Development of SOFCs for Liquid Fuels

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Outline

1. Introduction to Acumentrics
2. Acumentrics' SOFC Technology
3. Development of SOFC for Military Use
4. Reliability
   - Mechanical strength- Shock and Vibration
   - Thermal Shock
   - Liquid Fuels
5. Future Work

Acumentrics Corporation

- *~ 80 Employees*
- *Manufacturing since 1994*
- *Based in Westwood, Mass.*
- *~40,000 sq. ft facility*
- *Profitable for the past 30 months*
- *Critical disciplines in-house*

Electrical Engineering
Mechanical Engineering
Chemical Engineering
Thermal Modeling
Ceramics Processing
Manufacturing
Sales & Marketing
Automation
Finance

Acumentrics
Trusted Power Innovations

Acumentrics *Battery based UPS*

Uninterruptible Power Supplies for Harsh Environments

Industrial-UPS®
Commercial

Rugged-UPS®
Military

Features:

- Sealed electronics
- Able to withstand vibration
- Unity power factor input
- Wide input 80VAC - 265VAC
- Isolated 120 / 240VAC output
- Hot swap battery case
- Parallelable to 20 kWatts

Why Solid Oxide Fuel Cells?

- PEM
  - Polymer MEA, H^+ charge carrier
  - Low temperature
    - Light weight assembly

    But
    - Acutely susceptible to poisons (CO and Sulfur), thus heavy fuel processor
    - Expensive Pt catalyst because of slow kinetics
- SOFC
  - Ceramic MEA, O^{2-} charge carrier
  - High temperature
    - Heavy ceramics and metals

    But
    - Inexpensive catalysts (e.g. Ni) due to fast kinetics
    - CO is a FUEL, not a poison
    - Bottoming cycle is possible, *high efficiency*

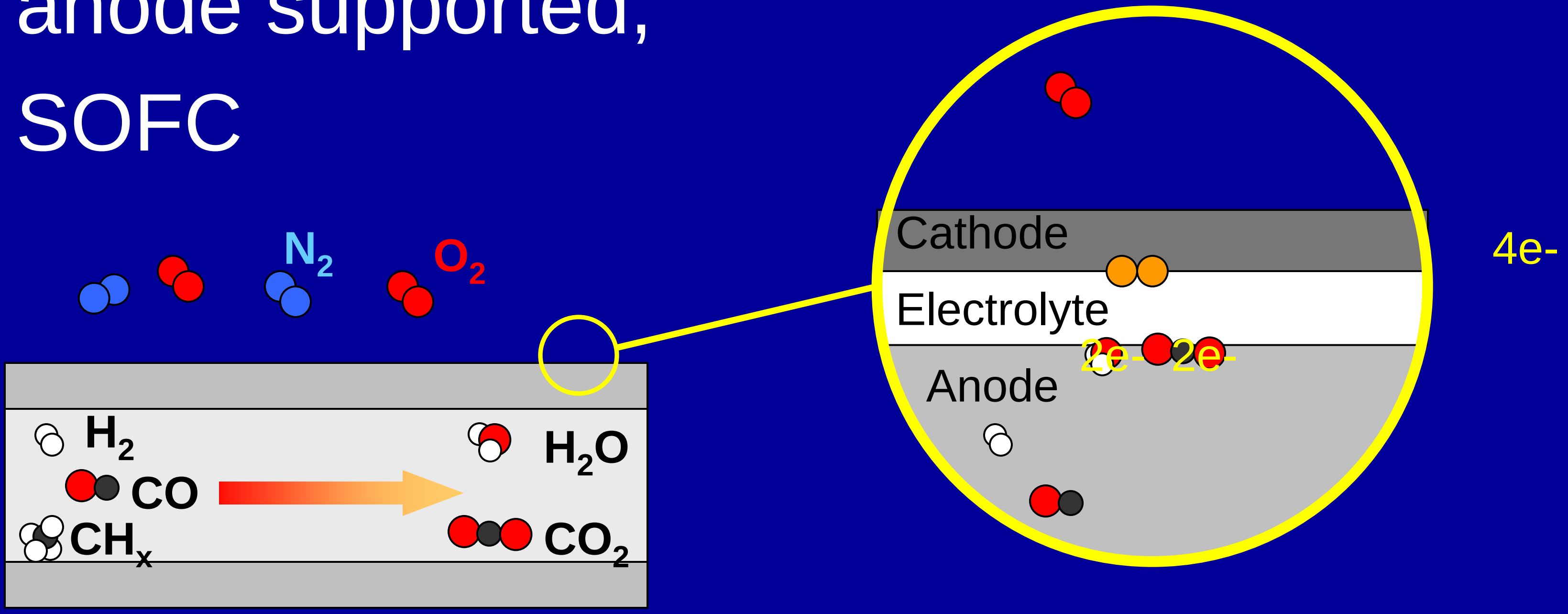
High temperature favors reforming kinetics and thermodynamics, SYNERGY

