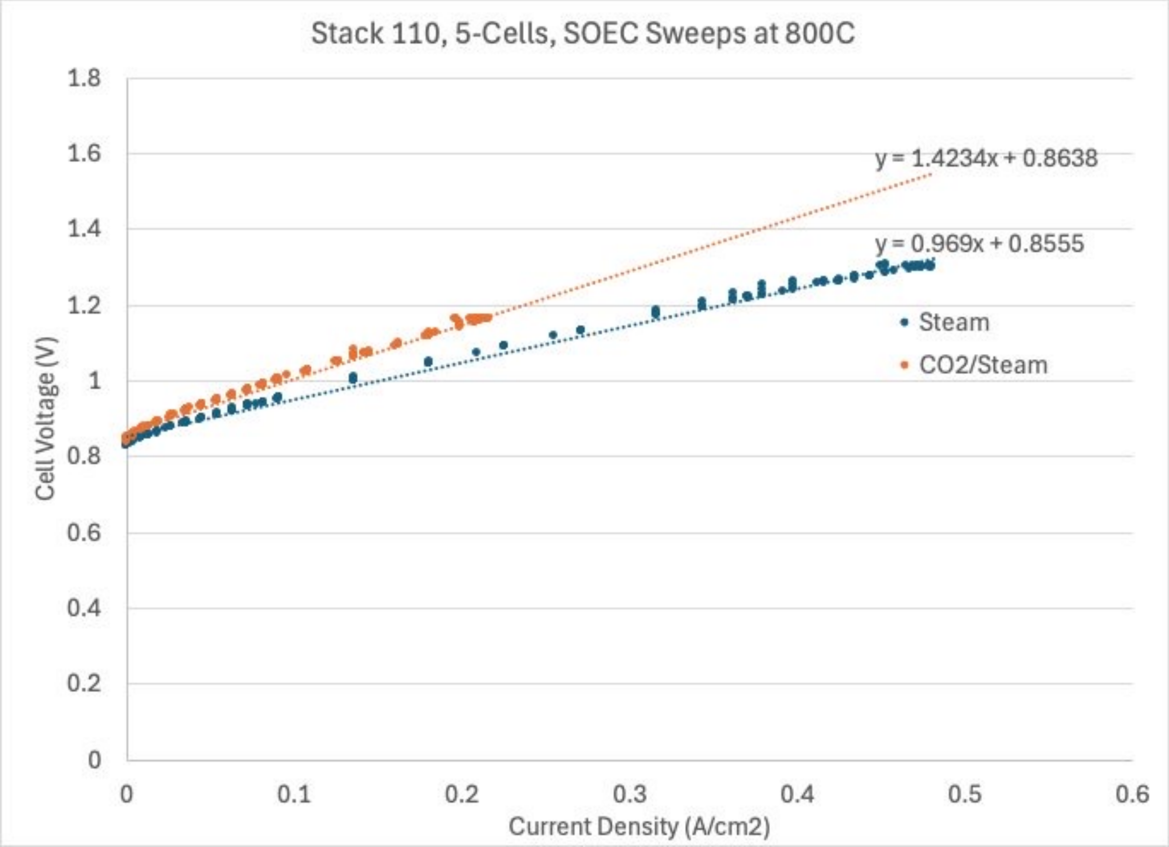
Materials Development–anode

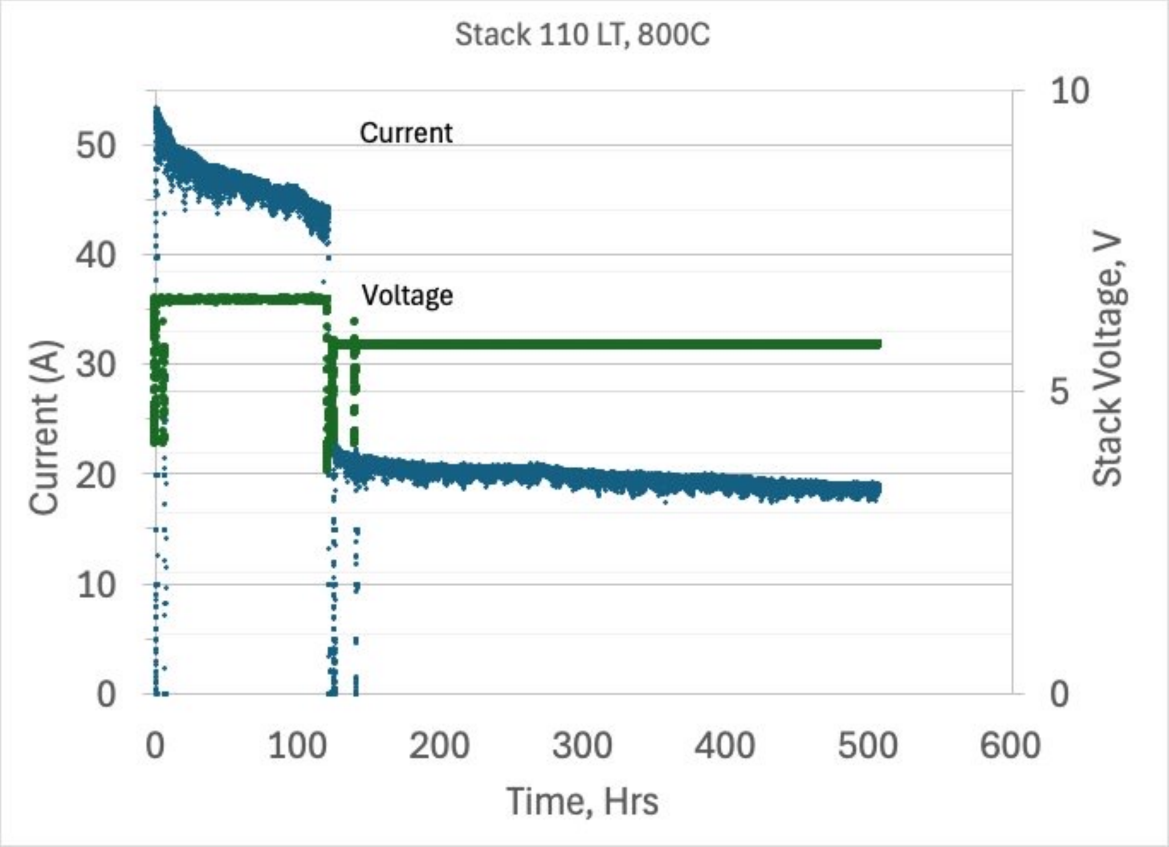
MOMS materials development (current effort)

MOMS

Full size cells used for a 5-cell stack

- Initial sweeps with steam and steam/CO_2 showed ~25% greater current





Planned stack testing

Long term testing

- 20-25 cell stack
- 5,000-10,000 hours of operation planned

Short term carbon formation resistance testing

- Increase stack voltage at regular intervals until carbon formation observed
- 10-cell and 60-cell stacks

Coking kinetics testing relative to carbon formation potential

- 3, 25-cell stacks to evaluate operation at a set stack voltage for 1,000 hours
- Stack voltages will be based on carbon formation potential (below, equal to, above)

