SECA
Solid Oxide Fuel Cell Program

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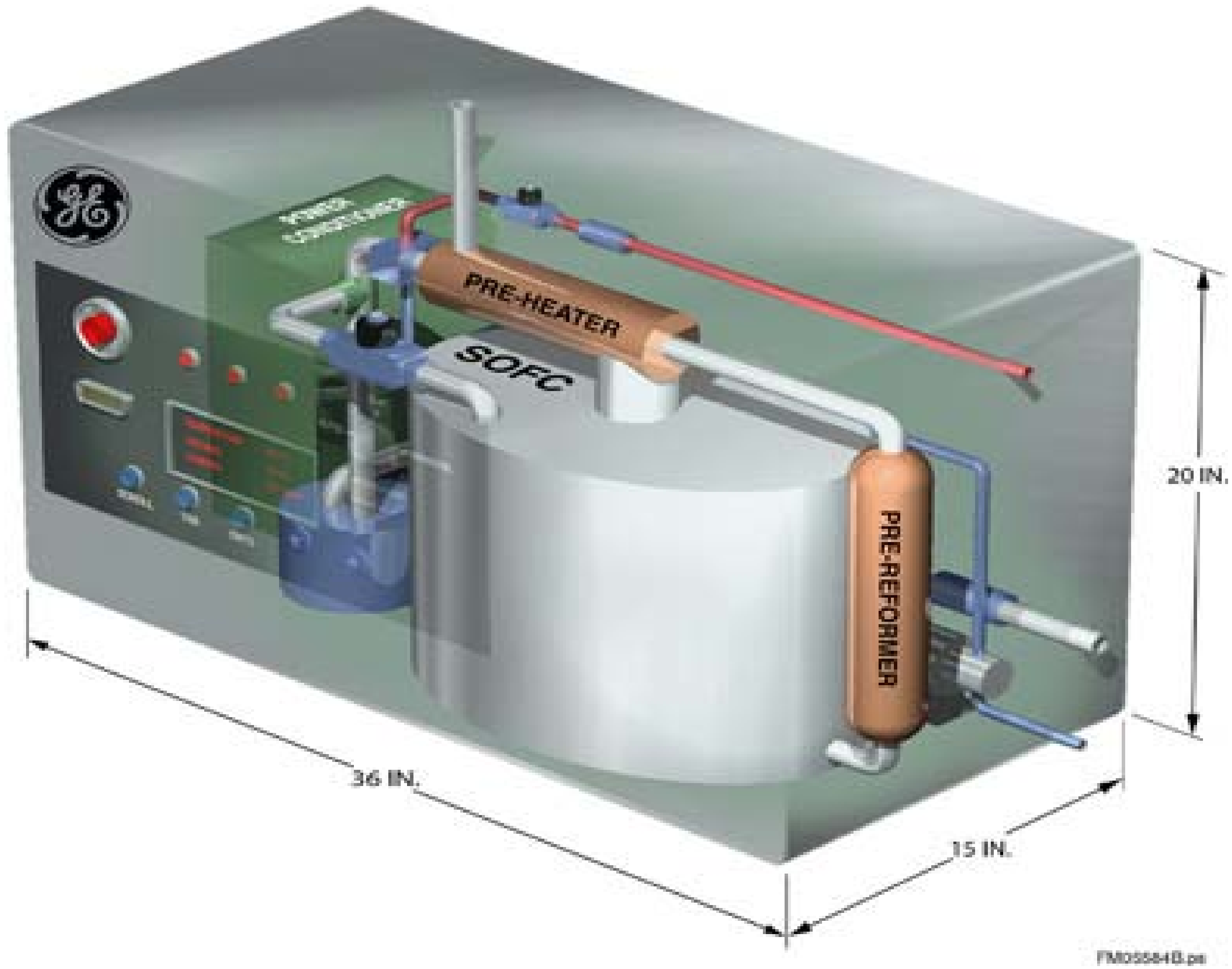
SECA Annual Workshop and
Core Technology Program Peer Review
Boston, MA, May 11 – 13, 2004

Program Objectives

- **Overall objective**
  - > Demonstrate a fuel-flexible, modular 3-to-10-kW solid oxide fuel cell (SOFC) system that can be configured to create highly efficient, cost-competitive, and reliable power plants tailored to specific markets

- **Development team**
  - > GE Energy
    - – Torrance, CA
    - – Schenectady, NY
    - – Greenville, SC
  - > GE Global Research
    - – Niskayuna, NY