Rugged Tubular SOFC

Tubular,

anode supported,

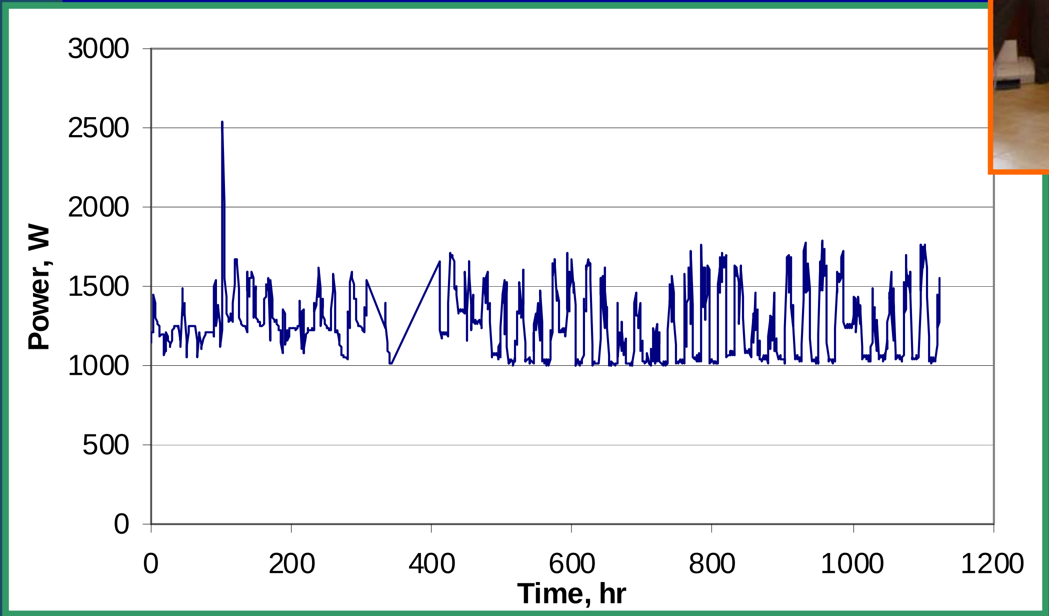
SOFC



Exit Glacier

Operation for another summer at Exit Glacier Visitor's Center

Shutdown at end of season

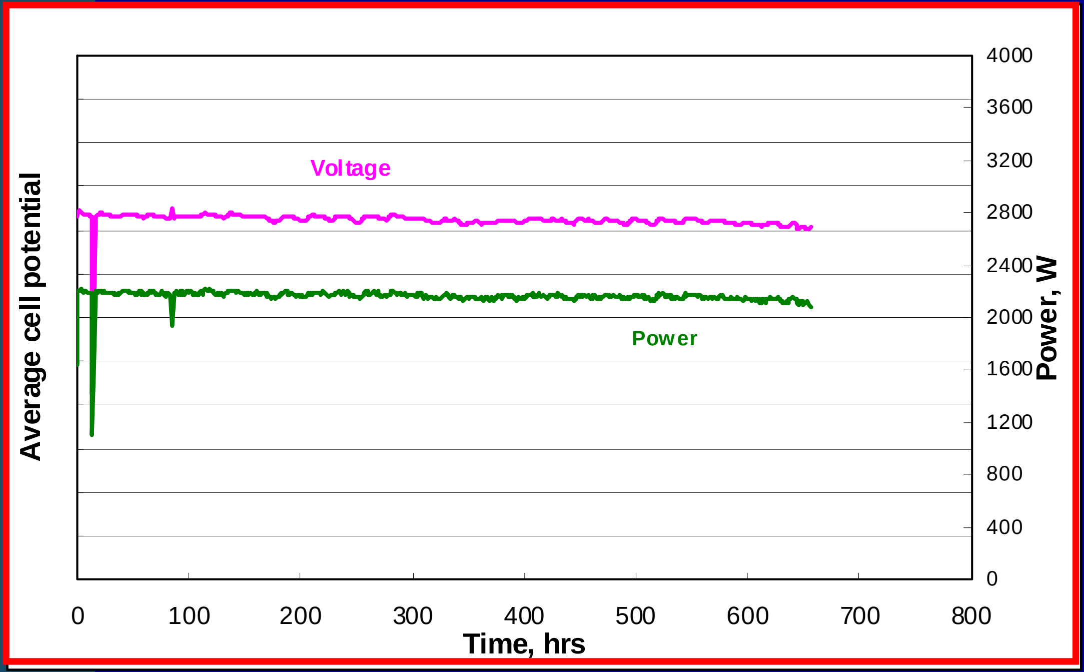


Fuel: Propane

Products: hot water for radiator heating and electrical power

Cuyahoga State Park

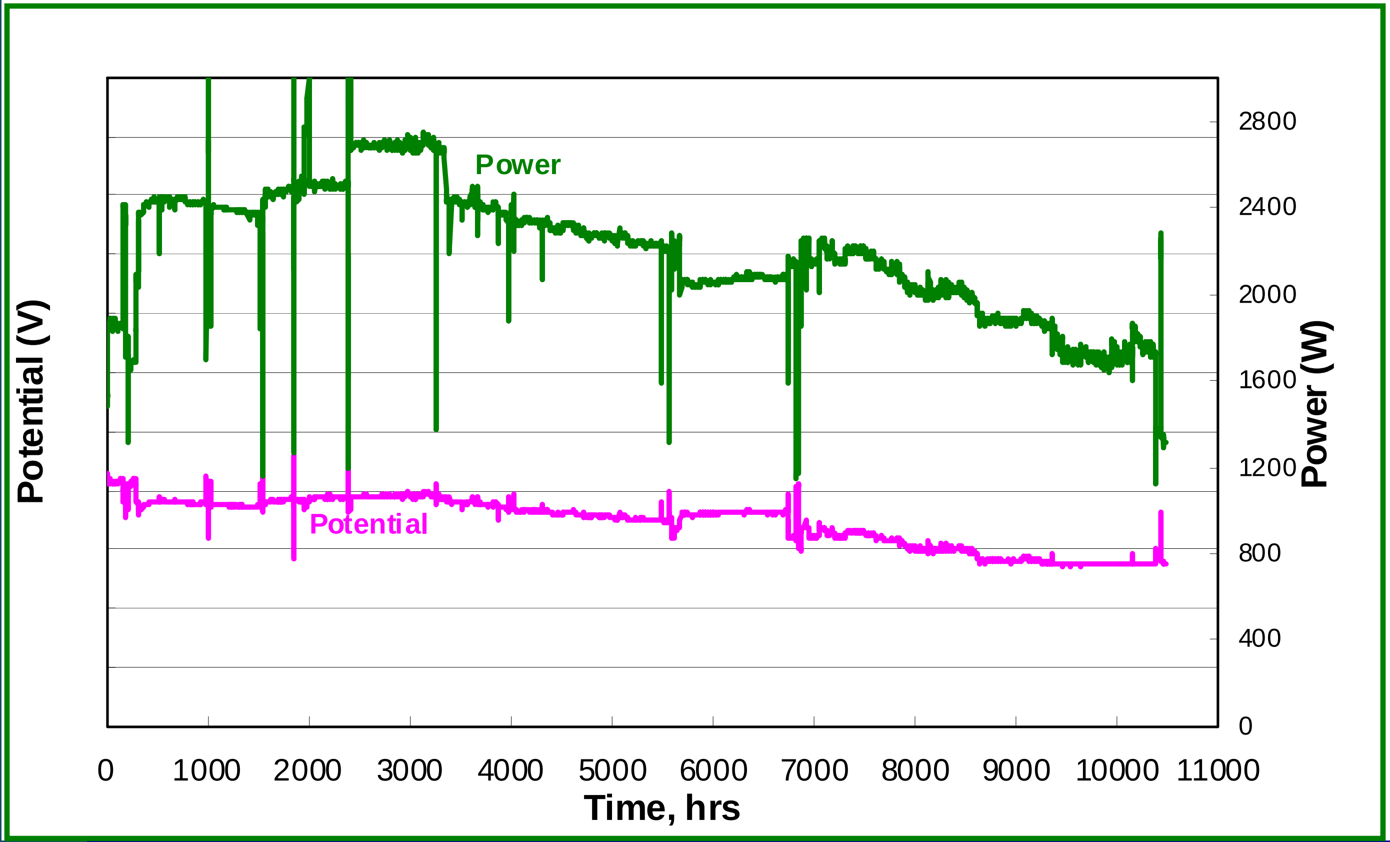
Location: Outside, grid tied



Fuel: Natural gas

Products: electrical power

SECA Phase I Generator



- Total run time 10,500hr
- Major ESTOP event at 3200hrs
- 18 Thermal cycles
- Shipped twice (part of SECA Phase I testing at NETL)
- 2004 cell technology

Micro CHP

3 have been built to date

Has started CE certification

Plan to undergo testing with the MTS consortium in the next month

1kWel AC out, 20kWth eff(all)=85%,

SOFC for Military Applications

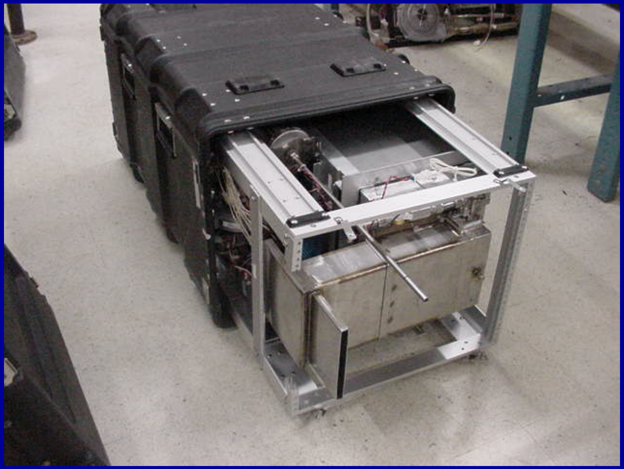
High Performance

- High power density, small and light
- Silent
- Rapid start-up
- Efficient, water neutral

➢ Reliable

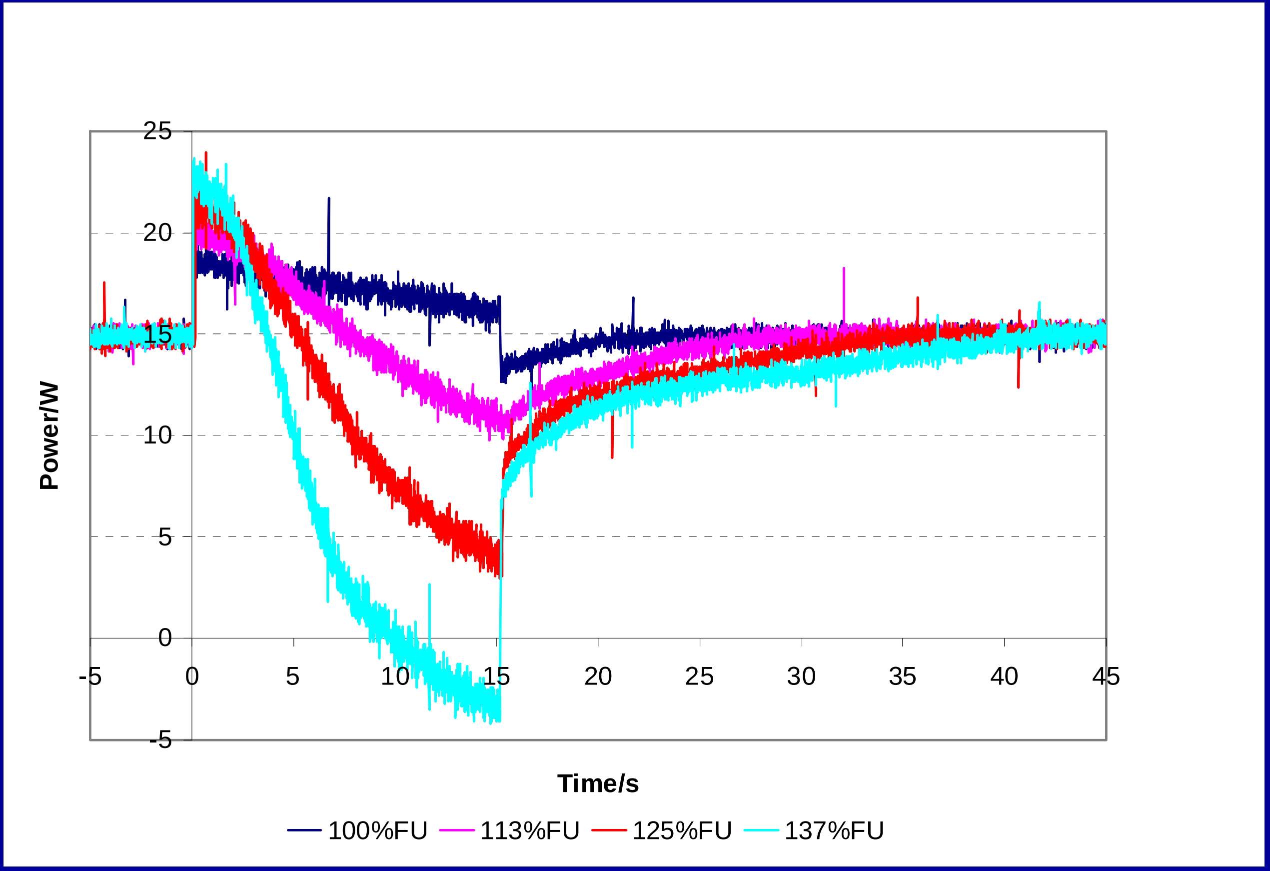
- Mechanical, shock and vibration
- Thermal, shock and thermal cycling
- Electrical, load cycling
- Chemical, poison (sulfur) and fouling (carbon) resistance

