Cost-effective, Intermediate-temperature Fuel Cells for Carbon-free Power Generation

Project ID: ARPAE-15

PI: Greg G. Tao

Chemtronergy, LLC.

3619 W 1987 S, Salt Lake City, UT 84104

2019 DOE Hydrogen and Fuel Cells Program Annual Merit Review

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Overview

Timeline

- Start: November 2017
- End: August 2019
- Percent complete: 80%

Budget

- Total Project Value
  - ARPA-E $1,100,000
  - Cost-share $ 122,222
- Funding received in FY18
  - $ 510,000
- Funding for FY19
  - $ 450,000

Barriers

Fuel Cells

- A – Durability
  - Longer operation
  - Lower degradation
- B – Cost

Manufacturing

- F – High cost and complexity of processing
- I – Lack of standardized BOP components

Partners

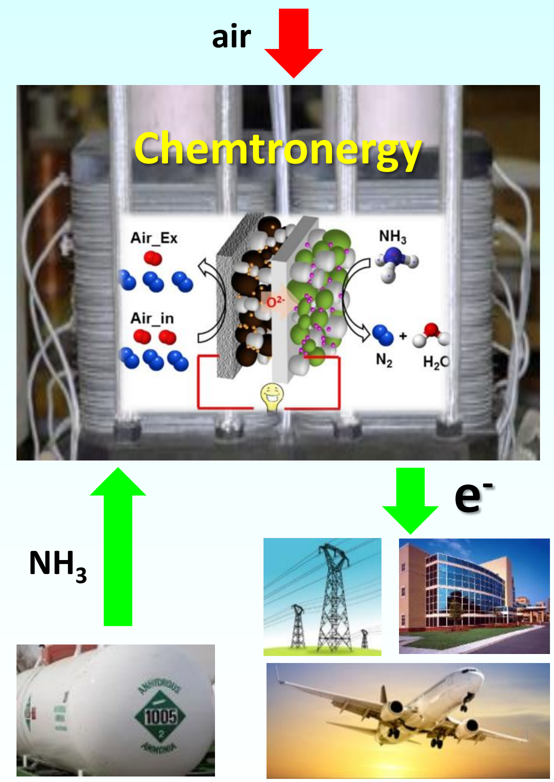
- University of Maryland
- TechOpp Consulting Inc.

Relevance

Objective: **develop and demonstrate a transformational technology that cost-effectively and efficiently converts the chemical energy of ammonia fuel directly into electricity at a reduced temperature (≤650°C) through the design and manufacturing of an advanced IT-SOFC with unique hierarchical structures**

Targets

Metric	State of the Art	Proposed
Delivered SUE Cost	> $0.3 /kWh	~ $0.3/kWh
Max operating temperature	800~900°C	≤ 650°C
Current density at 0.75V	0.4 A/cm^2	0.3 A/cm^2
Electrical efficiency	52~60%	> 55%
Cell degradation rate	> 1%/1kh	< 0.3%/1kh



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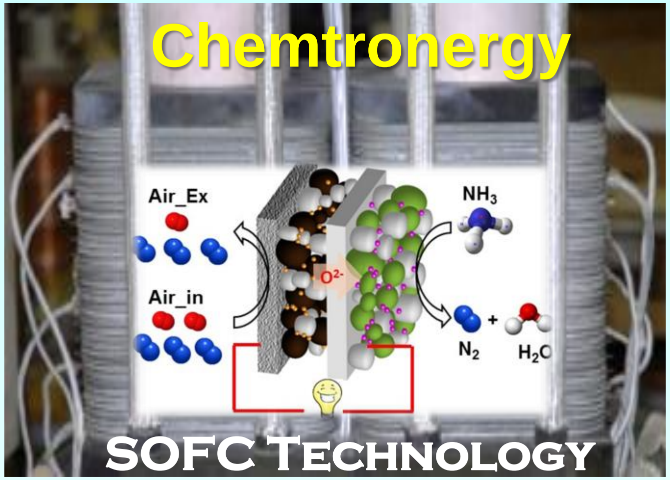
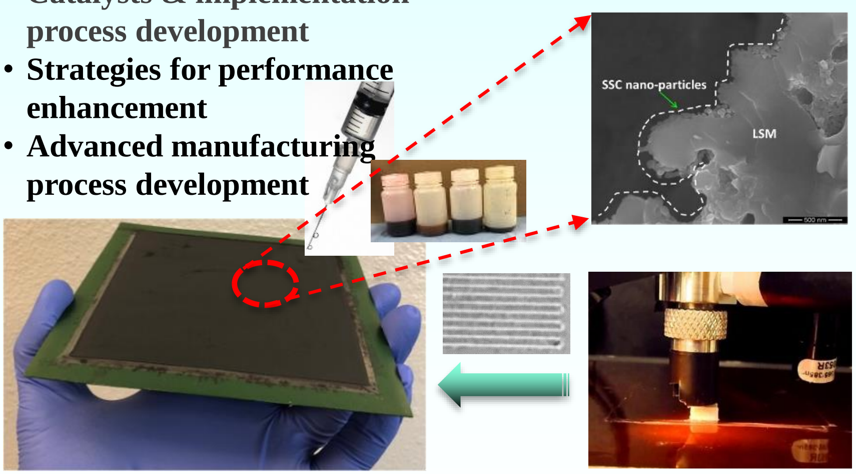
Approaches



