Evaluation studies of a 800W solid oxide-based fuel cells stack for electrical power in aviation

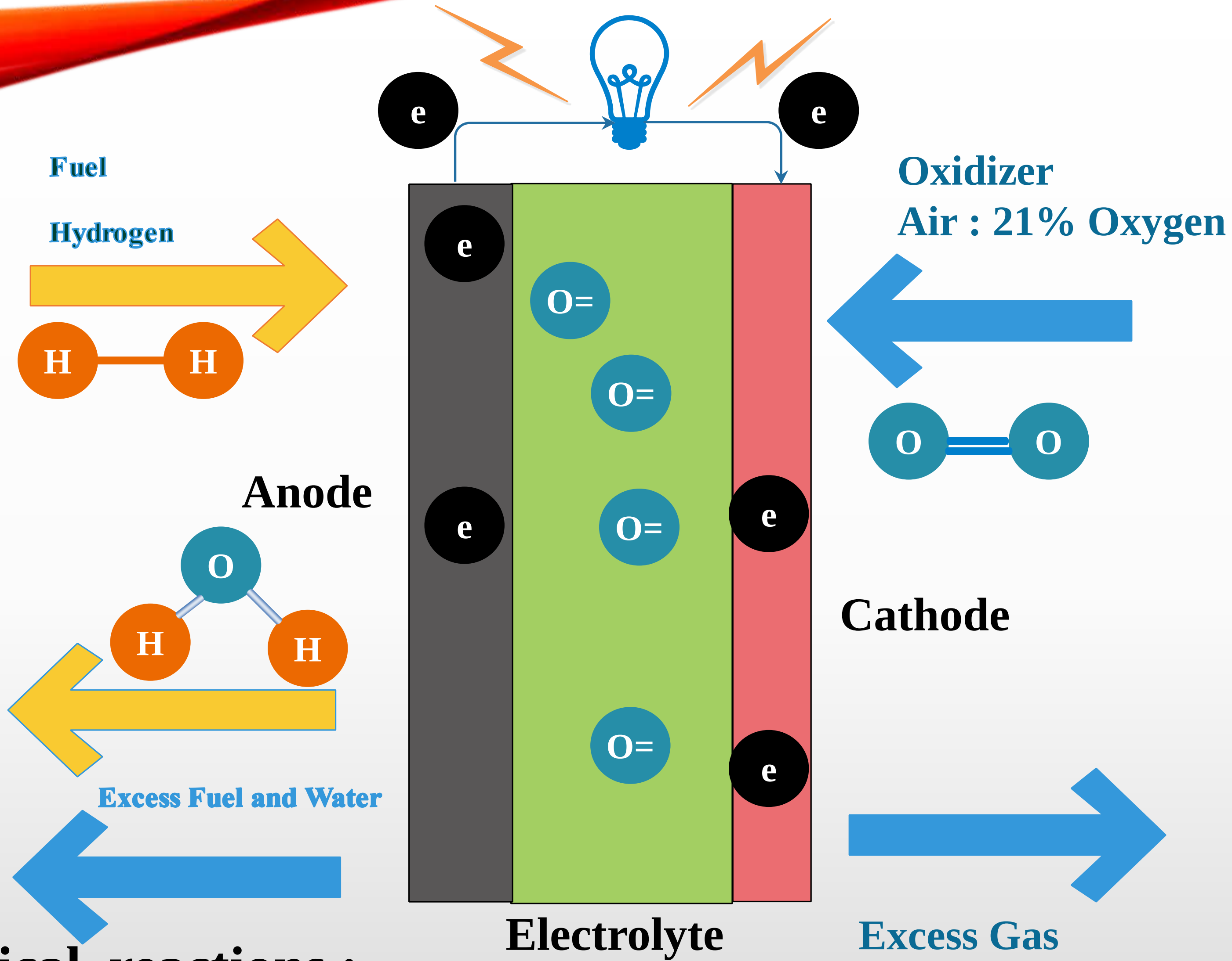
Jon C. Goldsby, Ian J. Jakupca, Serene C. Farmer,
Robert D. Green, Brianne T. Demattia, and Patricia L. Loyselle

NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, Ohio, 44135, USA

- NASA is investigating the feasibility of a hybrid-electric, solid oxide fuel cell power (SOFC) system for generation of electrical power for airborne propulsion and secondary/auxiliary power.

- Investigating the performance of SOFC hardware in aviation-like environments, to establish the barriers, and potential suitability, of this power generation technology for airborne use.

- Typical SOFC configurations, and discusses the test procedures used by NASA to evaluate SOFC performance. It concludes with a report of the early results of these tests, particularly with respect to response after multiple thermal cycles.



The electrochemical reactions :