SOFC for Military Applications



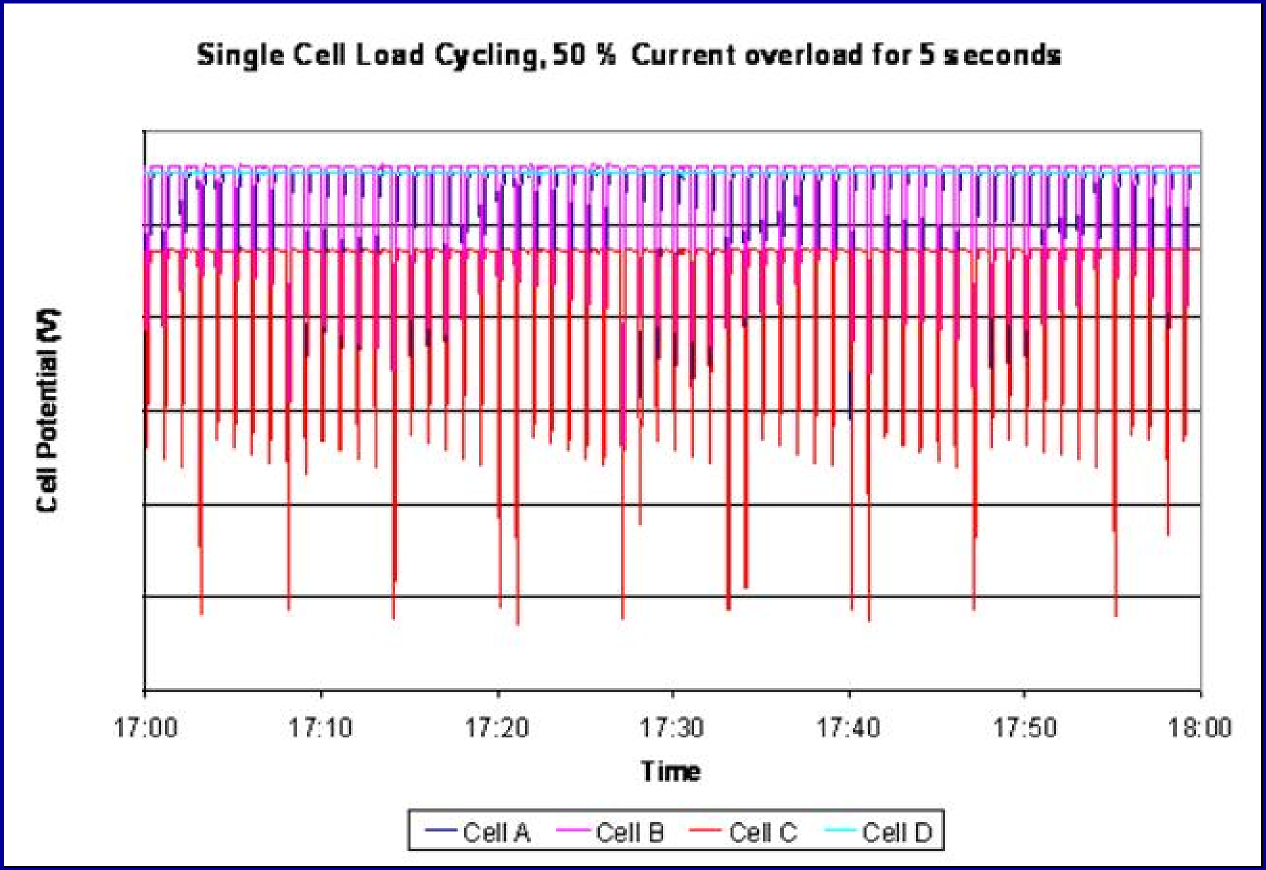
The fuel cell stack and BOP assembled onto the frame of a transit case

Electrical Load Cycling



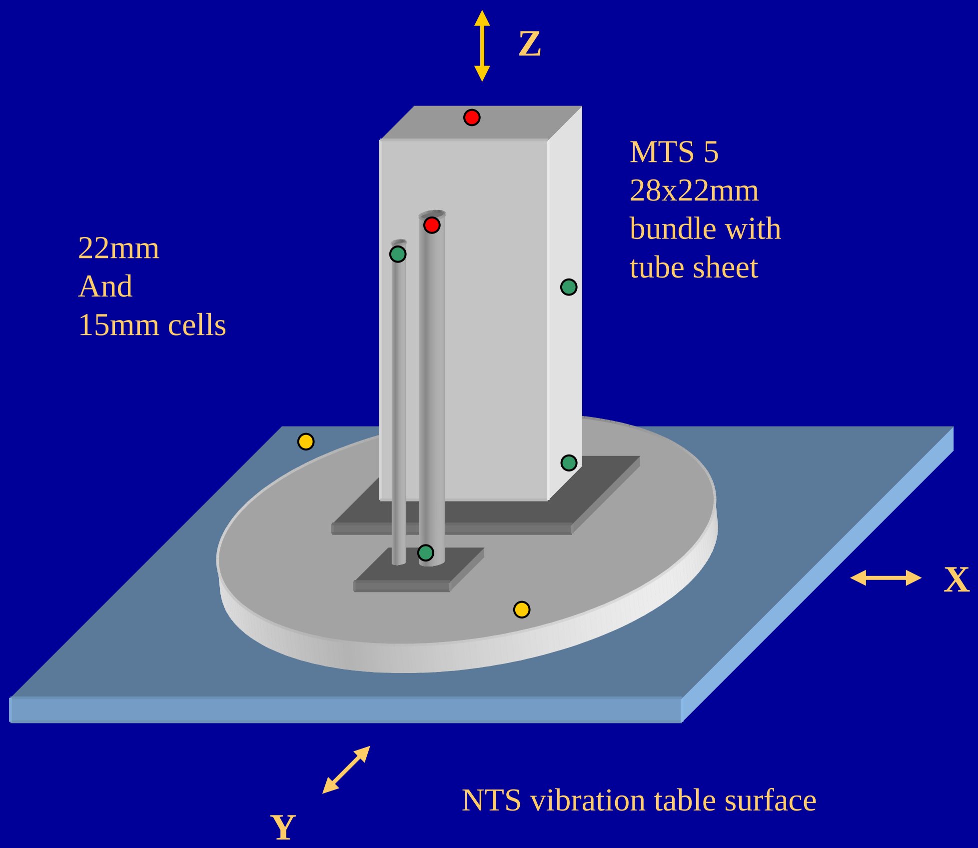
Cell voltage recovery after operation at >100% Fuel Utilization

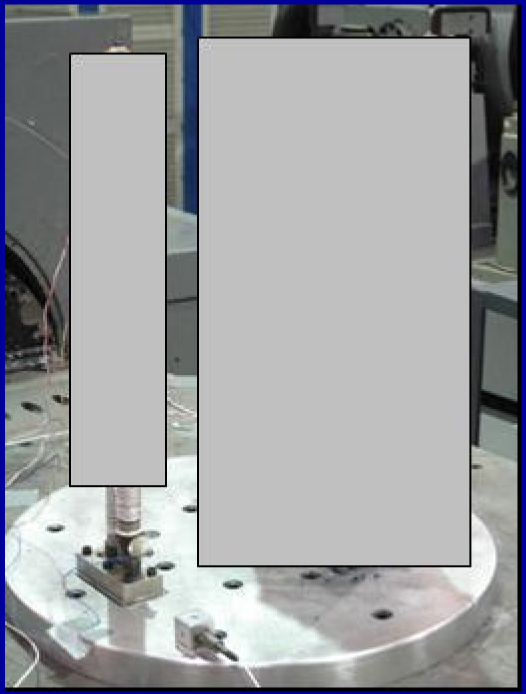
1000x Load Cycling



Mechanical Testing

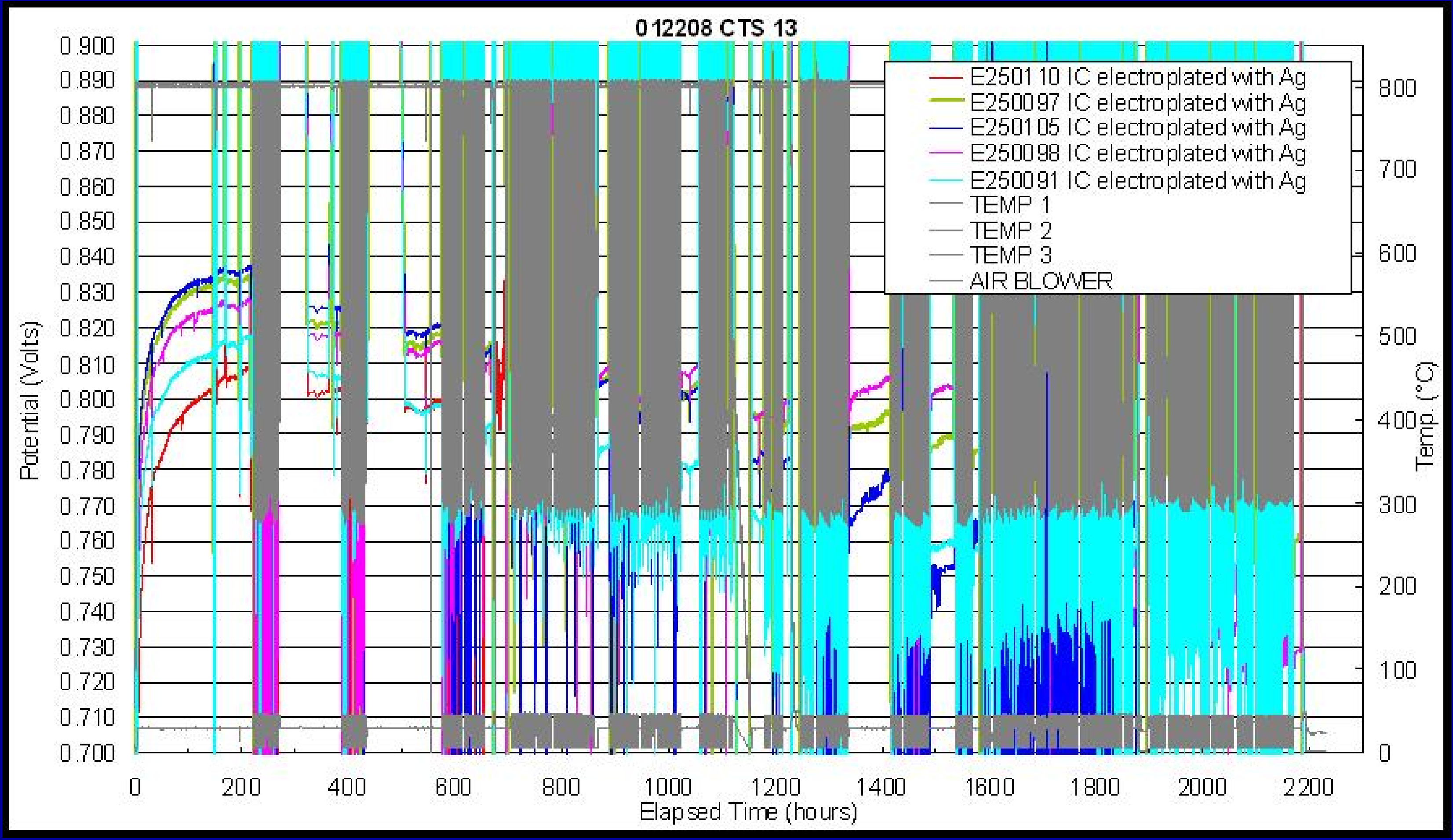
MIL-STD-810F 2 Wheel trailer 30 min vibration test