- **Catalysts & implementation process development**
- **Strategies for performance enhancement**
- **Advanced manufacturing process development**



❑ Materials Development

- ○ NH_3 catalyst – nano metal oxides
- ○ Cathode catalysts

❑ Cell Fabrication Process Development

- ○ Cathode deposition optimization
- ○ Anode fabrication process development
- ○ Scale-up

❑ IT-SOFC Experimental Evaluation

- ○ Button sized cells (2 cm^2/cell)
- ○ Single cells (100 cm^2/cell)

❑ Technology-to-Market (T2M)

- ○ Techno-economic analysis (TEA)
- ○ T2M development

Schedule

❑ 21-month Project (11/2017 – 08/2019)

- Concept development phase (12-month) focusing on materials development & evaluation, advanced process development, and T2M plan development

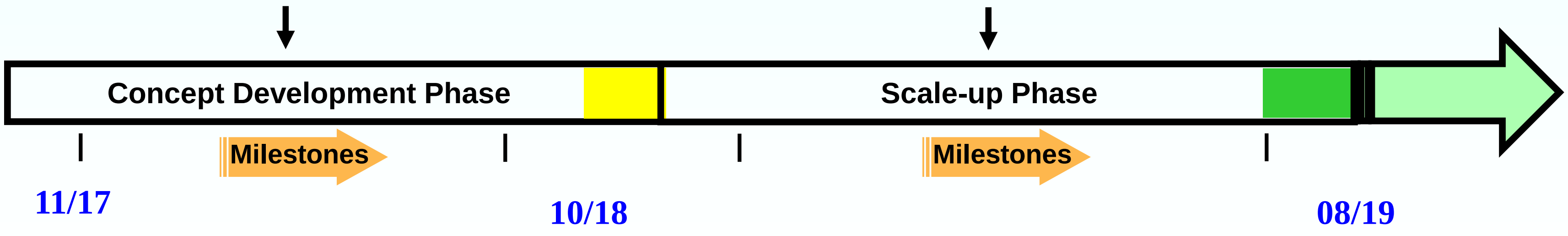
- Scale-up phase (9-month) focusing on scaling up & large-cell evaluation for proof-of-conception (PoC) demonstration, and T2M plan updating

Concept phase (12-month):

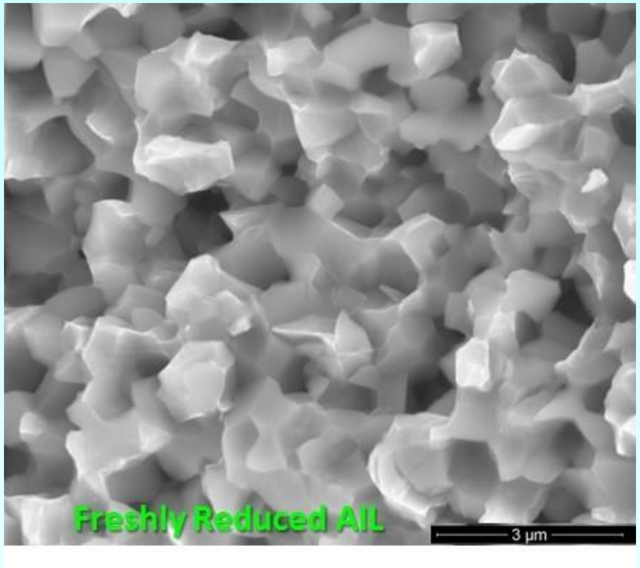
Critical cell components development, cathode, catalysts, anode fabrication processing, small cell fabrication, T2M plan initialization

Development Phase (9-month):

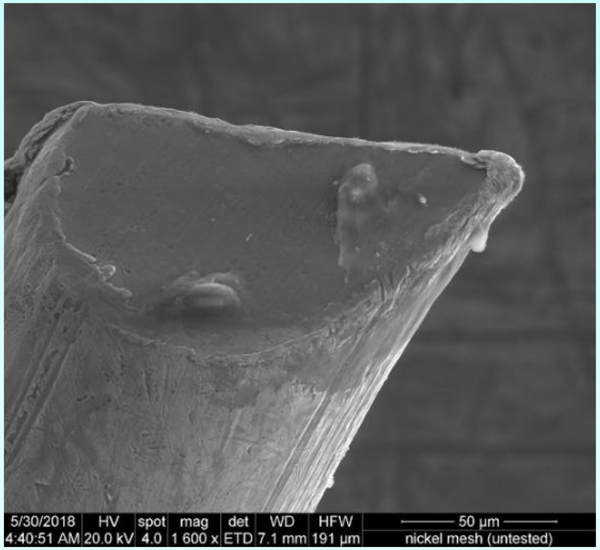
Cell materials integration, large cell fabrication (100 cm^2/cell), single cell construction, & evaluation, T2M updating