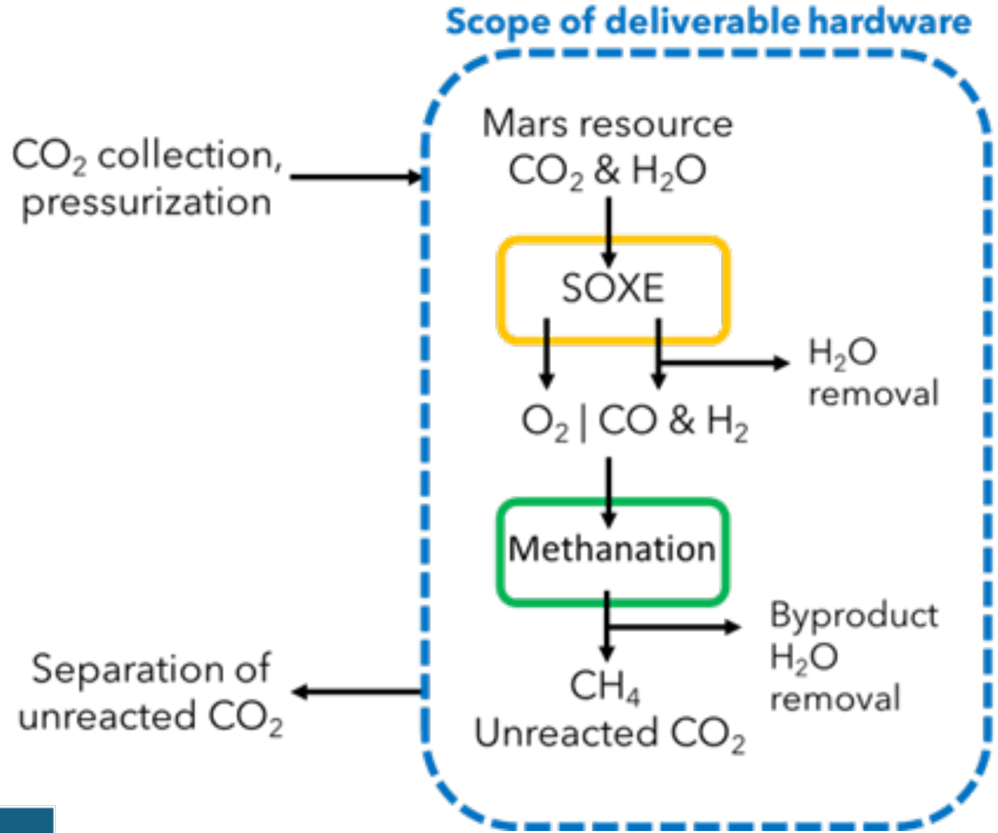
Performance mapping

System simulation to optimize performance and size hardware

- Stack feed conversion
- Operating pressure
- Intrinsic Area Specific Resistance
- Syngas H_2/CO ratio
- Operating voltage

Working with NASA subject experts

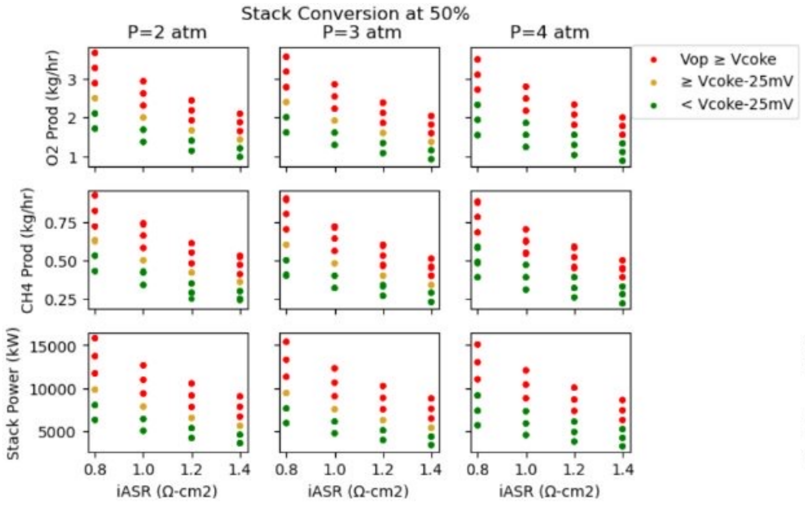
- CO_2 collection, compression
- Downstream product handling