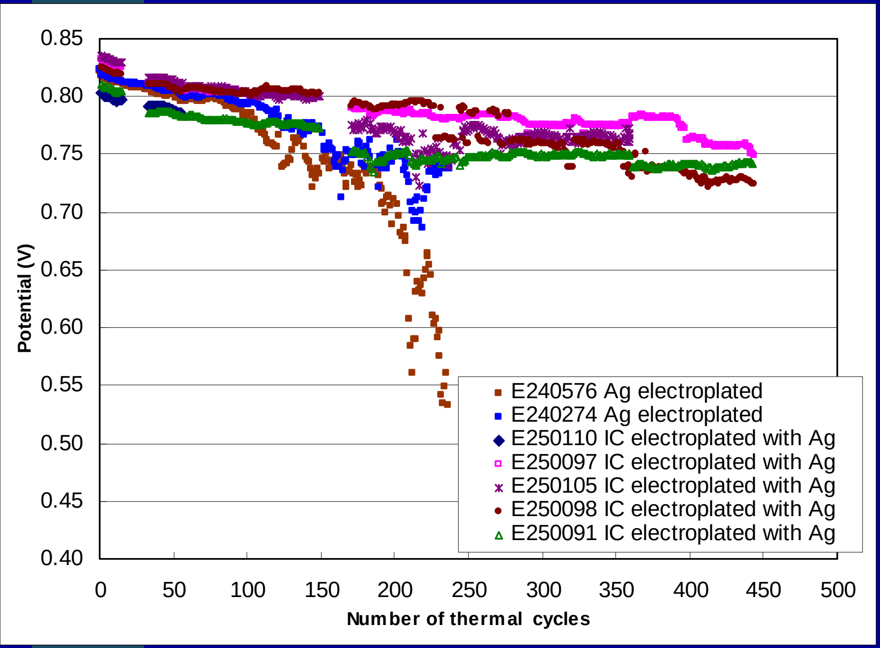


- Single axis accelerometer
- Triple axis accelerometer
- Single axis control accelerometer

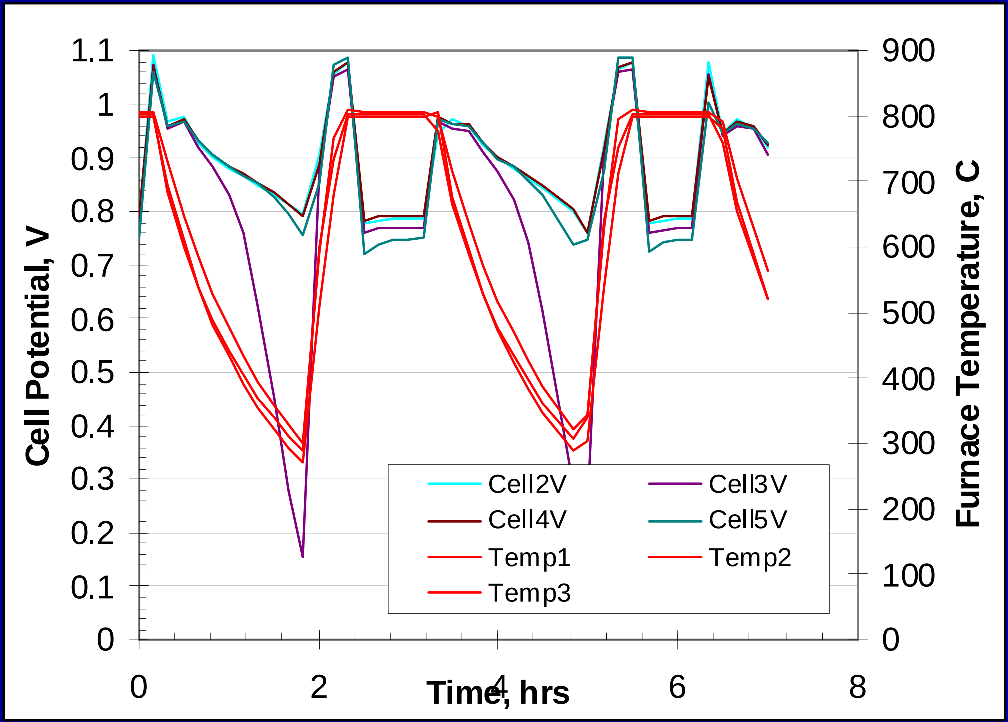
Electrical Testing- Thermal cycling



Electrical Testing- Thermal cycling

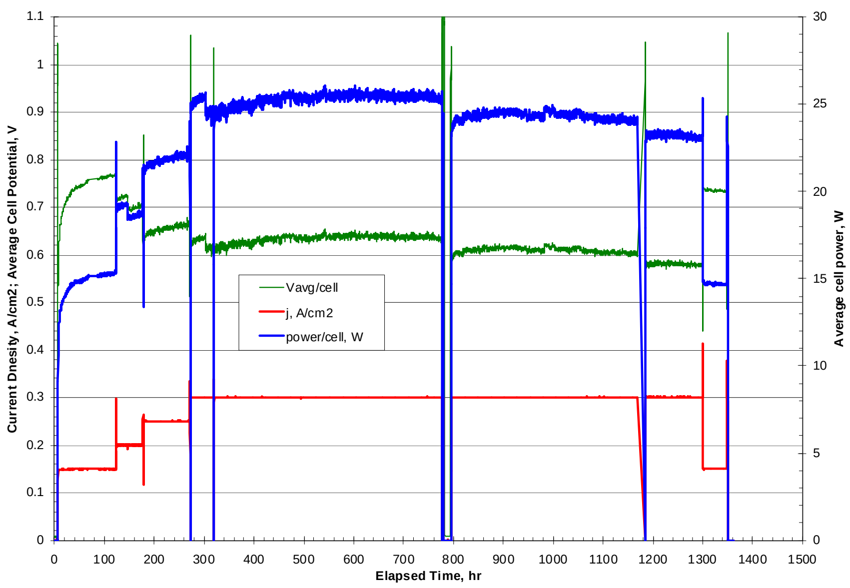


Loaded Cell performance graphs show a Loss rate of about 1%/100TC
~4000hr run time/1500hrs at power

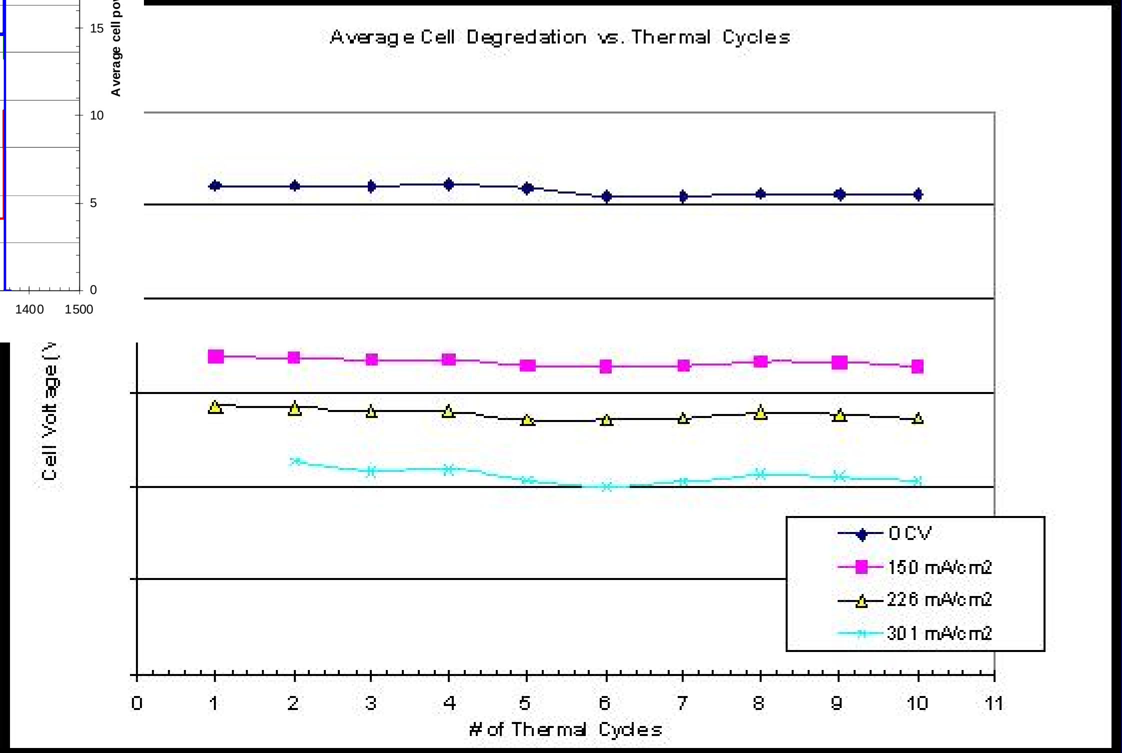


1. Unload cell and go to OCP- 5min
2. Go to Purge gas-Lower Temp to 300C
3. Back to 800C-start H2, wait 10min
4. Load 30 minutes and record data
5. Loop