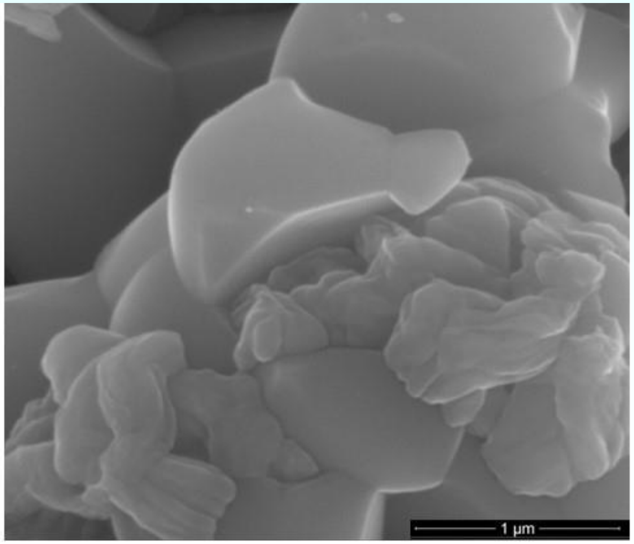
Challenges for Direct NH_3 Fueled SOFCs



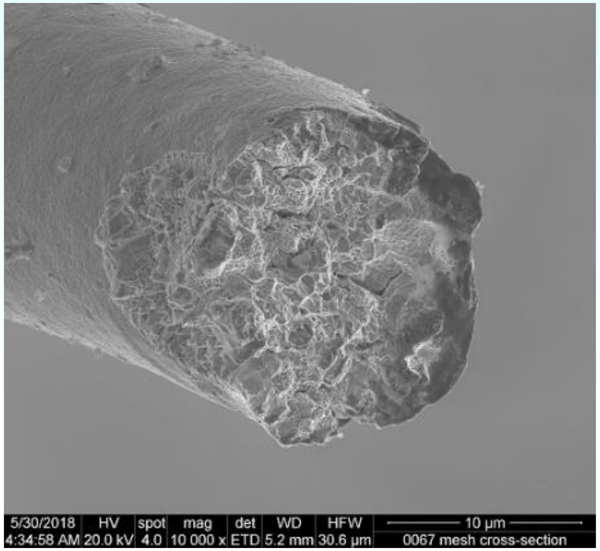
Freshly reduced anode



Pristine Ni mesh



After exposure to NH_3 fuel at 650ºC