anode: $1/2\ O_2 + 2e- = O$

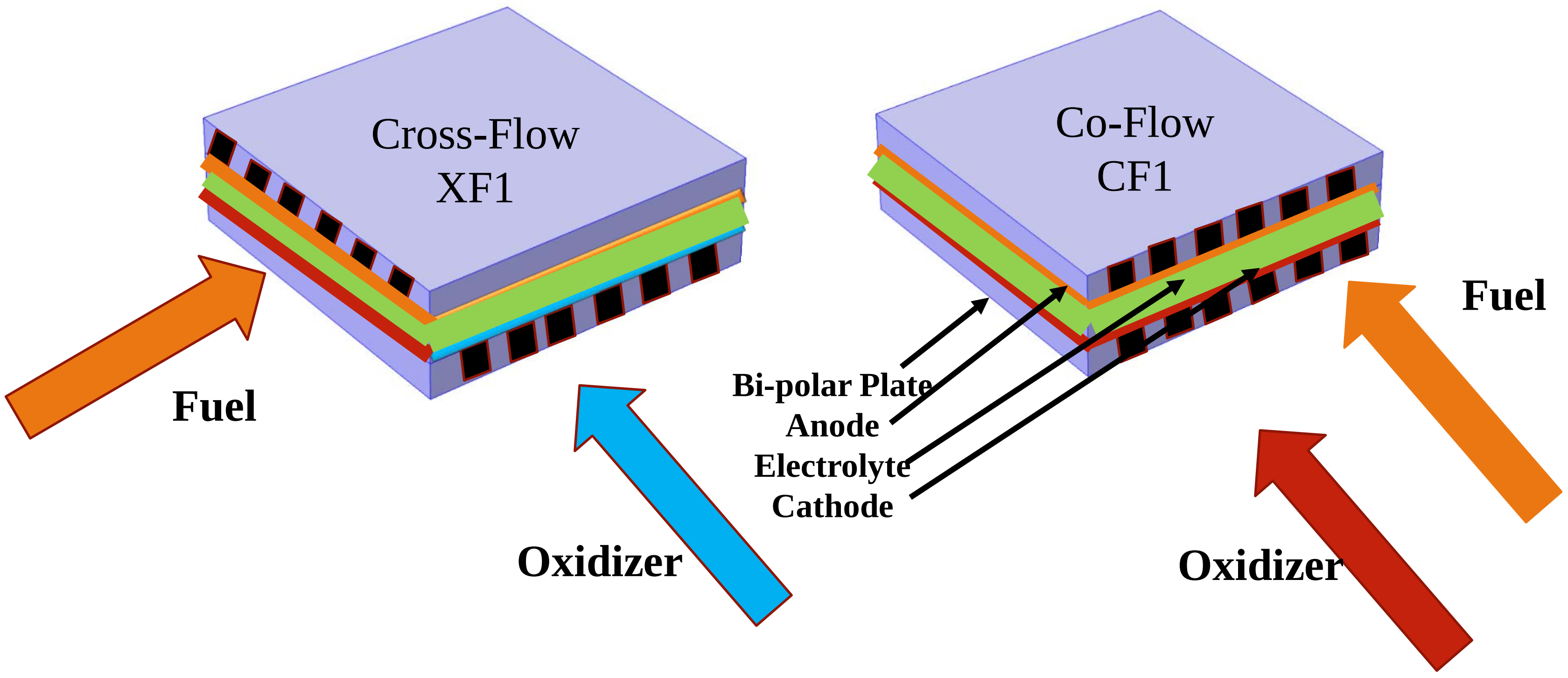
cathode: $H_2 + 1/2O_2 = H_2O + 2e-$

overall cell reaction: $l/2O_2 + H_2 = H_2O$

Solid Oxide Fuel Cell Stack Technology Challenges

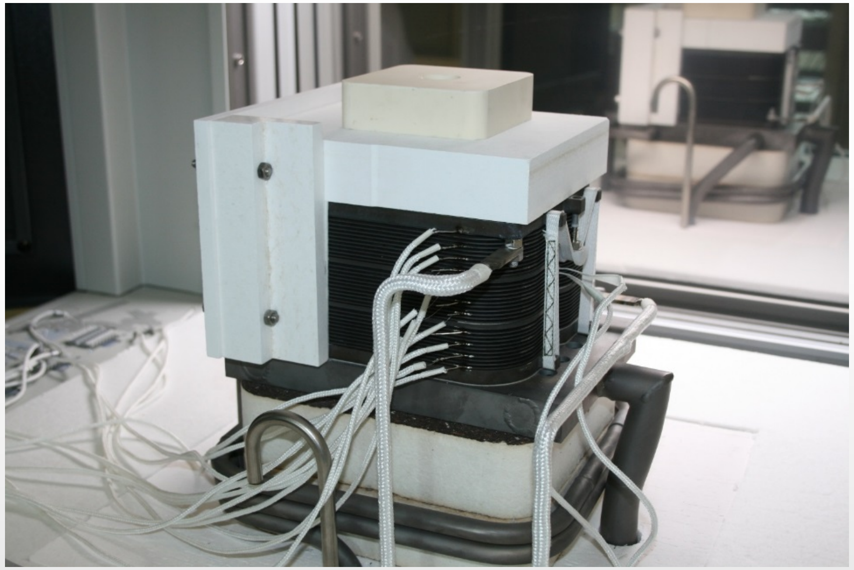
- High temperature operation (800-1000 ^{o}C)
- Thermal cycling
  - CTE mis-match, thermal gradients due to poor thermal conductivity of ceramic layers.
  - start-up time
- Performance degradation
  - Electrode microstructure stability.
  - Anode (delamination of electrode layer under high current density, high ionic O^{2-} flux).
  - .
- Structural integrity
  - Structural materials are brittle (ceramics).
  - Require metal-to-ceramic interfaces.
- Sealing
  - Sealing for long-term high temperature operation. Limited work in other technologies above 700 ^{o}C
  - Thermal cycling adds additional challenges, again due to CTE mis-match between sealing materials and sealing interfaces.
- Packaging
  - High temperature thermal insulation, electrical heaters, gas connections, etc.