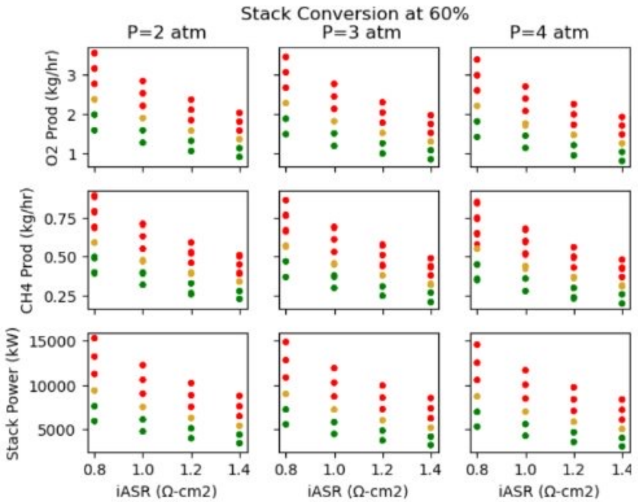


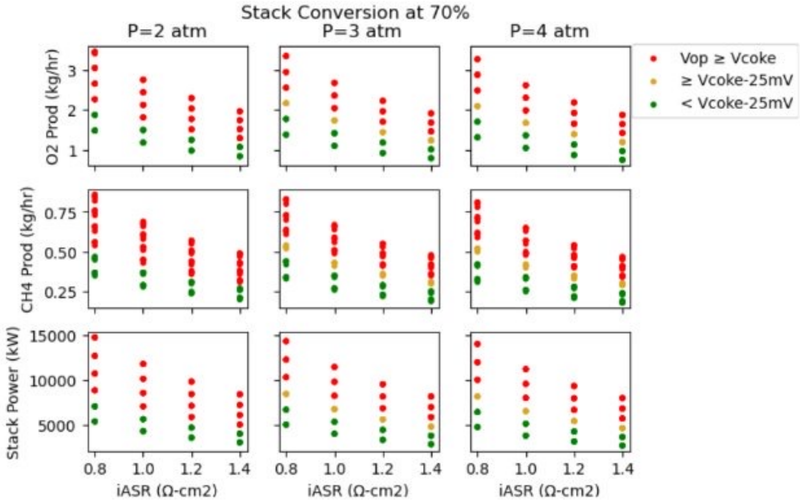
Simulation Parameters					
	Single Pass Stack Conversion (%)	Pressure (bar)	intrinsic Area Specific Resistance (Ω-cm2)	H2:CO Ratio	Operating Voltage (V)
Low	0.5	2	0.8	3	1.100
High	0.8	4	1.4	5	1.285

