


Solid Oxide Electrolysis Stack Development for Oxygen Production by In-Situ Resource Utilization on Mars

Hannover Messe, Technical Forum
April 27th, 2017

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MOXIE: PROGRAM OVERVIEW

"The Oxygenator"
1 of 7 major experiments to fly on the \$2.1 billion Mars 2020 Mission

Demonstration of In-Situ Resource Utilization (ISRU) technologies to enable propellant and consumable oxygen production from the Martian atmosphere
MOXIE is a ~0.5% scale prototype of expected final O₂ production

Solid Oxide Electrolysis (SOXE) Development Team
Supported by NASA and the Jet Propulsion Laboratory (JPL)

Mars2020 Mission Overview



LAUNCH

- MSL Class/Capability LV
- Period: Jul/Aug 2020

CRUISE/APPROACH

- 7.5 month cruise
- Arrive Feb 2021

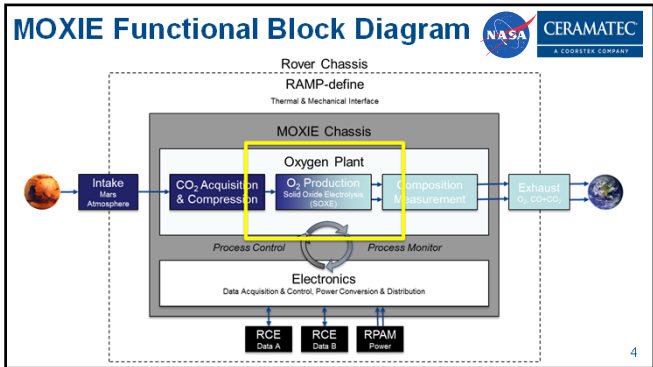
ENTRY, DESCENT & LANDING

- MSL EDL system guided entry and powered descent/Sky Crane
- Access to landing sites ±30° latitude, 5-0.5 km elevation
- ~950 kg rover

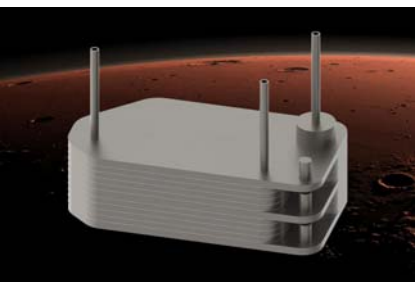

SURFACE MISSION

- Prime mission of one Mars year
- 20 km traverse distance capability
- Seeking signs of past life
- 7+ Instruments on board
 - International instrument teams
- Returnable cache of samples
- Prepare for human exploration of Mars

<http://mars.jpl.nasa.gov/mars2020/>




SOEC on MARS?

MOXIE: Operational Design Drivers

	Heritage	SOXE
Gas Flow	Cross flow	Internally manifolded for O ₂ Purity & dP
Feed	Steam + feed gas	DRY CO ₂ in a range of 30-80 g/hr
Product	System Dependent	99.6% Pure O ₂ , internal manifolding
Structural	Stationary Applications	Robust to survive Launch, EDL Shock and Vibe, Compression Load Requirements
Power	As Needed	Highly constrained
Mass	As Needed	1 kg max
Volume	As Needed	Rigidly constrained
Operation	Continuous runs (10,000+ hours)	20+ 120 minute cycles
Heating Ramps	100°C/hour from ambient to 800C	90 minutes (~515°C/hour) from ambient (potentially -40°C) to 800°C
Heat Application	Stack housed inside furnace enclosure	Heaters on endplates only

Ceramatec SOXE

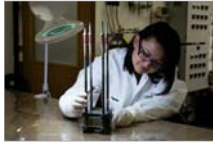


MOXIE: Materials Design Drivers



24 month development timeline from kickoff to the Manufacturing Readiness Review/Flight Qualification

	Heritage	SOXE	Reason for Change
Interconnects (IC)	Stamped Ferritic Stainless	Powder metallurgy (CFY, Plansee)	CTE Match between IC and electrolyte for durable sealing
Seals	Edge Rail/Compression	Glass Seals	Internal Manifold for O ₂ purity requirements, dP
Current Busbars	Welded Tabs	Brazed rod / welded wire	Mass and heat leak path reduction, change in interconnect material
Feed Manifolds	Cross flow	Inlet tube/internal manifold	O ₂ purity
Anode Electrode	Perovskite	Perovskite	Same class
Cathode Electrode	Ceramtec proprietary Cermet	Modified proprietary Cermet	Limit degradation during operational cycling
Electrolyte	ScSZ	ScSZ	No change



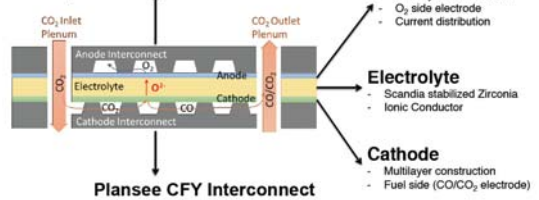
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MOXIE: Cell Design