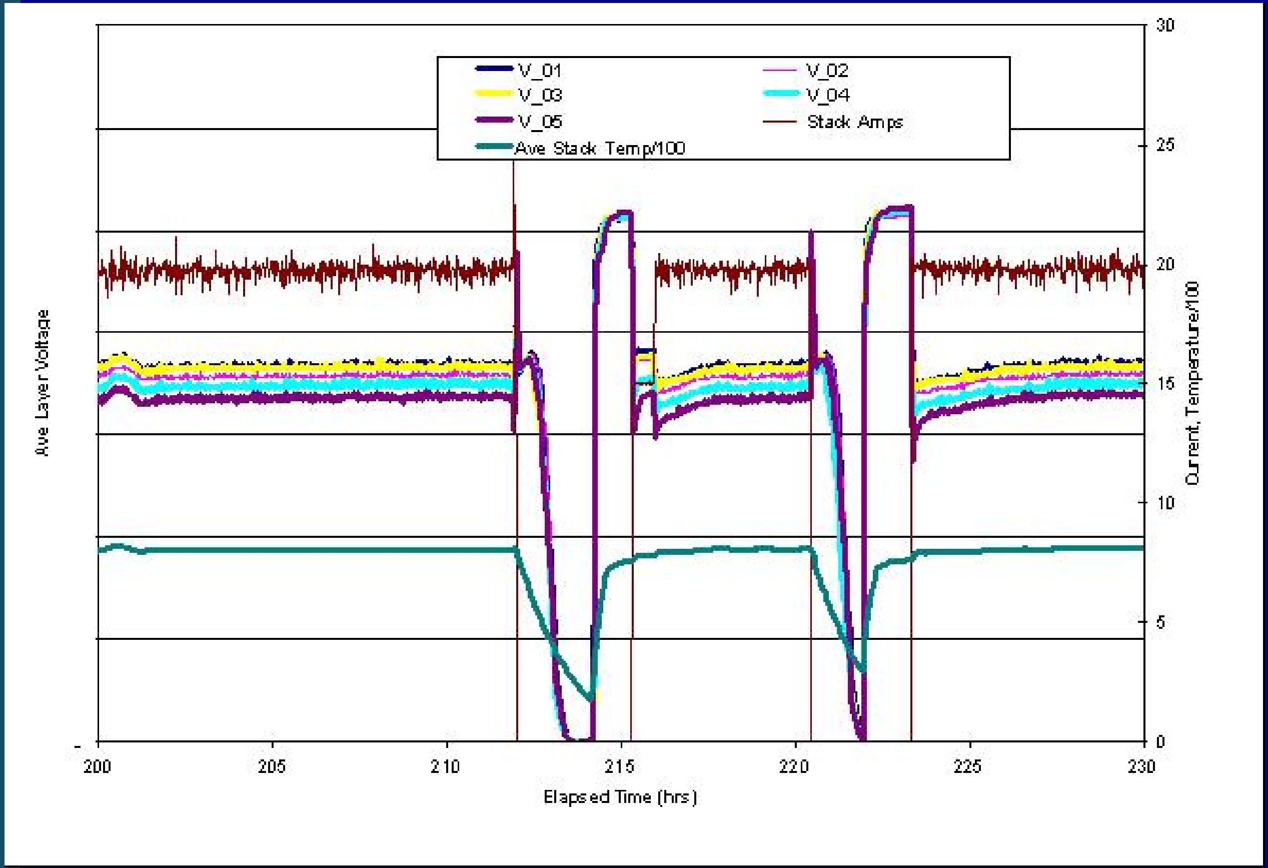
Thermal Cycles on Stacks



Hours Run	Time	Notes
0	**7/29/08 10:21**	**Start / Cycle 1**
0.59	7/29/08 10:57	light reactor
0.99	7/29/2008 11:21	CPOX
3.17	7/29/08 13:32	Pre-Reactor inlet sa
4.48	7/29/08 14:50	OCV
5.71	7/29/08 16:04	150
5.85	7/29/2008 16:12	226
5.95	7/29/08 16:18	shutdown, stack vo



Micro CHP Thermal Cycling



Schedule:

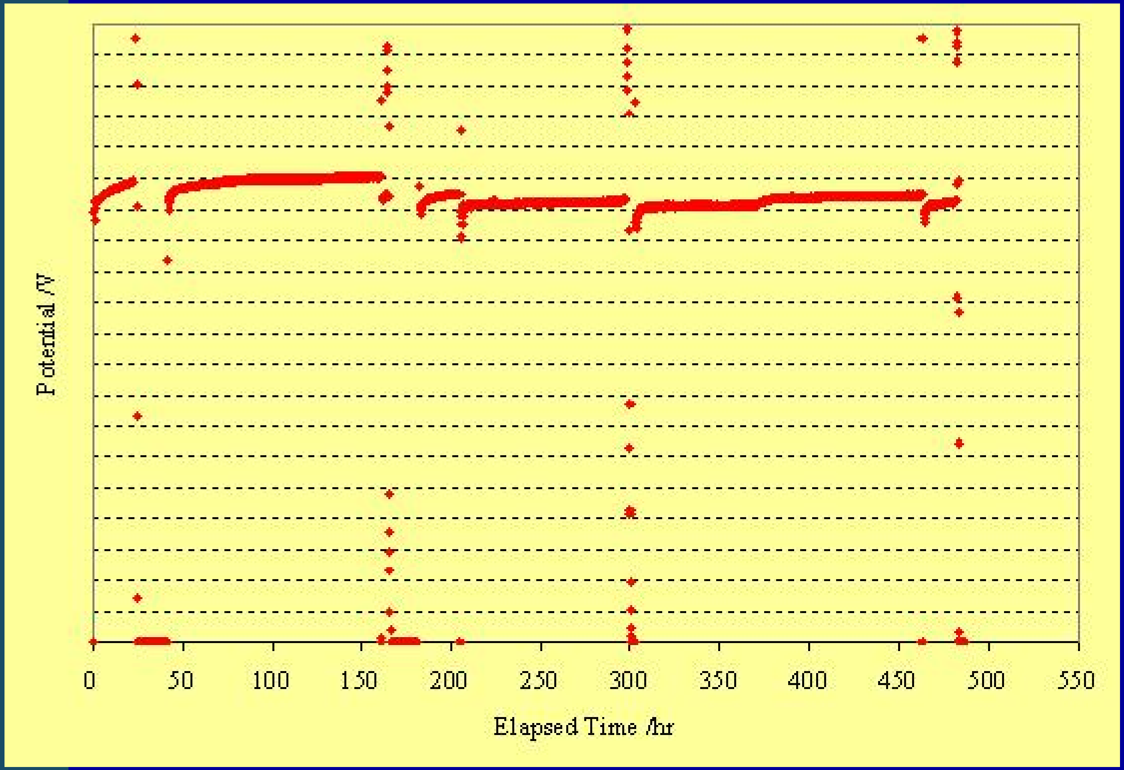
- About an hour down to ~200C
- Less than 30 min back to power
- Run
- Redo

20 thermal cycles

Purgeless cycles

Excellent recovery

Thermal Gradients



1/3 cell sitting *OUTSIDE* furnace

6 Thermal Cycles

459 load hours

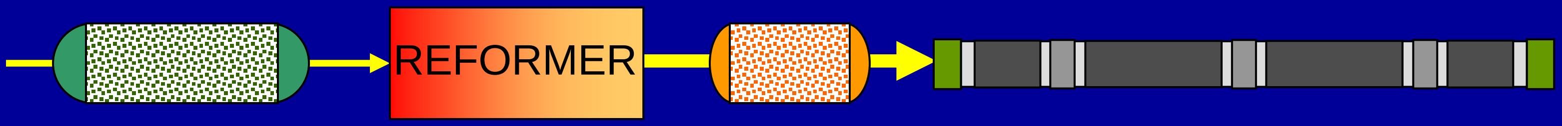
Fuel Flexibility

High energy density fuels

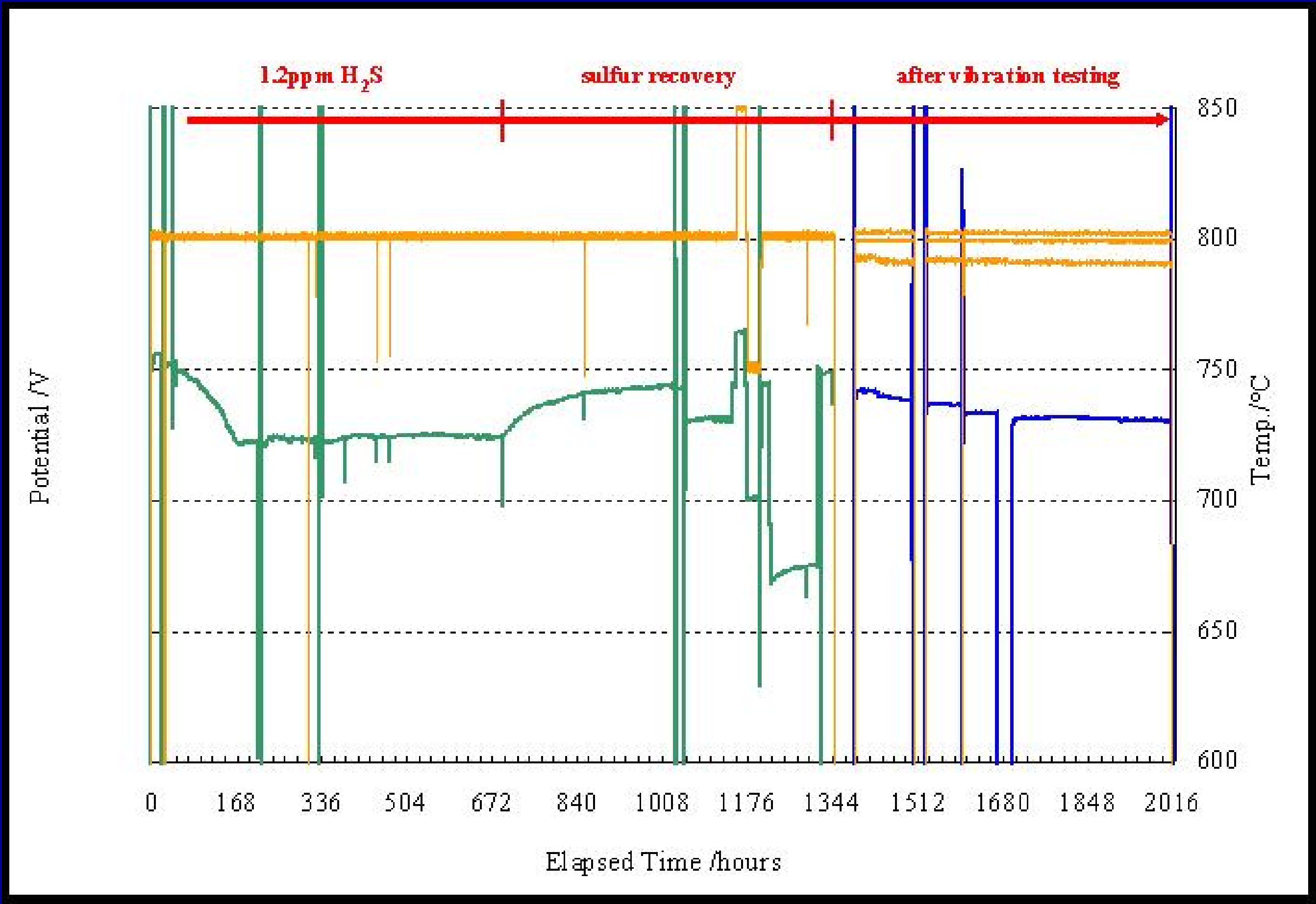
- JP-8 MIL-T-83133
  - Aromatics 15-20%
  - Olefins 1-2%
  - Saturates 78-83%
  - Sulfur 10-1000ppm
- Synthetic JP-8
  - Saturates 100%
  - Sulfur < 0.1ppm
- LPG
  - Sulfur up to 180 ppm