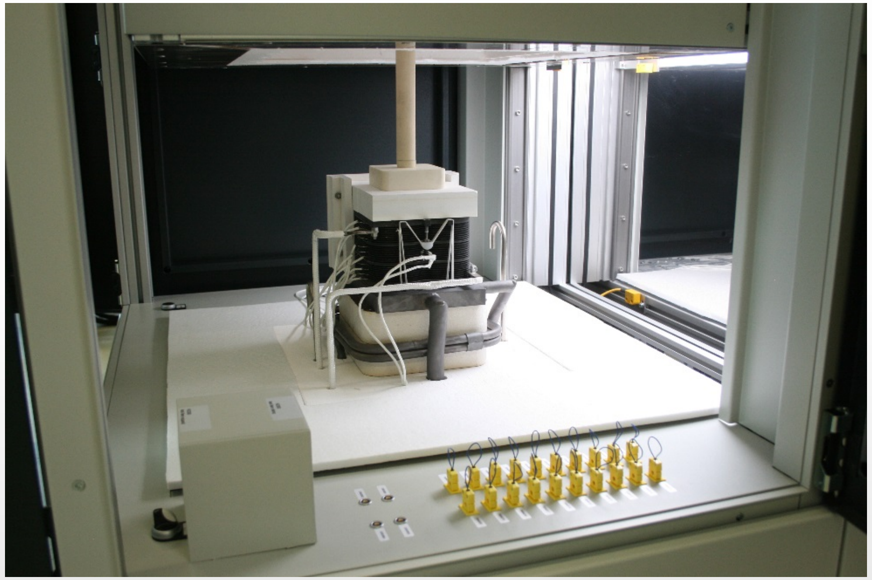
Gas flow manifold configurations



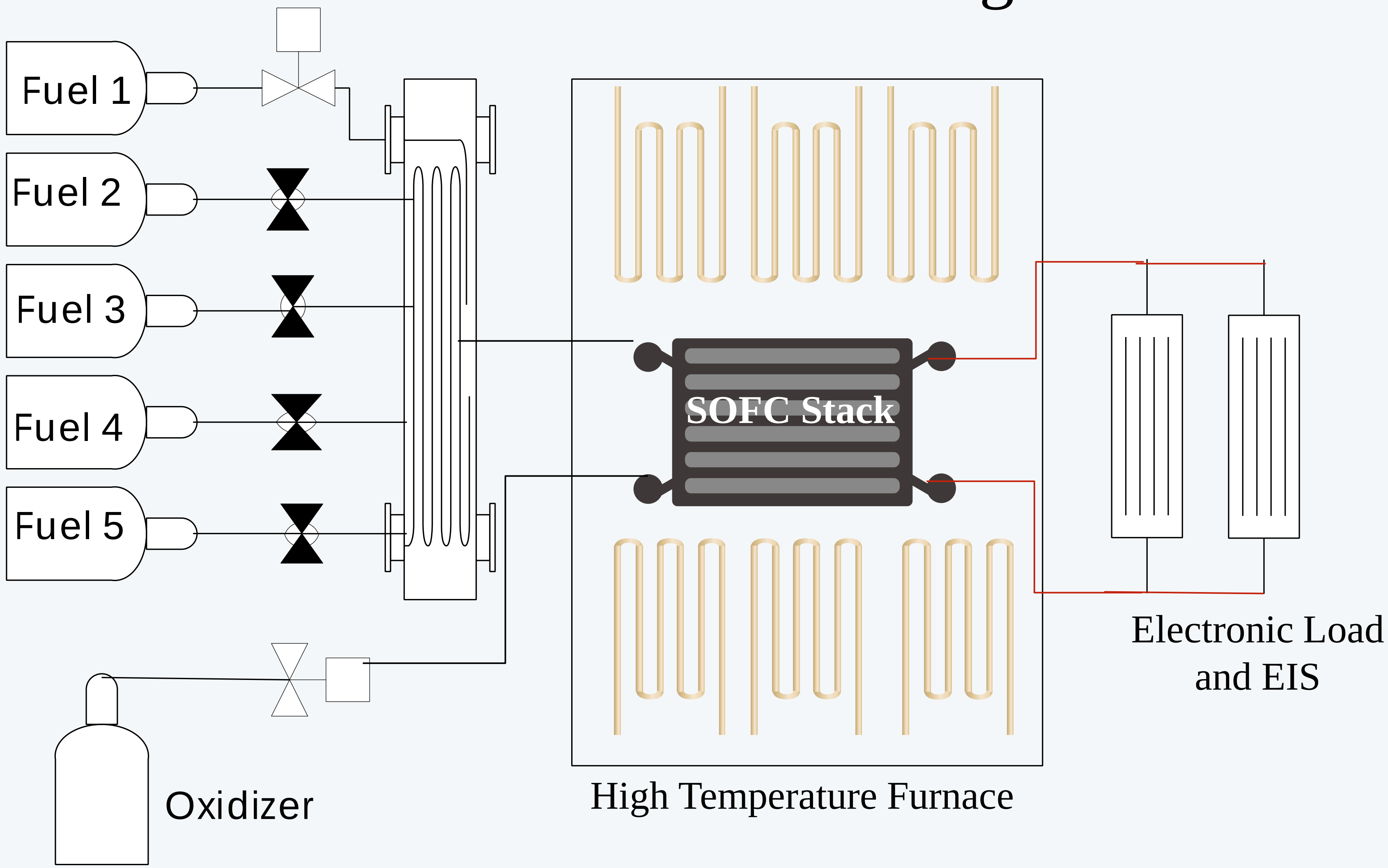
EXPERIMENTAL

Commercial 30 – cell 700 Watt stack





SOFC Stack Flow Diagram



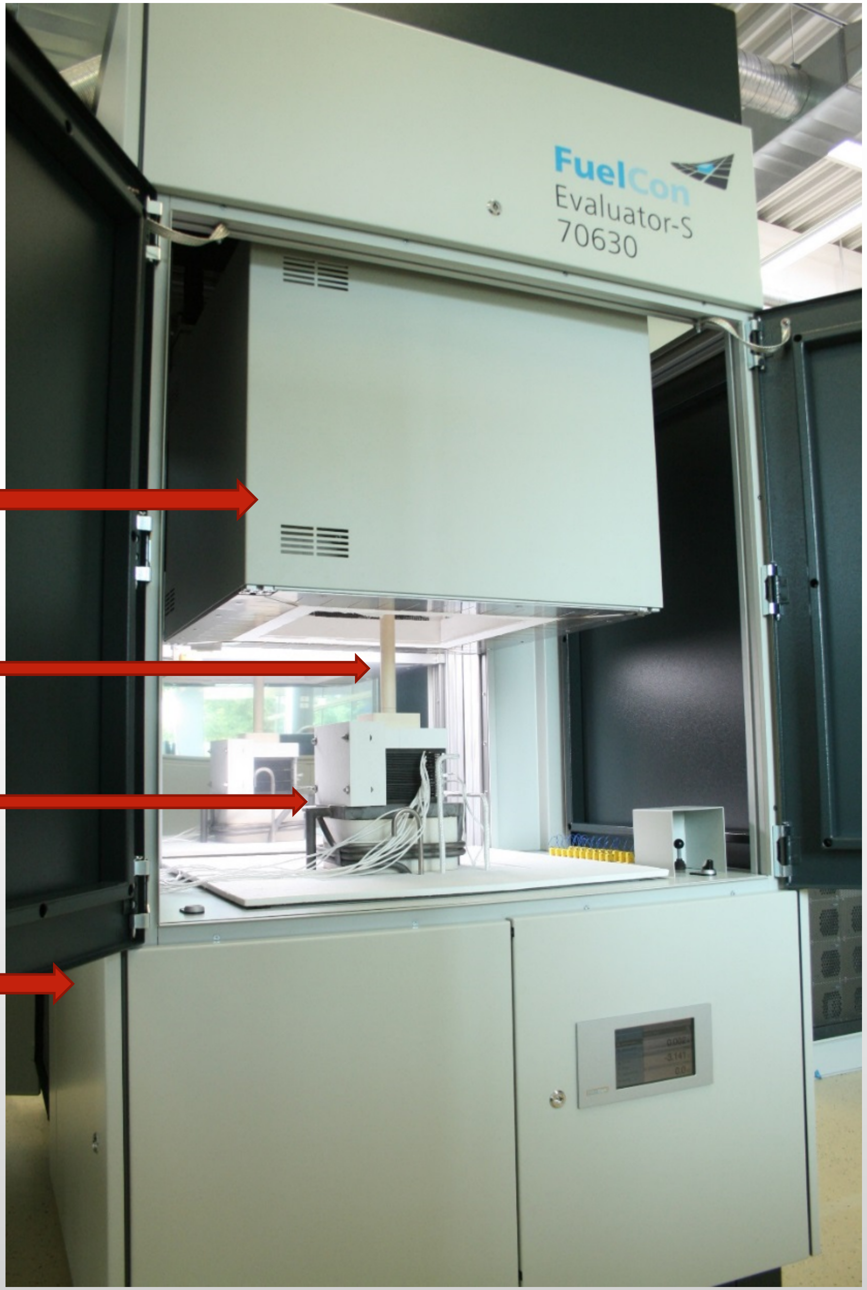
FuelCon Model: Evaluator –S 70630

Furnace (electric hoist)

Applied external clamping

SOFC Stack

Electronic Load