After hundreds hours test under NH_3 environment at 650ºC

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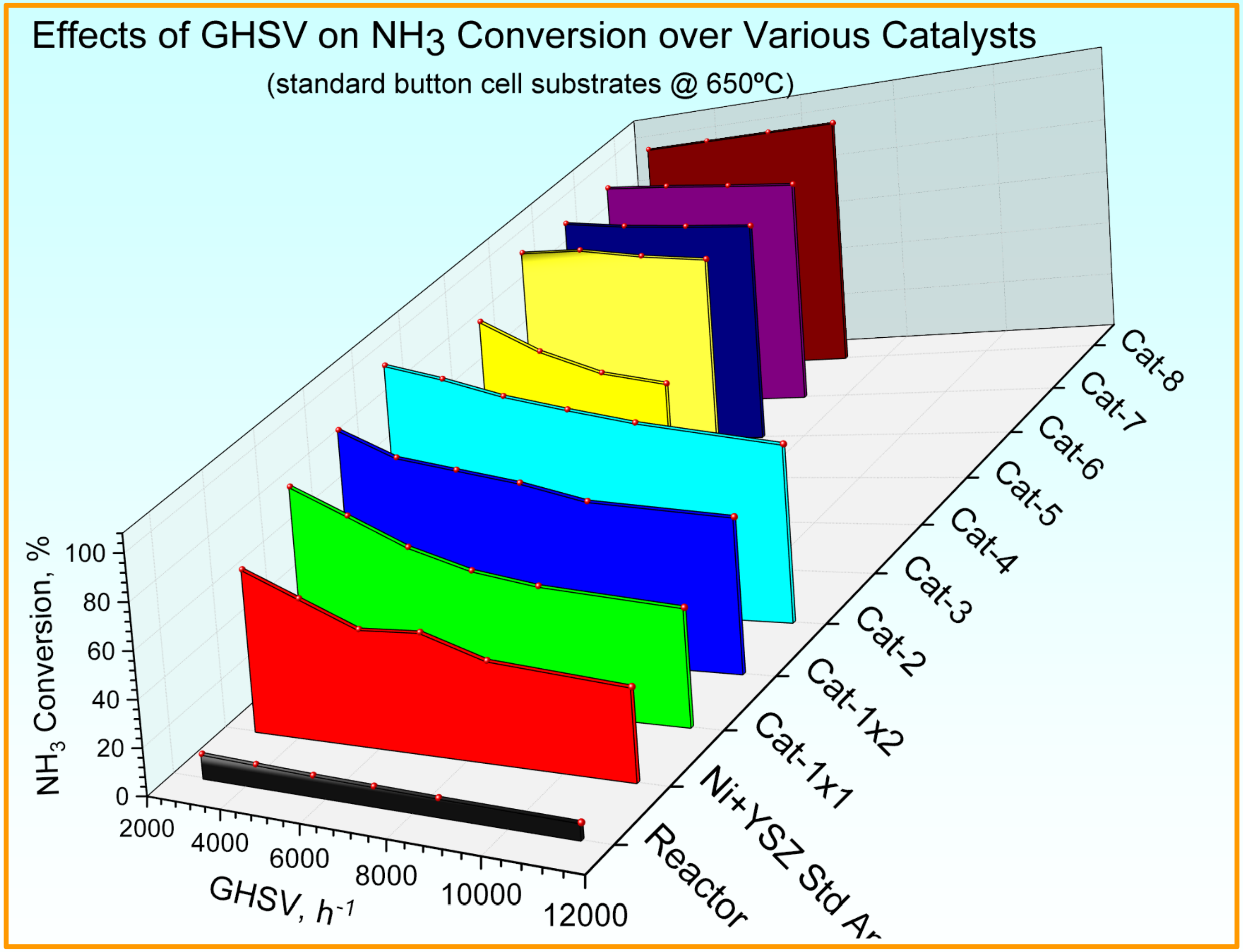
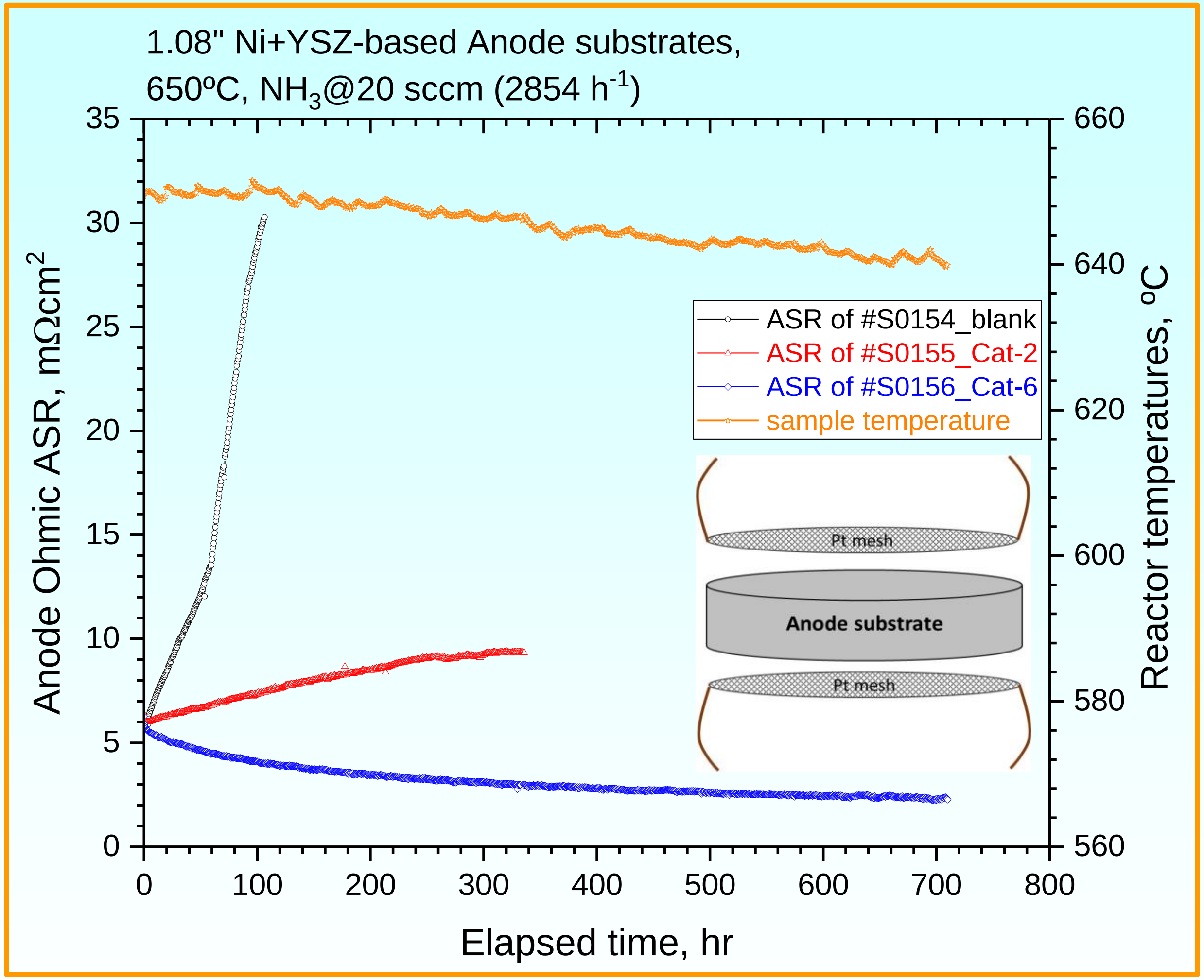
Technical Accomplishments – NH_3 Cat.