Sulfur Poisoning

- Sulfur present in large quantities in military fuels (possibly up to 1wt%)
- Common fuel cell catalysts susceptible to sulfur poisoning (need <10ppm)
- Solutions:



Sulfur Testing on Single Cells

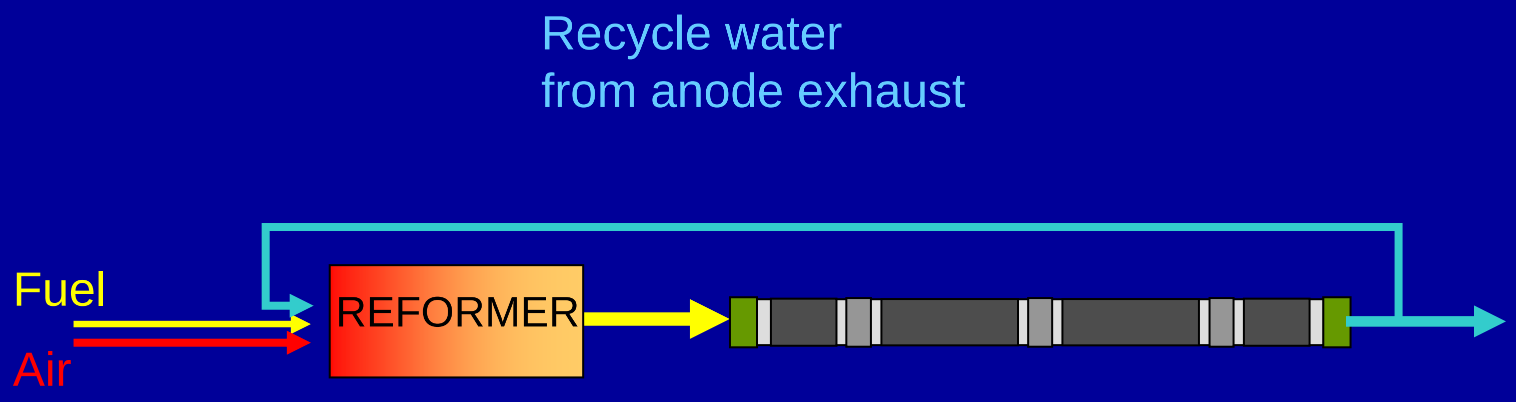


JP8 Reforming

- Reforming Modes
  - Steam reforming (H_2O, CH_x)
    - High efficiencies, requires significant water (high S/C), heat transfer difficulties, larger reactors, upstream liquid phase desulfurization
  - Partial oxidation (O_2,CH_x)
    - Less efficient, but small reactors and fast dynamics, down stream gas phase desulfurization
  - Autothermal reforming (O_2, H_2O, CH_x)
    - Best (and worst) of both worlds?
- Reforming Techniques
  - Catalytic, Plasma, Thermal

Water Neutrality

- Water at the military front is expensive!
  - e.g. 1 gal JP8 requires ~2 gal water at S/C=2
- Solution: Fuel cells produce water



Catalytic Reforming at Acumentrics

Breadboard testing of reformers

- Steam Reforming
  - >1000hr testing on S-8 (zero sulfur) S/C=4
  - 300W stack test
- Partial Oxidation
  - JP-8 (~280ppmS) CPOX reformer at steady state
  - 24 hr test on 1kW stack
- ATR
  - ATR reformer
  - 1000hr testing on JP8 (~10 ppmS) on a 1kW stack
  - 2 days of transient testing, load following and cycling

Steam Reforming of Synthetic JP8

- 48 gal of Synthetic JP8 reformed over 1550 hours.

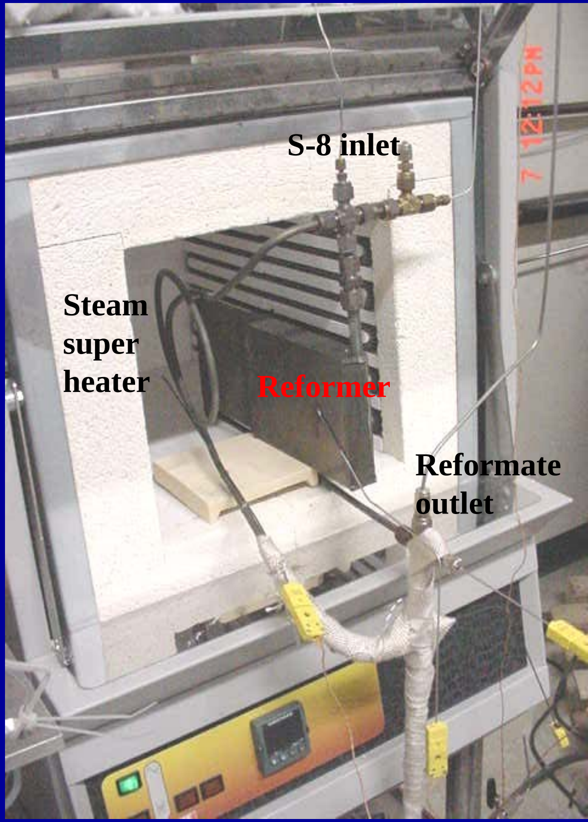
  Total cell testing time on reformate was 1330 hours.

- Longest continuous cell testing (300W bundle) were 624 and 427 hr periods; stops due water and diesel pump failures.

- Longest continuous reformer operation was 1171 hours.

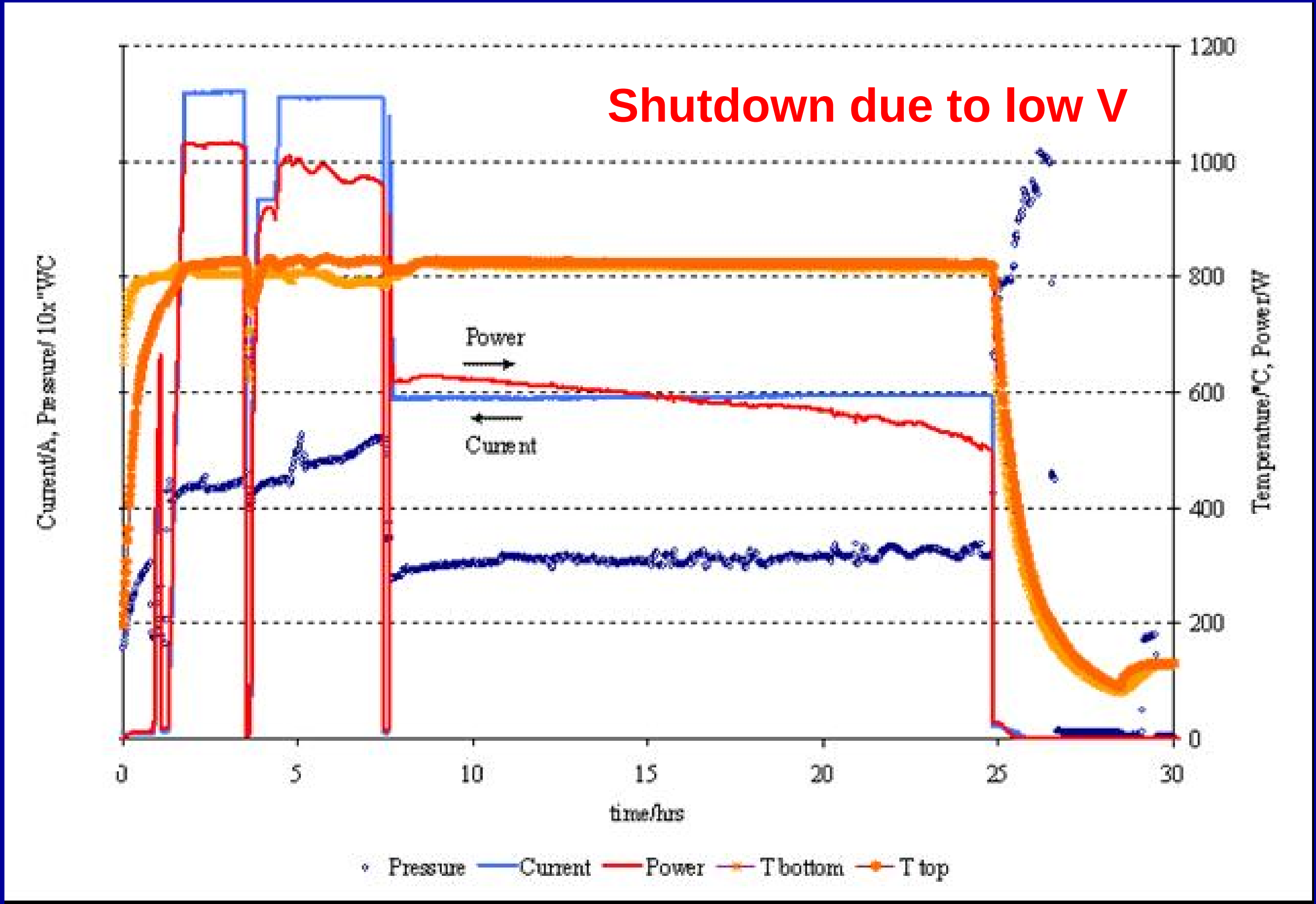
- Testing done mostly at S/C=4, also down to 3.5

- Total reformer testing to date approximately 2500hrs as scheduled.