Plansee CFY Interconnect

- Provides Electrical Connection between adjacent cells
- Separates gas from anode and cathode of cells
- CTE matched to that of the electrolyte for sealing capabilities



Anode

- Multilayer construction
- O₂ side electrode
- Current distribution

Electrolyte

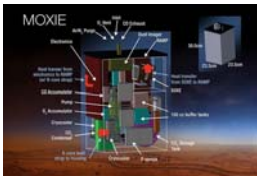
- Scandia stabilized Zirconia
- Ionic Conductor

Cathode

- Multilayer construction
- Fuel side (CO/CO₂ electrode)

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MOXIE: Targets



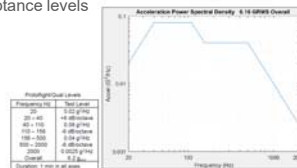
- 20+ full operational cycles – 10 preflight, 10+ mission,
- 60 full operational cycles for proof of extensibility
- Oxygen Purity: 99.6%+ at end of life
- Capability to cycle to -65C proof temperature
- Withstand 8 kN compressive force
- Withstand flight shock and vibrate requirements (PF +3dB)

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MOXIE: Verification Vibration



- For loads caused by flight dynamic inputs, SOXE adopted a demonstration by margin of confidence testing of development hardware:
- Testing conducted at protoflight (PF) + 3dB levels, demonstrating 2x margin (+3dB) on flight acceptance levels



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MOXIE: Verification Thermal



- Stack integrity to thermally induced stresses has been demonstrated by cycling to 3x flight cycles plus temperature margin testing
- Vibe stack cycled to -40°C (40 cycles), -55°C (3 cycles), -65°C (1 cycle)
- Components and brazed joints also tested through low temperature cycling and mechanical testing/inspection

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MOXIE: Verification Shock

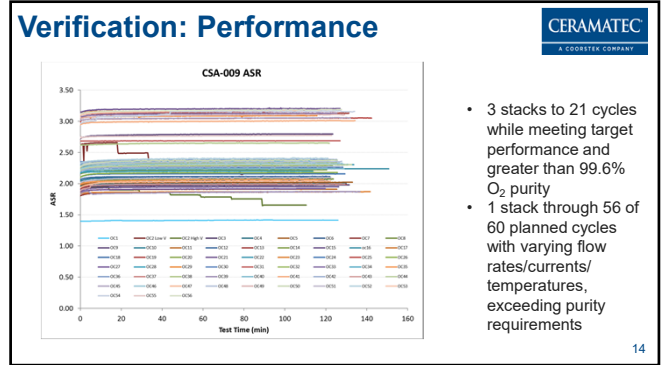
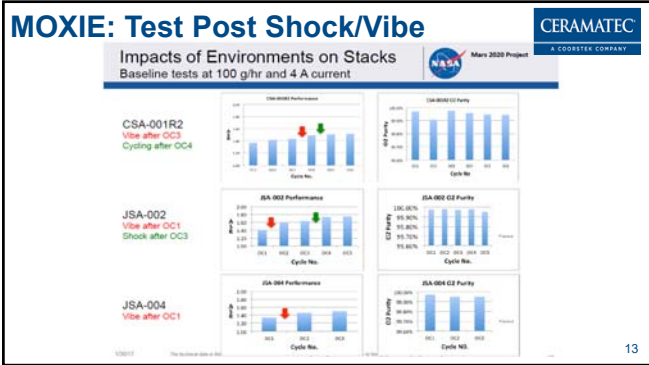


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4" diameter projectile

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MOXIE: Accomplishments

Baseline Performance

- 21 consecutive stacks built with *aerospace quality standards and traceability* having a maximum baseline performance of 1.6 ohm-cm² dry CO₂ and 99.9%+ O₂ purity

Cycling Performance

- 3 stacks with 21 cycles of identical test procedure having varying cycle-to-cycle flow rates and final cycle averages of 10.11 g O₂/hr production and 99.8% purity – Targets exceeded
- 1 stack in cycle 56 of 60 with >99.6% purity at a controlled production rate of 6 g/hr at 55g/hr feed

Structural Stability Testing

- No leak or significant performance change after 10kN crush testing
- Stacks tested to 25kN force with no crossover or external leakage
- Only failure required 62.2kN (>30 margin of safety from design)

Shock/Vibe Testing

- Stacks vibrated at JPL and post vibe tested at Ceramatec
- No leak or significant performance change post vibe!
- No leak after shock testing, no significant performance change!

Cryo-Cycling

- Vibe stack cryo-cycled to -40°C (40 cycles), -55°C (3 cycles), -65°C
- Stack performance and purity unchanged in operational cycling post test

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CERAMATEC FUEL CELLS: OUTLOOK

Flight qualification completed and MOXIE flight build cycle underway
Operational modeling underway

Scale-Up and Manufacturing

- Formation of OxEon Energy
- Focus on Scale-up and commercialization of the ruggedized hermetic stack for hydrogen/syngas production, or fuel cell operation

www.OxEonEnergy.com

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Thank You

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