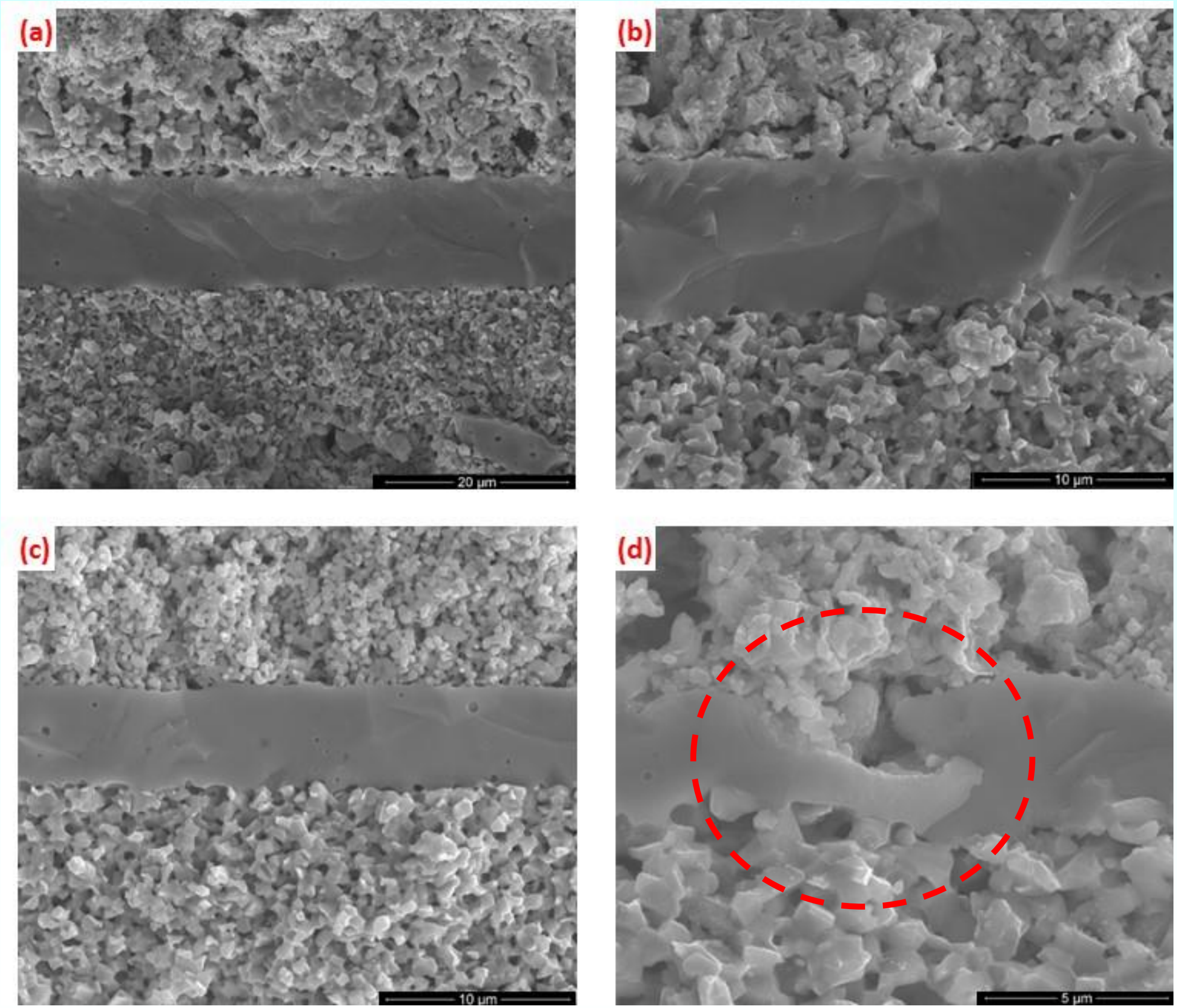
- Evaluated eight NH_3 catalyst candidates
- Standard Ni+YSZ doesn't possess sufficient catalytic effects on NH_3 decomposition at T ≤ 700ºC
- A few catalysts showed near complete NH_3 conversion (100%) ≤ 50 sccm (7137 h^{-1})

NH_3 Catalyst Stability Evaluation



- Measurement of ohmic ASR changes under NH_3 environment by 4-point method
- Three samples:
  1. blank substrate (anode support);
  2. w/ Cat-2
  3. w/ Cat-6
- Pt meshes for current collection
- 650ºC
- NH_3 flow rate @ 20 sccm (2854 h^{-1})
- Stability: Cat-6 >> Cat-2 >> anode base substrate

Electrolyte Optimization



(a) our standard cell (project onset), ~ 12 µm

(b) second generation cell (Q3), 8~9 µm;

(c) third generation cell (Q4), 5~6 µm;

(d) an example of electrolyte defect (~ 2 µm thick)