Stack Information

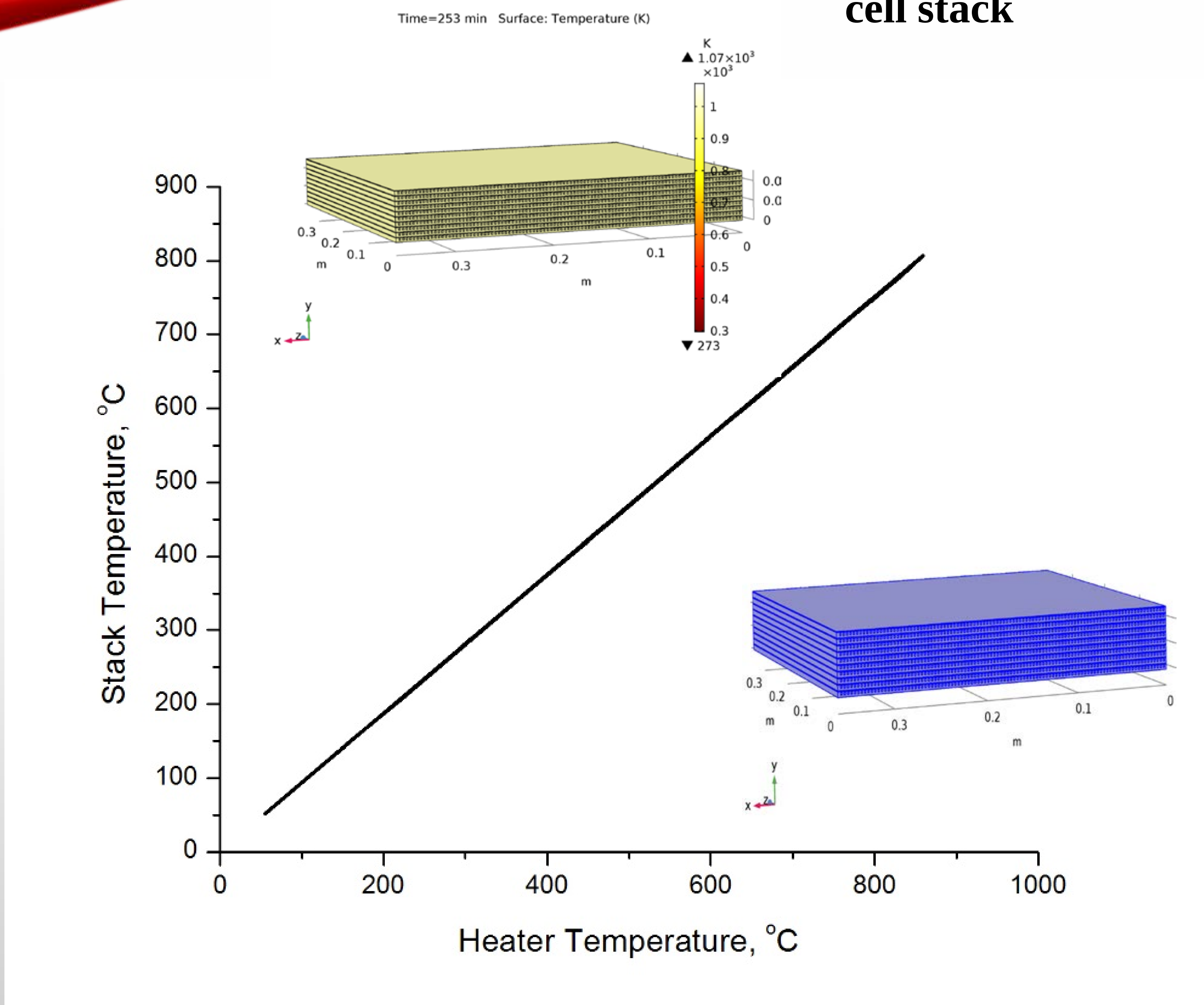
SOFC Stack Designation	Architecture	Number of Cells	Manifold Type	Power Rating	Operational Temperature	Normal Open circuit Potential per Cell	Active Area
				Watt	Centigrade	Volts	cm^2
Stack-XF1	Electrolyte Supported	10	Cross-flow	400	800	1.1	105
Stack-CF1	Electrolyte Supported	30	Co-flow	850	860	0.9	127.8