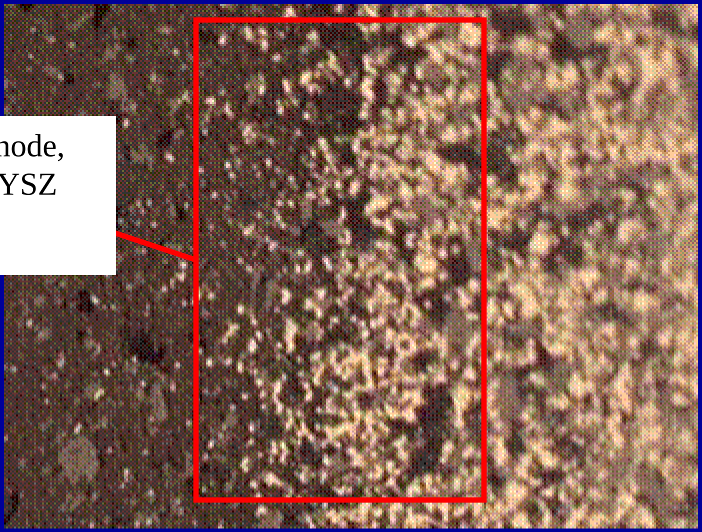
1 kW JP-8 CPOX

JP8, 280 ppmW S, O/C=1.03



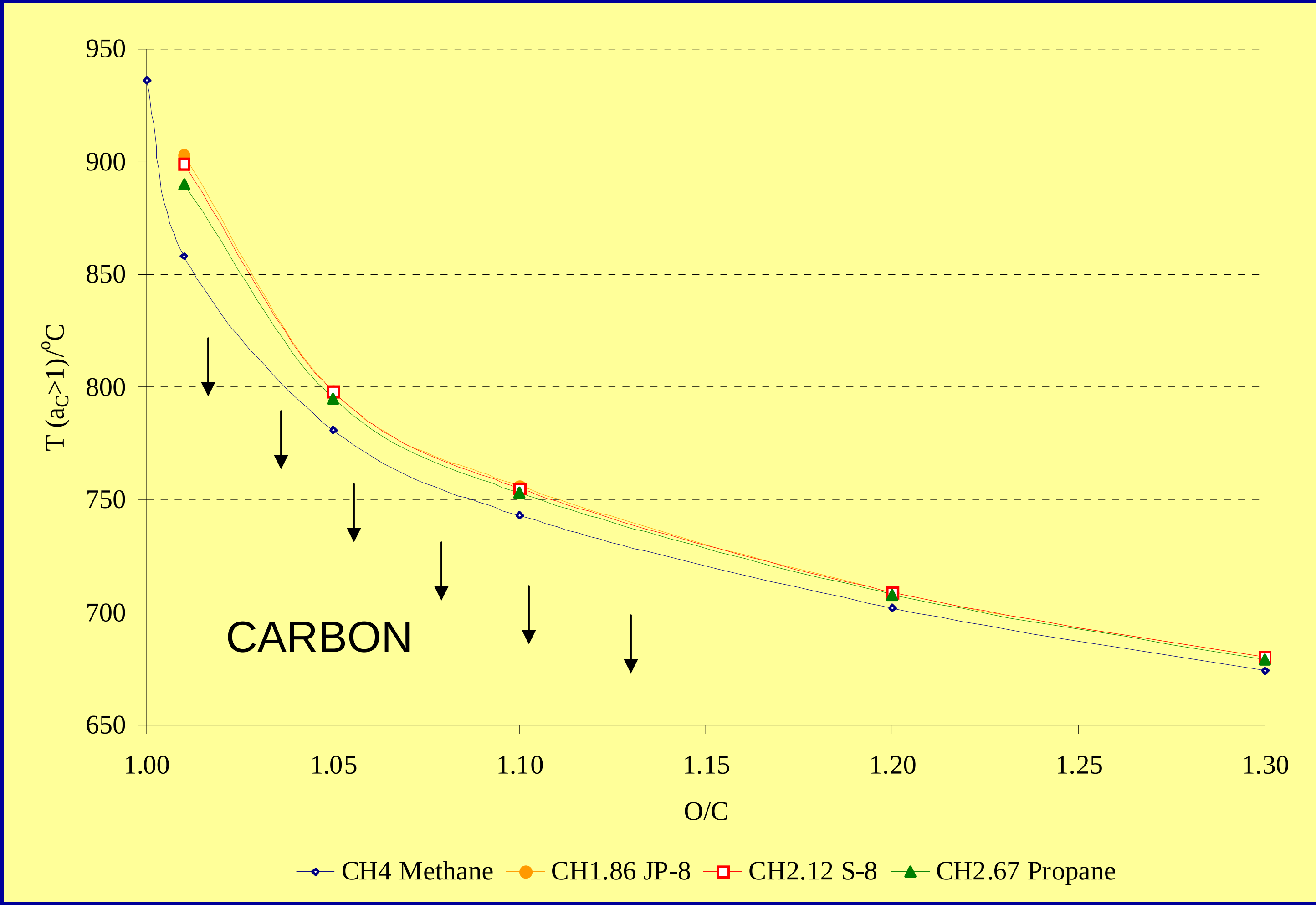
JP-8 CPOX 24 hr test

Disintegrated anode, carbon, Ni and YSZ free particles



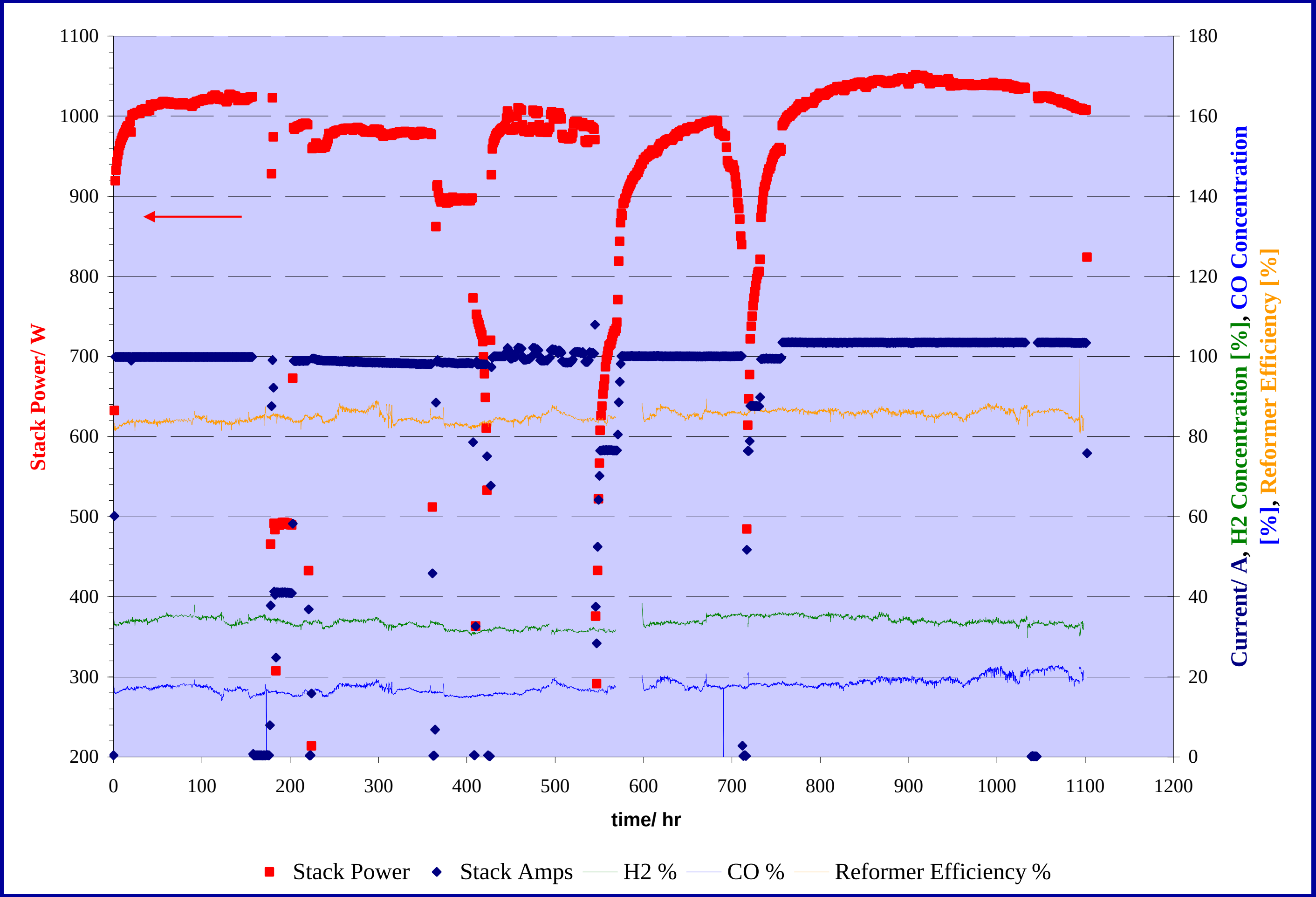
Carbon deposition throughout hot manifolds and cells (O/C~1). Temperature boundary for carbon deposition is ~800^{o}C (*thermodynamic*)