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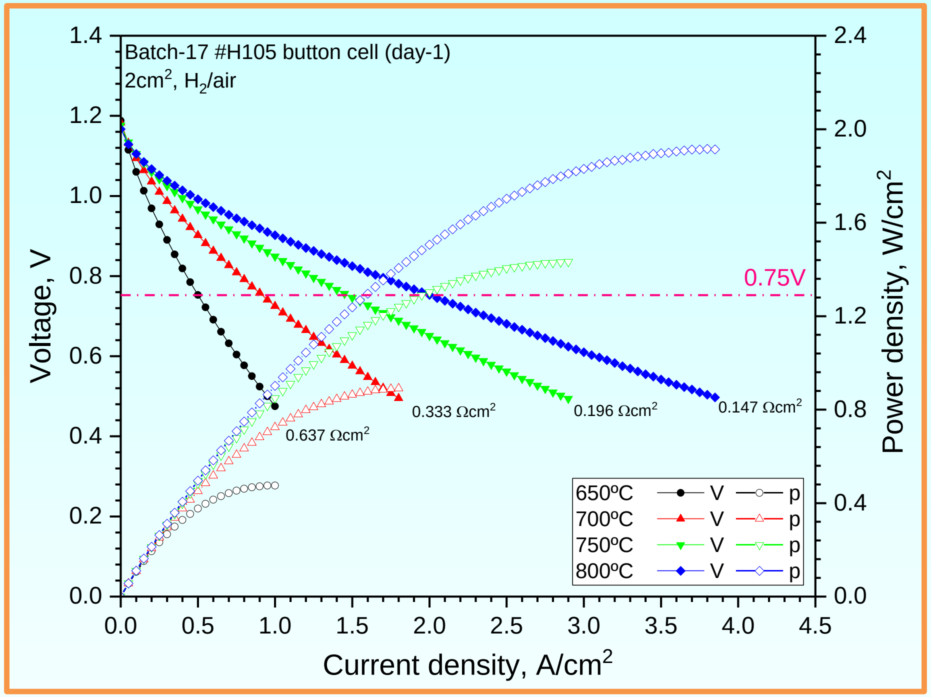
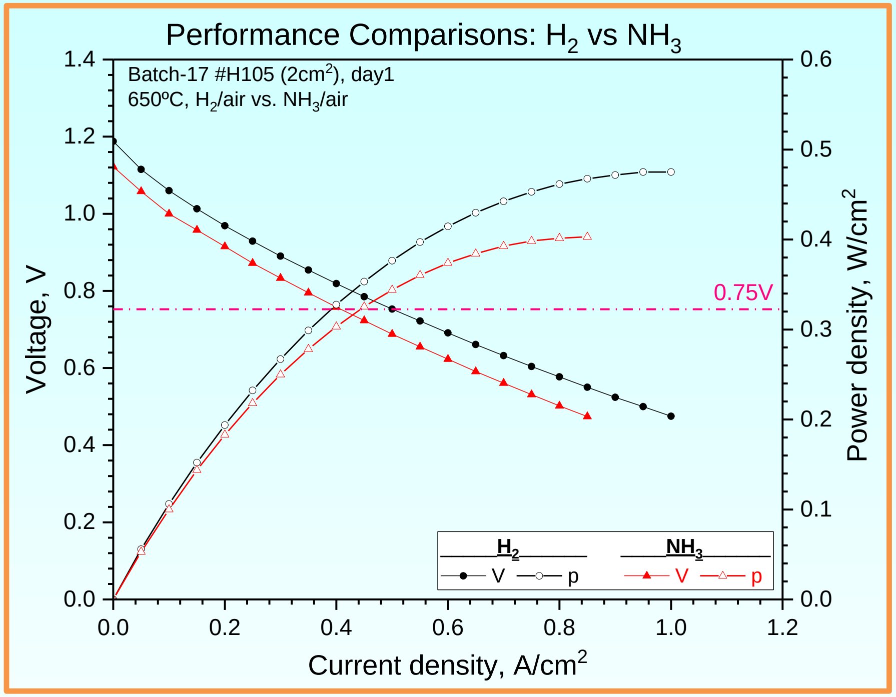
3rd Gen Button Cell Performance

Button cell baseline performance with H_2 at various temperatures (800ºC – 650ºC)