Start-Up Sequence

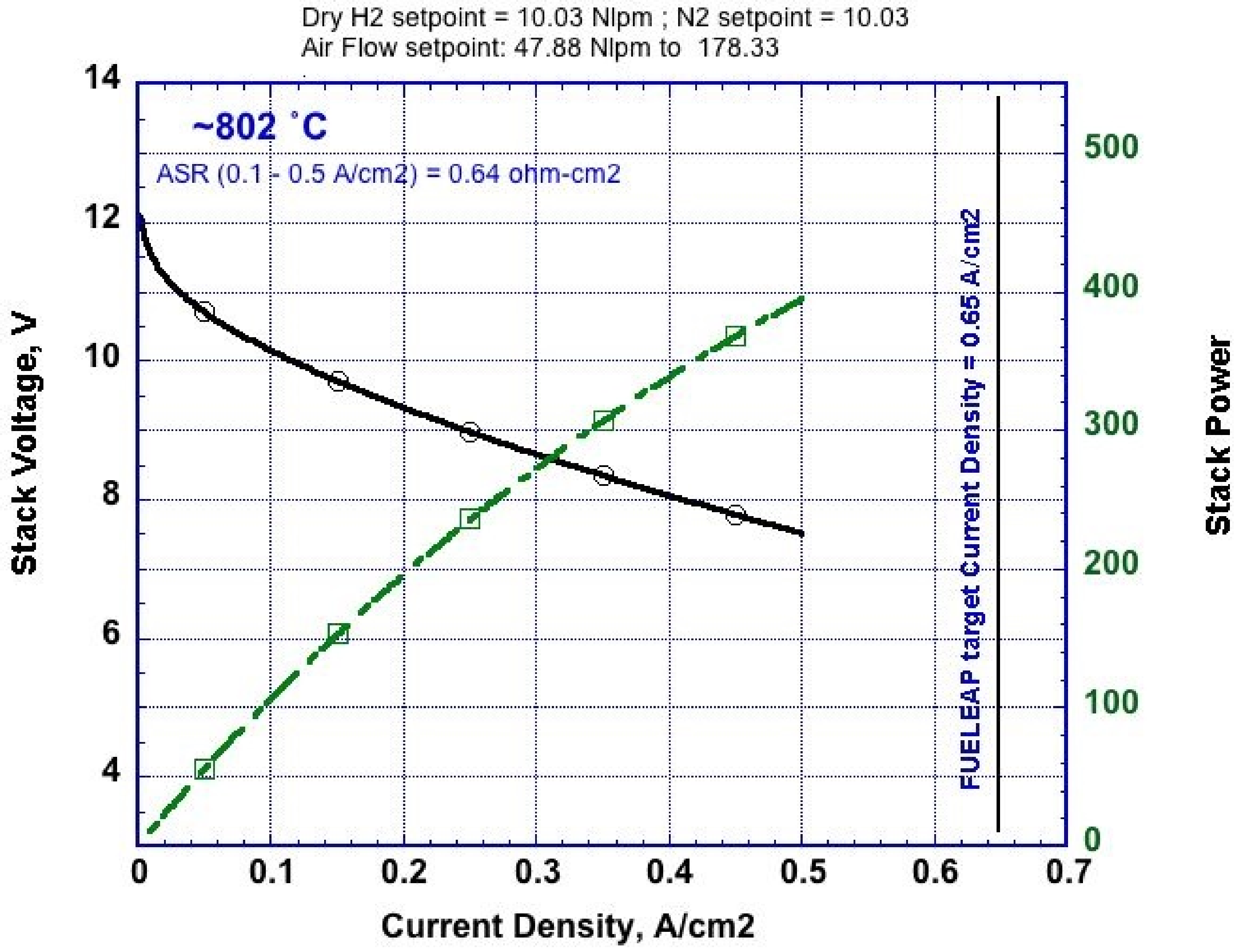
Stack	Heating Rate ^oC/min	Gas Temperature, Centigrade	Gas Flow, LPM	Applied Electric Current Rate, Amp/min
		Anode | Cathode	Anode | Cathode	
Stack-XF1	2	800|800	8|195	2
Stack-CF1	4	800|800	8|200	2

RESULTS

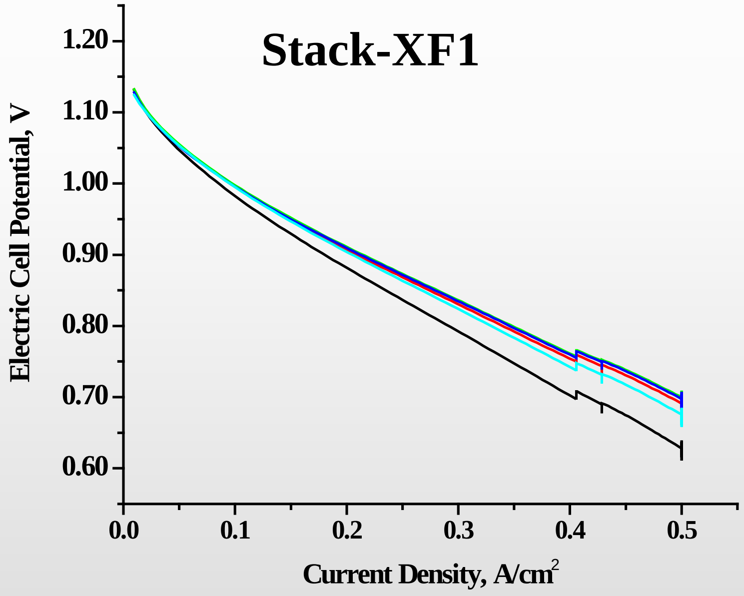
Thermal response when heating the fuel cell stack