CPOX Caveat

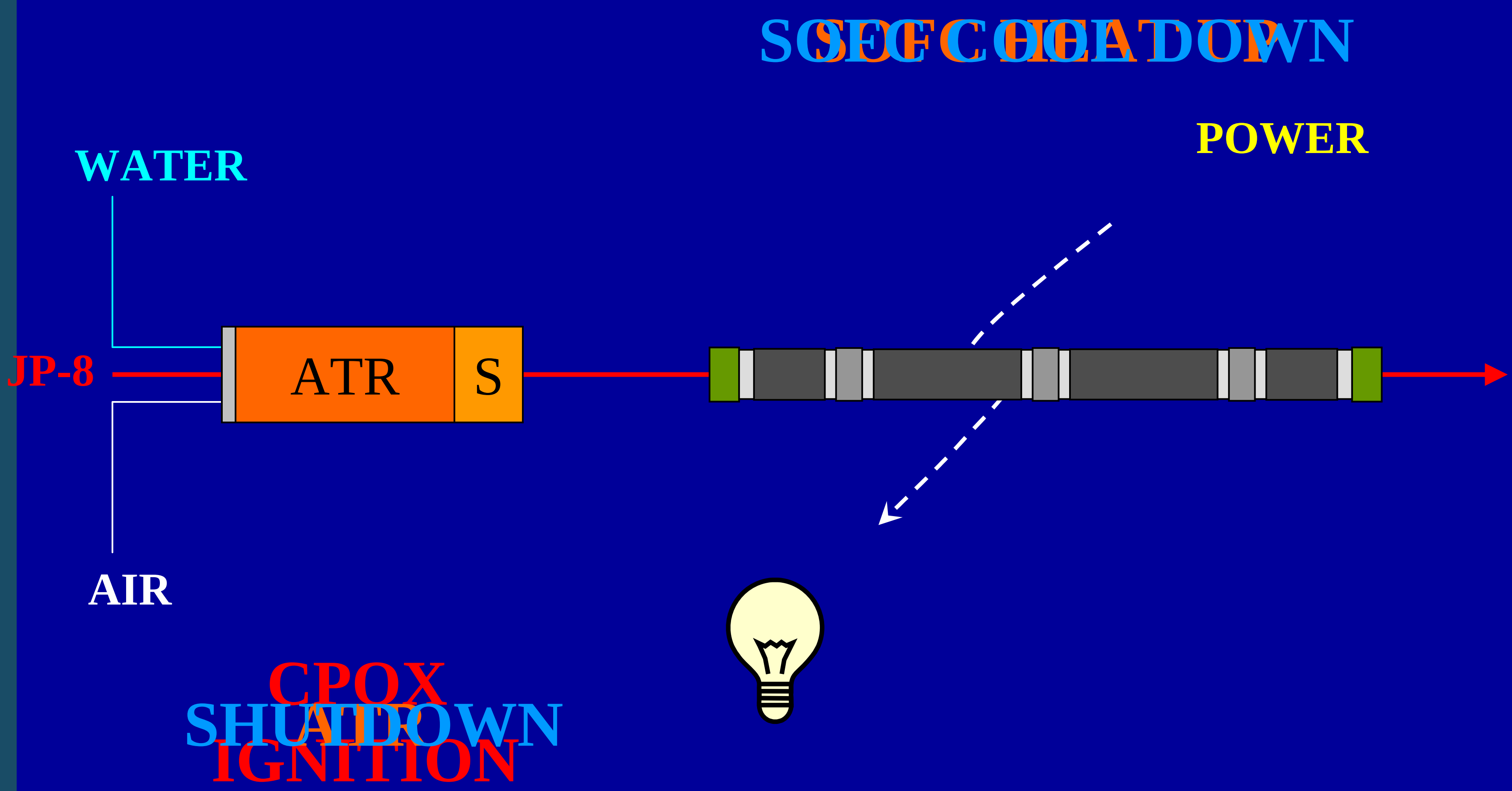


950
900
850
800
750
700
650
T (a$_C$>1)/^{o}C
CARBON
1.00
1.05
1.10
1.15
1.20
1.25
1.30
O/C
CH4 Methane
CH1.86 JP-8
CH2.12 S-8
CH2.67 Propane

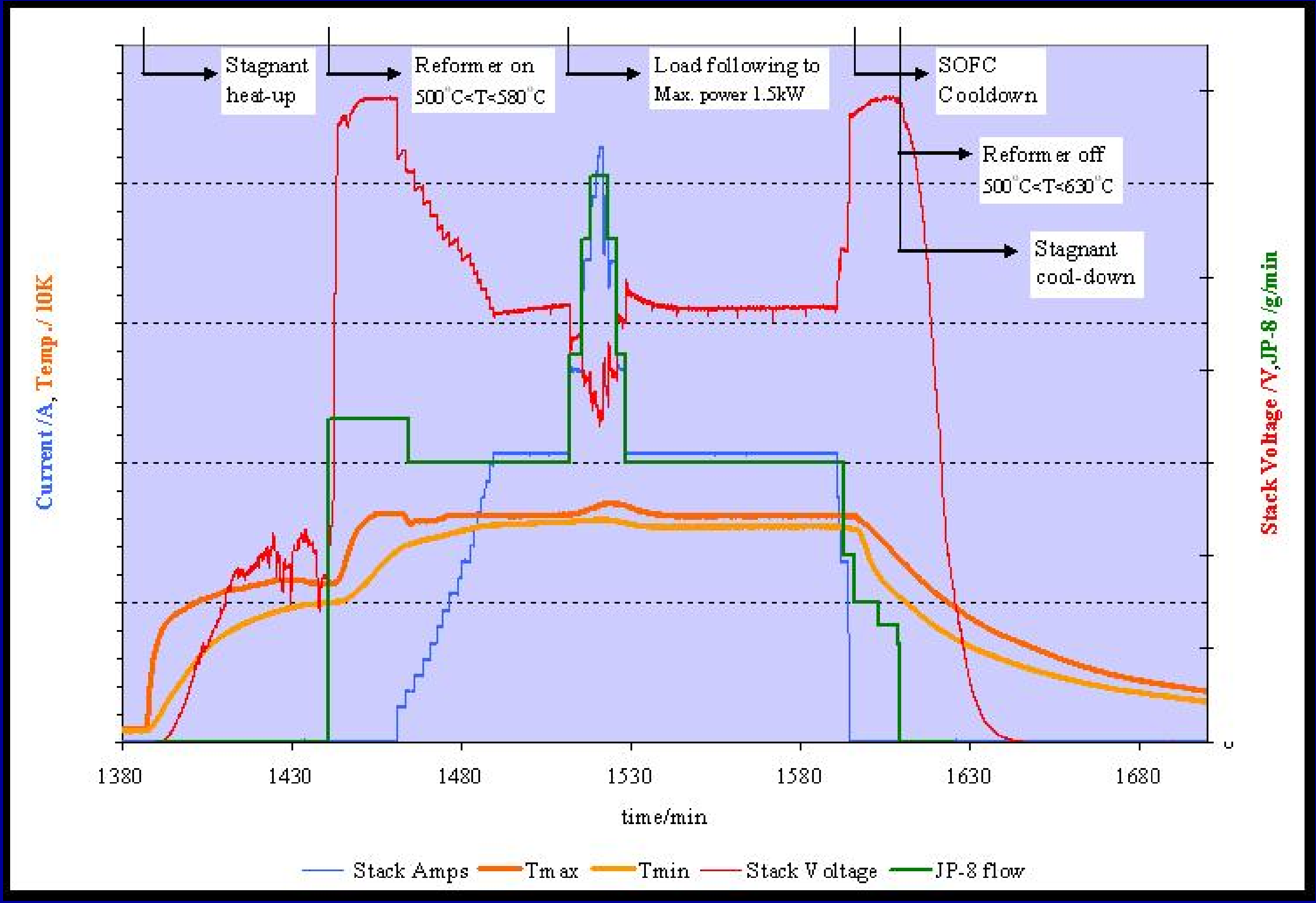
1000 hr ATR test on JP-8



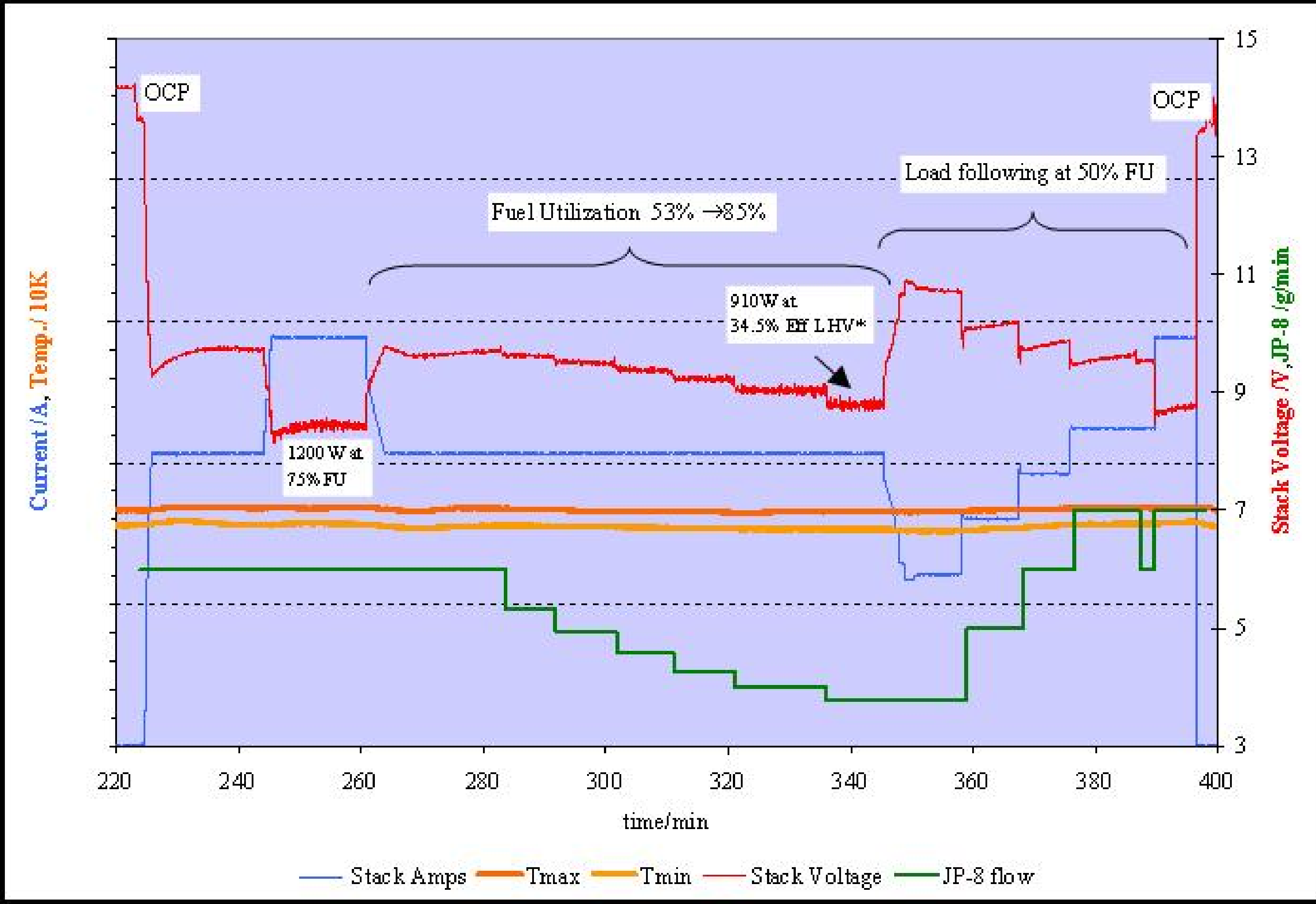
Direct JP-8 Start-up/Shutdown



Direct JP-8 Startup



Transient Testing



Going Forward

- Integration of SOFC stack with ATR reformer
  - SOFC controls ATR, enabling transient testing (fast start-up, load following, thermal cycling)
  - Incremental integration to full water neutrality
- Continued testing of reformers

Thanks to

- Reginald Tyler of EERE
- Don Hoffman, John Kuseian, John Heinzel of ONR
- MTS/Consortium members
- Acumentrics Team