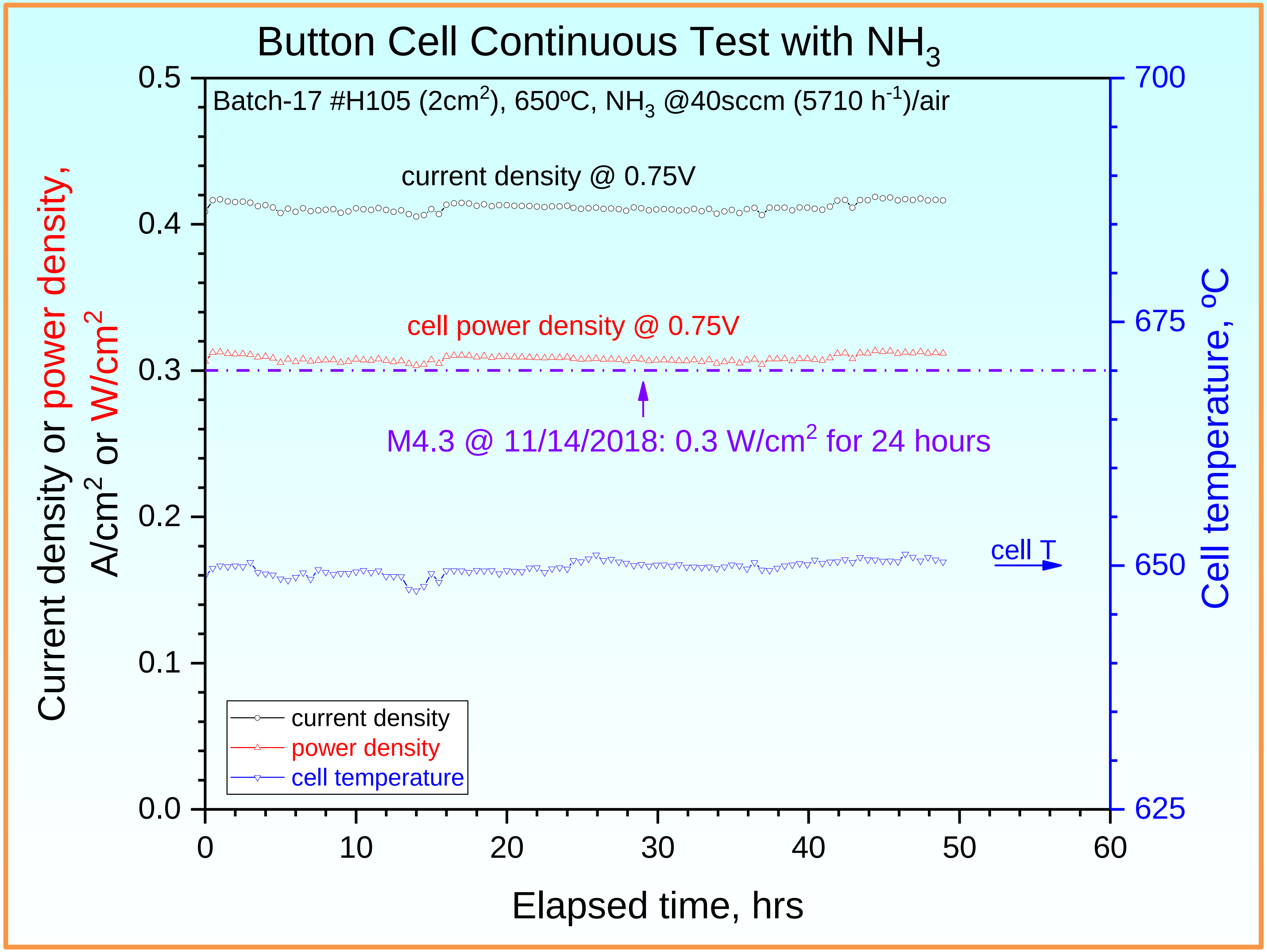


Button cell performance comparison between H_2 and NH_3 at 650ºC



T, ºC	OCV, V		Power density @ 0.75V, W/cm^2		Peak power density, W/cm^2		ASR, Ωcm^2	
	H_2*	NH_3	H_2	NH_3	H_2	NH_3	H_2	NH_3
650	1.188	1.122	0.377	0.308	0.475	0.403	0.637	0.73
700	1.183		0.692		0.891		0.333	
750	1.176		1.108		1.433		0.196	
800	1.167		1.514		1.913		0.147	