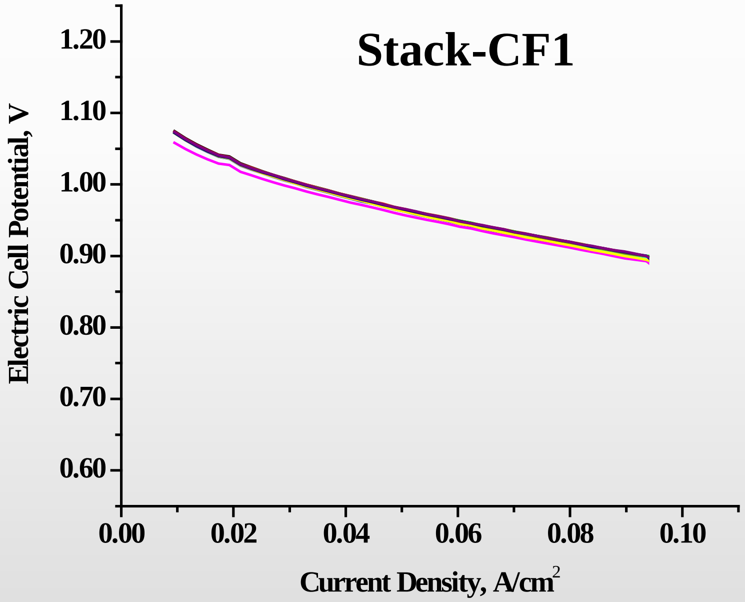


Stack XF1 Performance

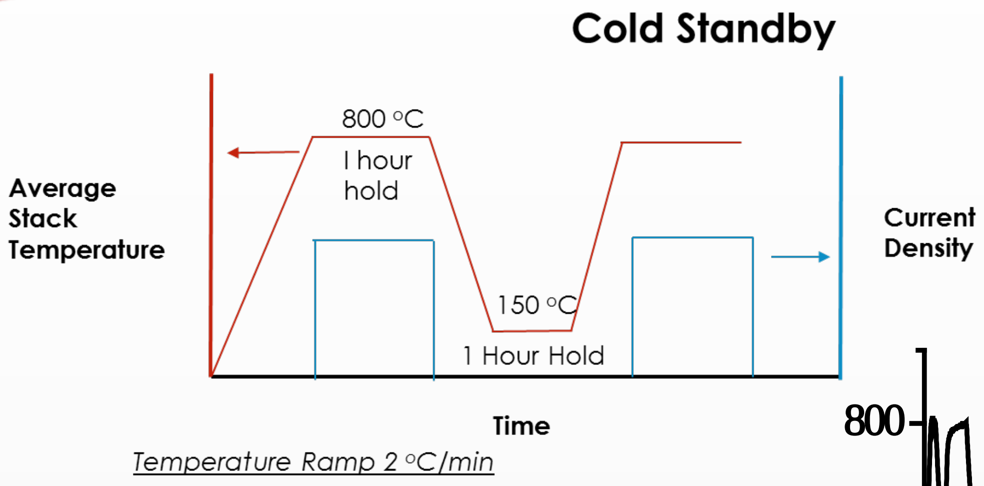


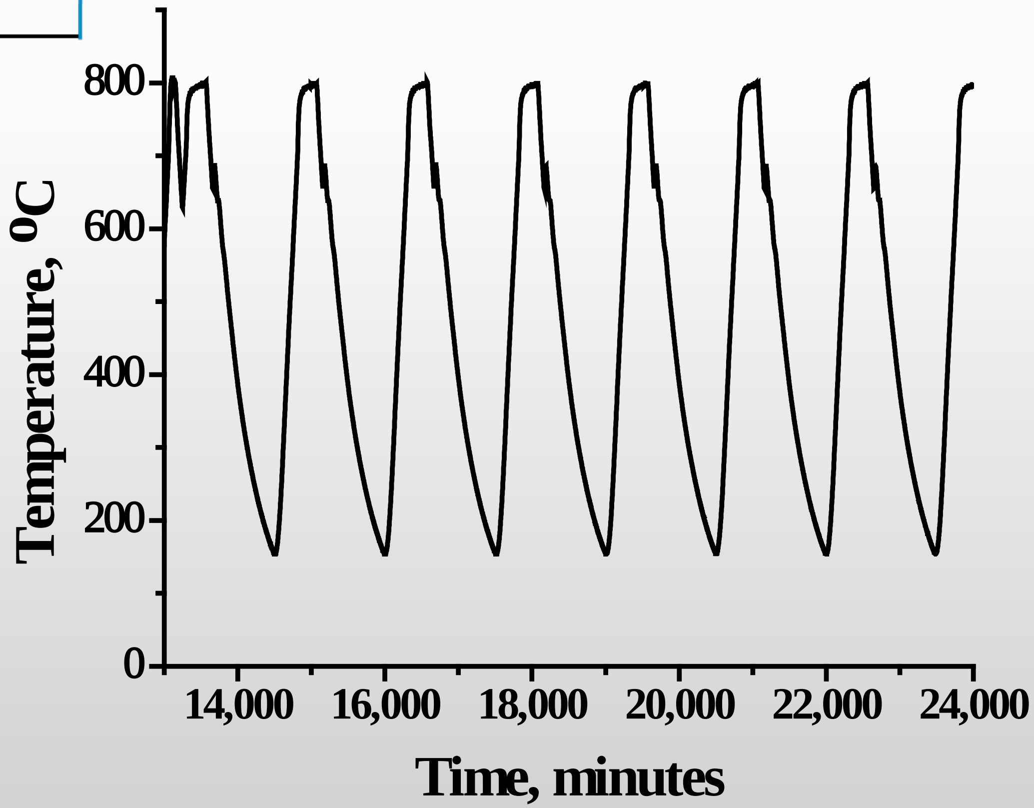
Average cell performance within the stack