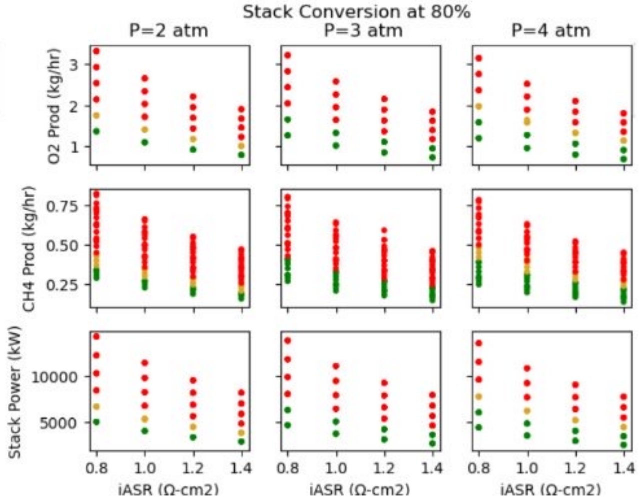
Performance Mapping

MOMS



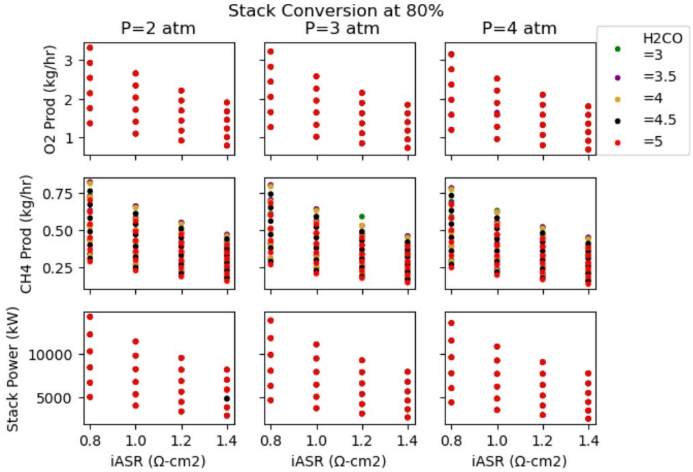






Initial results for hardware sizing

- iASR is most significant factor in stack productivity
- Ability to operate stack above carbon formation potential will improve production for a given device
- O_2 compression has minimal impact on stack power



Path Forward

MOMS

- Materials development will provide basis for 5,000-10,000 hour test (start Q3 2025)
- Mechanical design for deliverable hardware (Q3-Q4 2025)
- Stack testing for carbon formation resistance (2026)
- Hardware fabrication (2026)
- Hardware test demonstration (2026)

Solid Oxide Electrolysis for Space Application

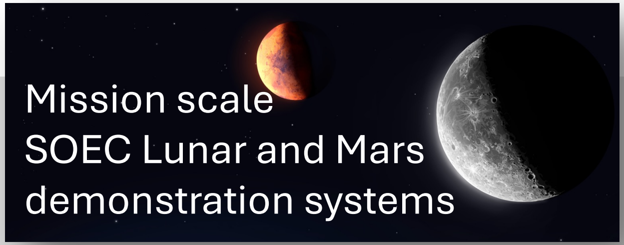
In situ resource utilization

SOXE device for MOXIE

- Only flight qualified SOEC stack in history
- Only TRL9 SOEC device in history
- First ISRU demonstration
  - Produce O_2 from Mars Atmosphere

MOXIE team

- MIT: Science Team Lead
- JPL: System integration & Qual
- **OxEon: SOEC development and production**

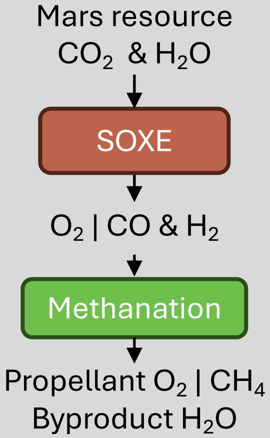


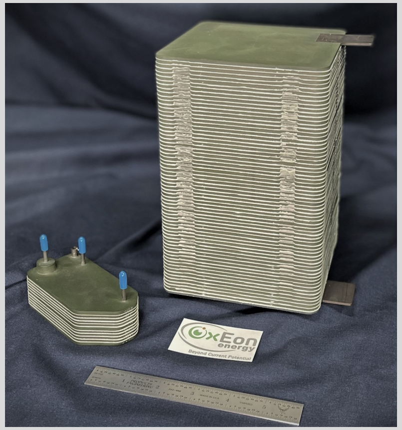
Scale-up of SOXE device

- 5x increase in cell area
- 6.5x increase in cells per stack

<u>Lunar ISRU</u>: production of propellant H_2 and O_2 from Lunar PSR ice

<u>Mars ISRU</u>: production of propellant O_2 and CH_4 from Mars CO_2 and H_2O





Mars Oxygen and Methane System (MOMS), next gen

- Target production of 1-3 kg/hr O_2 and associated CH_4 from H_2O and CO_2
- High purity (>99.6%) O_2 at 1-4 bar_a
- Overall CO_2 to CH_4 60-80%

Testing of new materials

- Coking tolerance
- Long term stability (10,000 hours)
- Contaminant exposure

Thank you

Questions: michele@oxeonenergy.com

Beyond Current Potential