Button Cell Stability Test – NH_3@650ºC



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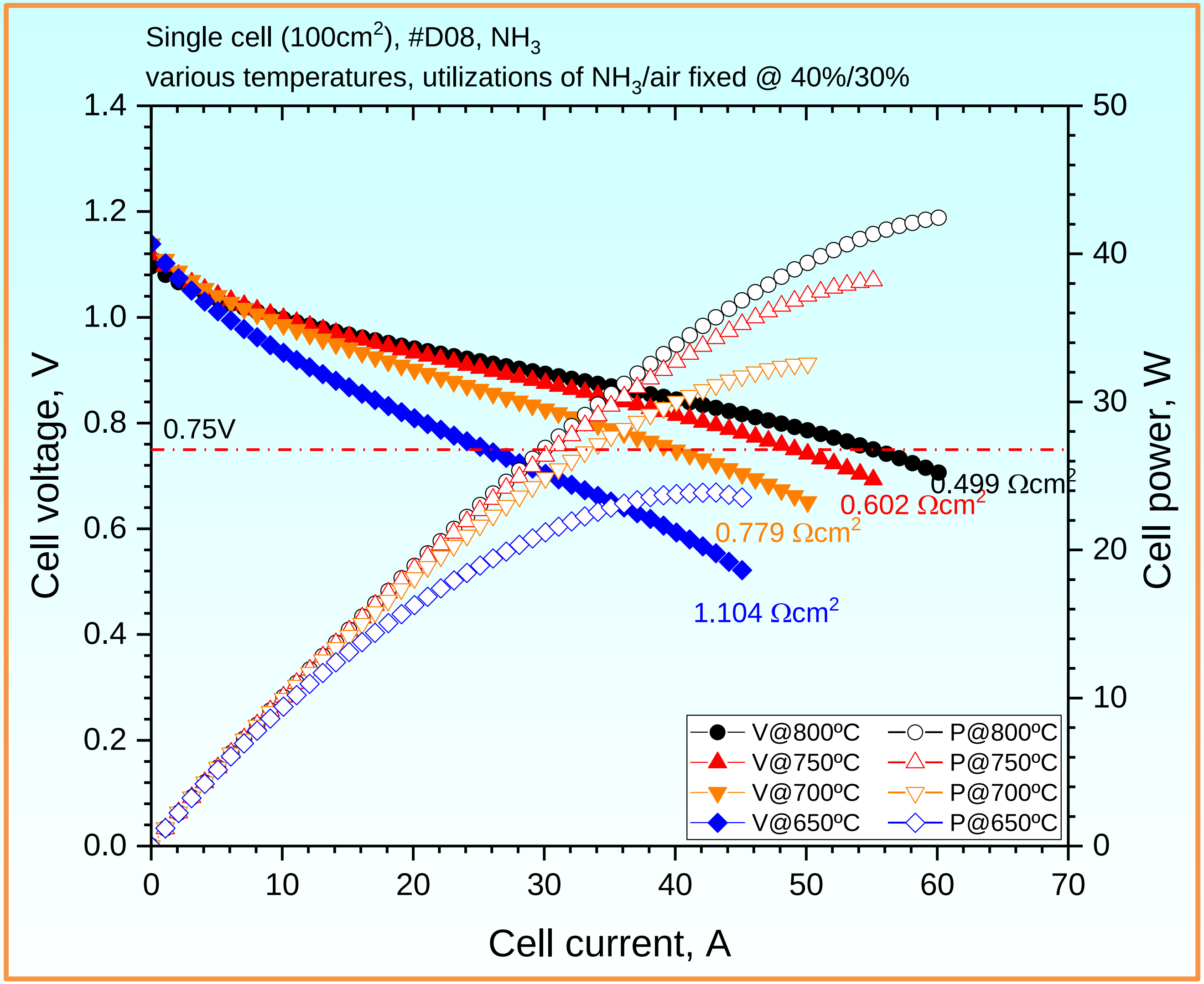
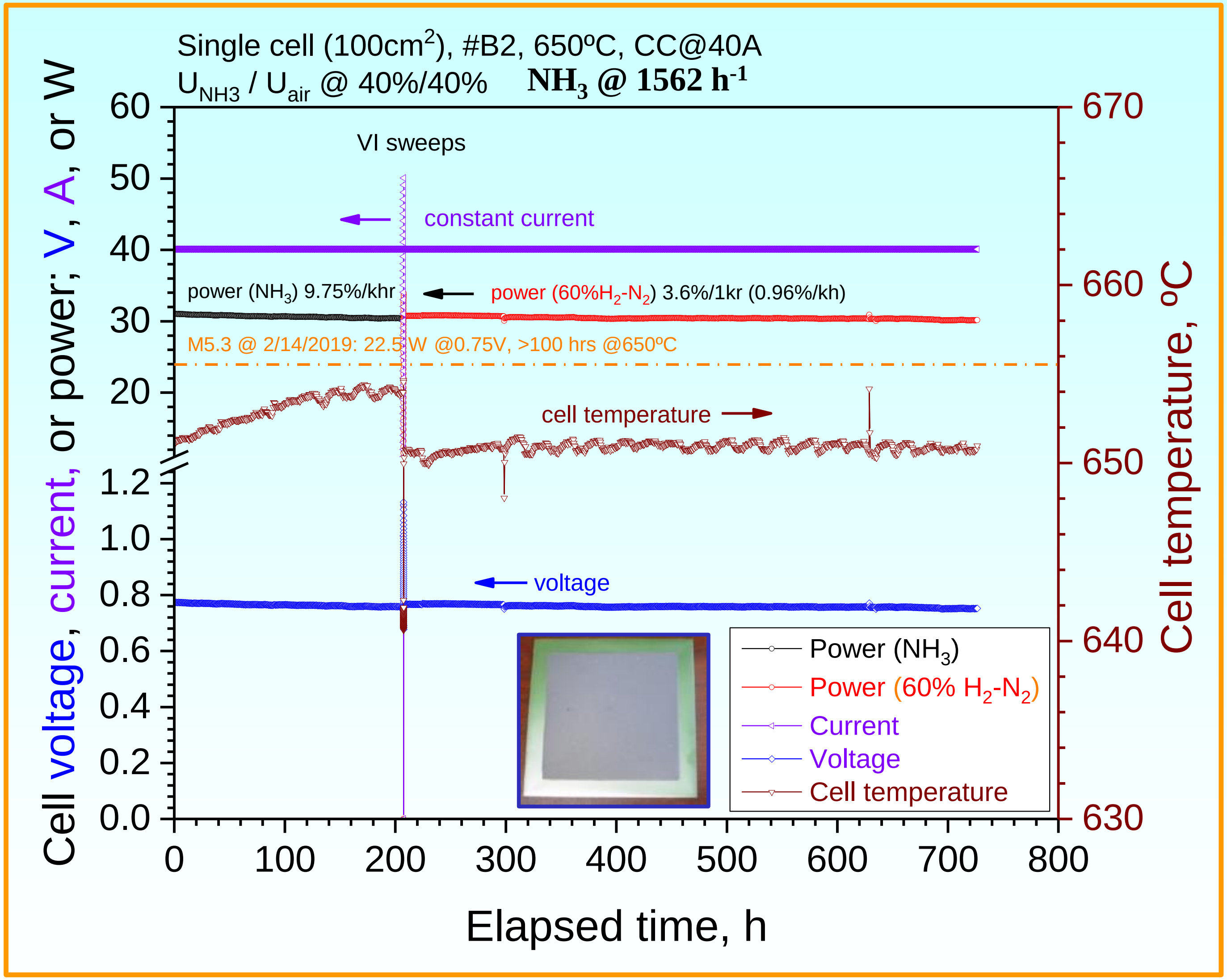
Scale-up Cell Performance w/ NH_3 Fuel



VI sweep characteristics of a single cell ($100cm^2$/cell) tested with NH_3 from 800ºC to 650ºC

Single Cell Long-Term Test Results



Long-term test results of a single cell at 650°C with NH_3 (200 hrs) and 60%H_2-N_2 (500 hrs)

Proposed Future Work

Any proposed future work is subject to change based on funding levels

❑ By Q3 FY2019

- Complete long-term tests of single cells (100 cm^2/cell) directly fed with ammonia fuel at 650ºC, demonstrating the degradation rate < 0.3%/1khr over 500 hours @ 0.225 W/cm^2 @ 0.75V
- Update T2M
- Complete TEA

❑ Beyond 2019

Look for partners who can help transitioning the advanced laboratory technologies into marketable products

- Scale-up demonstration at a kW stack scale
- System integration and demonstration at a kW level
- Investors (private & government)

Summary – Documented Progress toward Targets

- Successfully developed and implemented an ammonia catalyst system for preserving SOFC electrode functionality and mechanical integrity
- Improved manufacturing processes for SOFCs performance enhancement and suitable for cell scaling up
- Completed technical milestones on schedule