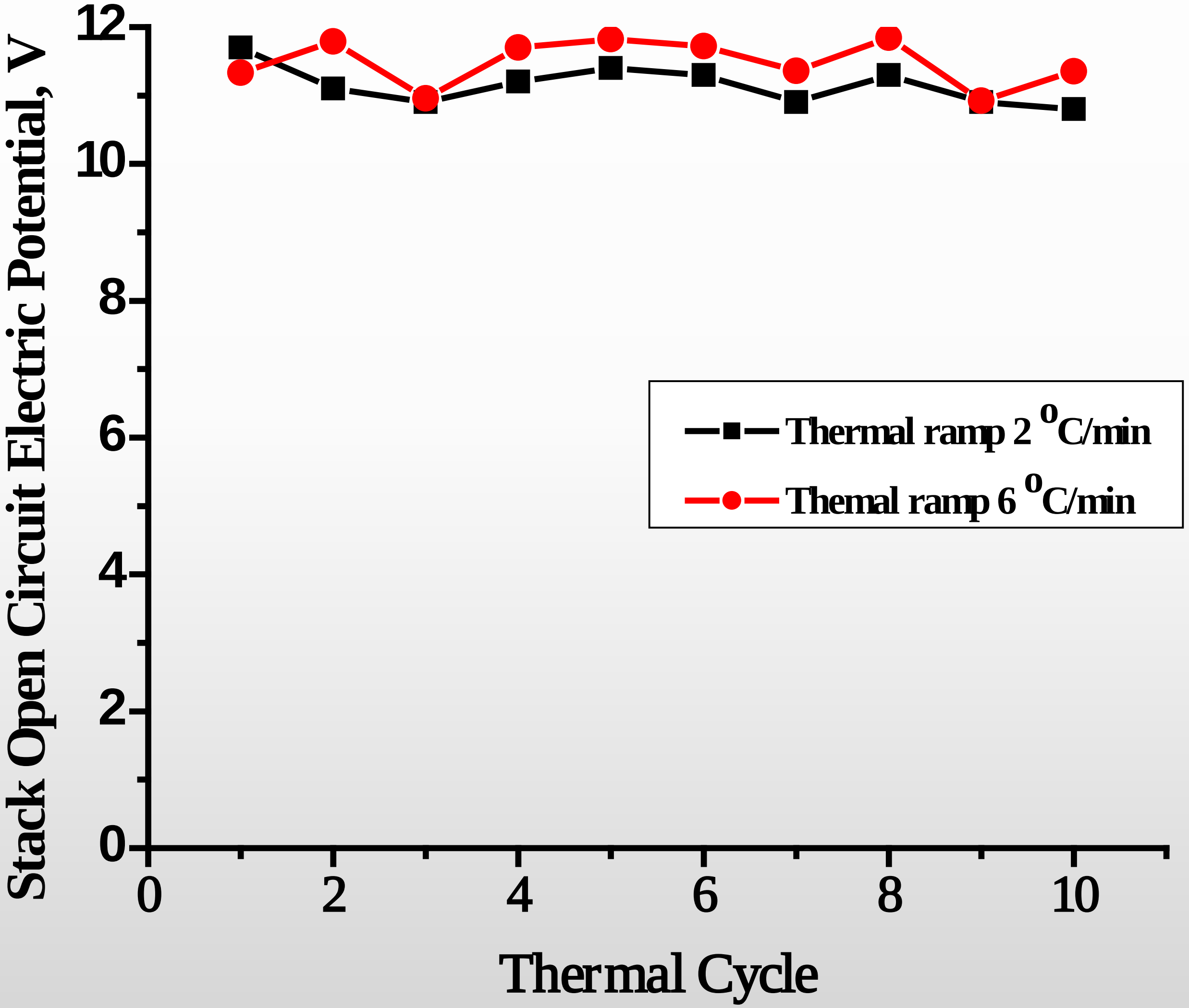


Thermal Cycling Schedule

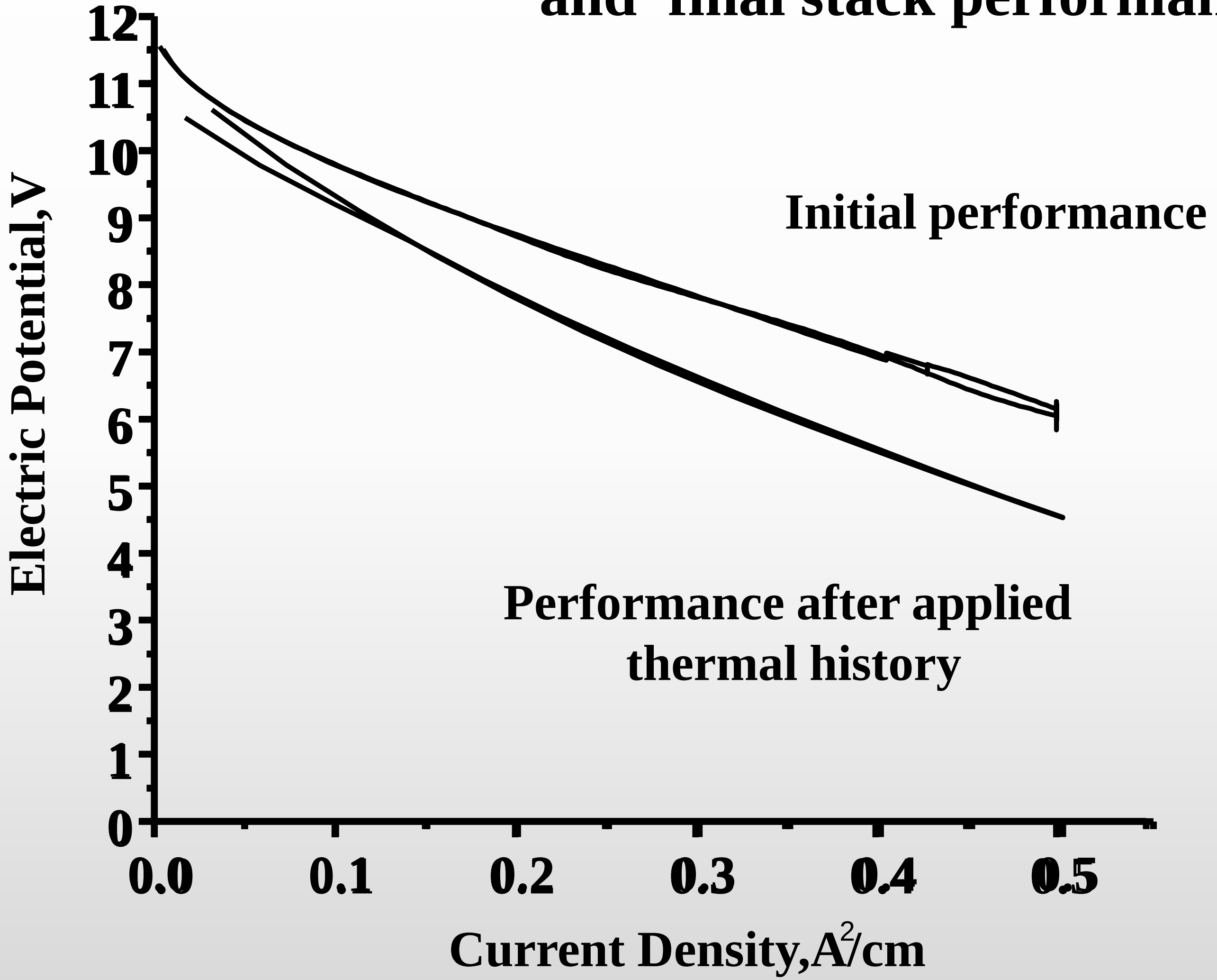




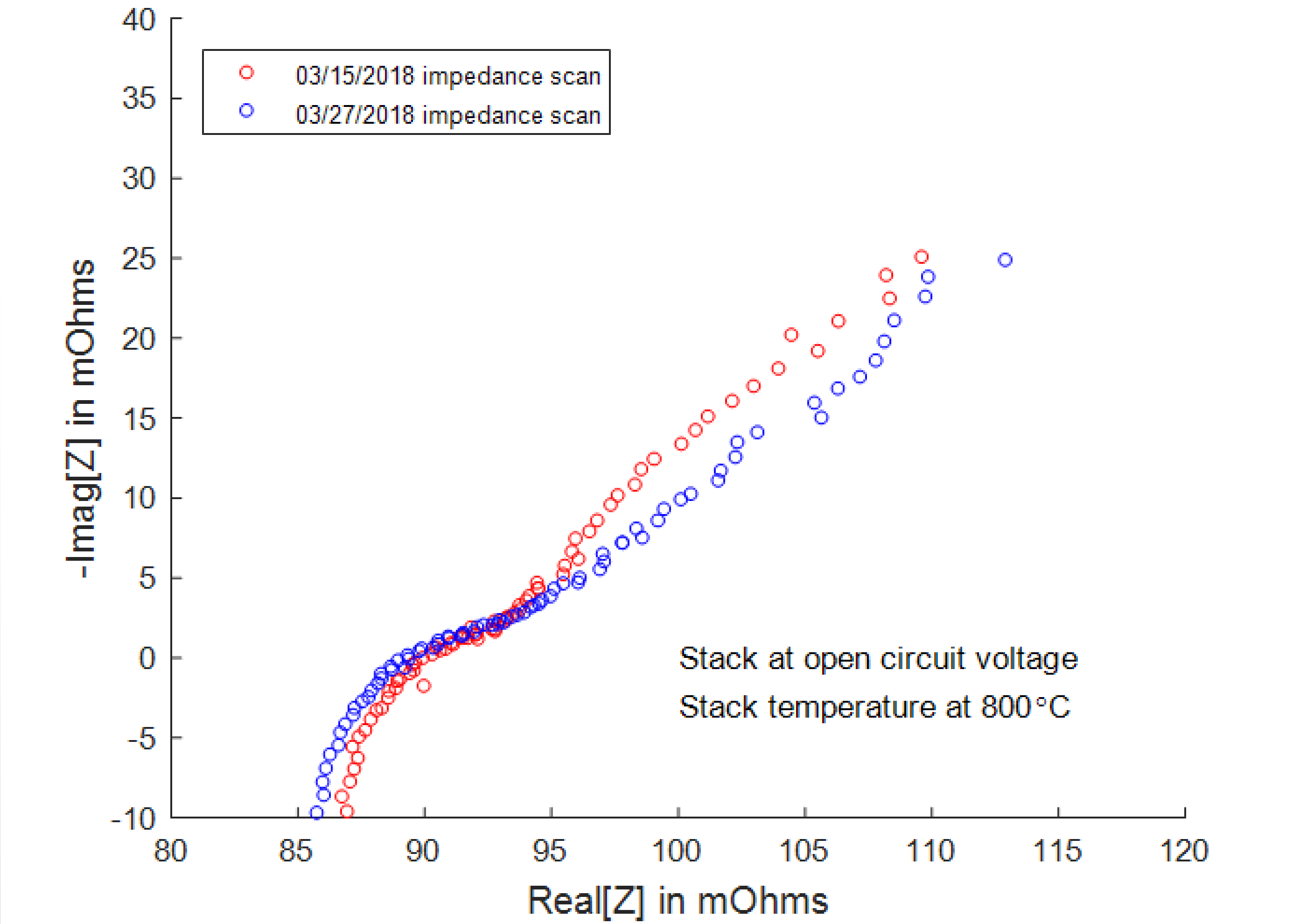
Open Circuit Potential as a Measure of Seal Integrity



Comparison between the initial and final stack performance



Electrochemical Impedance Spectroscopy (scans after two thermal cycles)



Additional testing to correlate and augment model analysis

- **Long term endurance testing**
- **Various fuel utilizations and compositions**
- **Additional more severe thermal cycling**
- **Comparison with different stack manufactures**

Conclusions

- Two solid oxide fuel cell stacks were evaluated for changes in static and dynamic performance when exposed to a thermal cycle test from near-ambient to operational temperature.
- Test results revealed that the open-circuit potential for start-up the fuel cell stacks needs to be increased for this technology to meet the requirement for the intended aeronautic application of the tested stacks remained unchanged when exposed to the thermal profile with existing thermal ramp rate limit, due to the ability of the stack to maintain gas tightness.
- However, when an external electric load is applied there is a marked decrease in performance. These changes are likely the results of microstructural changes induced by the stack's thermal history.

Acknowledgements

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