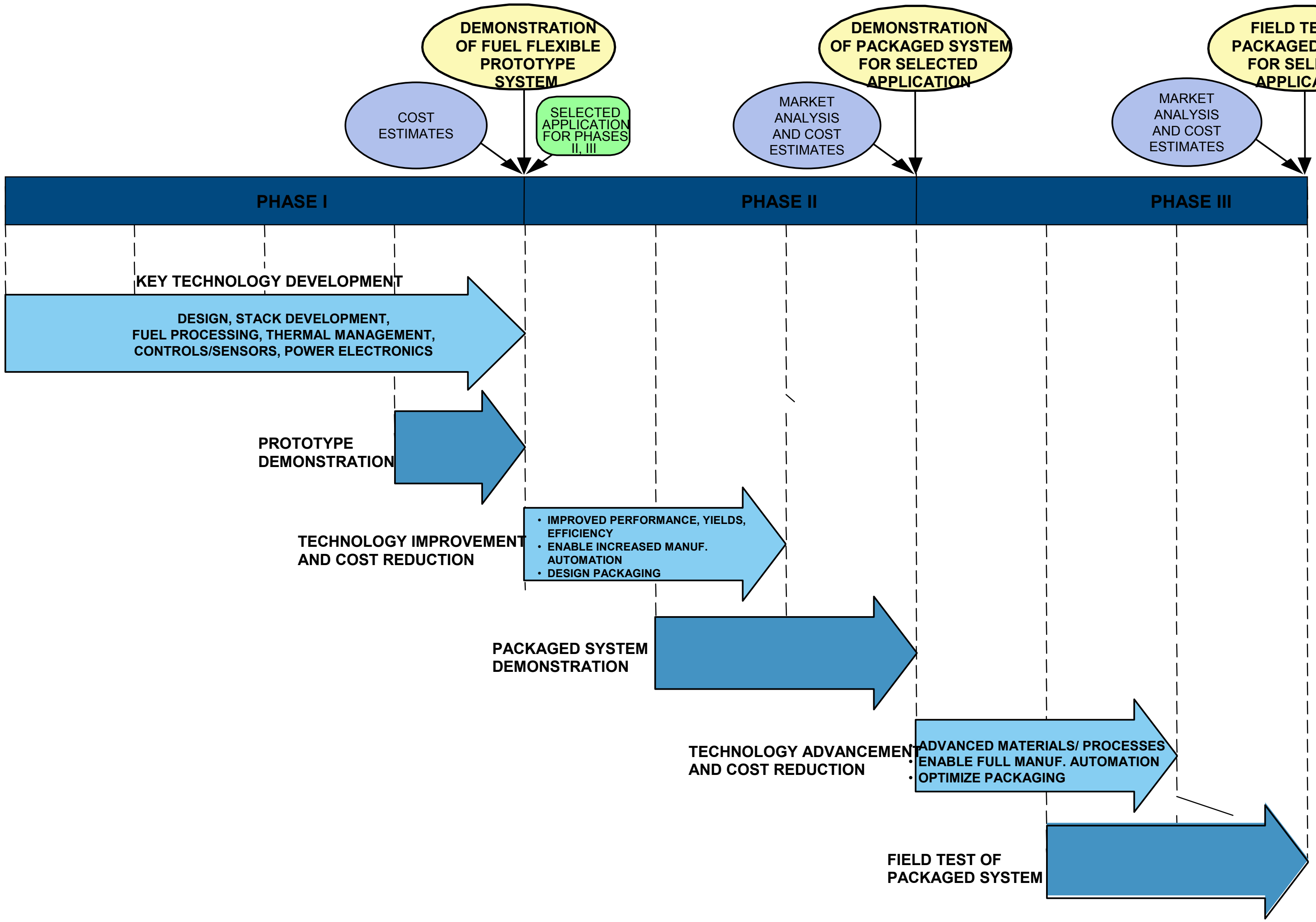
SECA SOFC System Concept



System Key Features

- **SOFC**
  - > High-performance reduced-temperature cells
  - > Operation on light hydrocarbons
  - > Tape calendering manufacturing process
- **Fuel processor**
  - > Low-cost, fuel-flexible fuel processor design
  - > Catalytic autothermal (ATR) process
  - > Pre-reforming function
- **Other subsystems**
  - > Integrated thermal management
  - > Flexible control system

Program Features



Phase I Work Elements

- System analysis
- Cost estimate
- Stack technology development
- Fuel processing
- Thermal management
- Control and sensor development
- Power electronics
- System prototype demonstration

SECA Phase I Requirements

PARAMETER	PHASE I REQUIREMENTS
POWER RATING (net)	3Kw - 10 kW
COST	$800/kW
EFFICIENCY (AC or DC/LHV)	Stationary-35%
STEADY STATE TEST @ NORMAL OPERATING CONDITIONS	1500 hrs
	80% avalability
	Delta Power = 2% degradation/500 hrs at a constant stack V with R >= 0.95
TRANSIENT TEST	10 cycles
	Delta Power = 1% degradation after 10 cycles at a constant stack voltage
TEST SEQUENCE	1) Steady state 1000 hours
	2) Transient test
	3) Steady state 500 hours
FUEL TYPE	Operate the prototype on either a commercial commodity, or a representative fuel. Utilize external or internal primary fuel reformation or oxidation
MAINTENANCE INTERVAL	> 1000 hours
DESIGN LIFETIME	Not less than 40,000 operating hours for stationary applications

SOFC Stack Requirements

Stack Performance:

- Power density: 0.3W/cm^2
- Stack LHV efficiency: 47% on ATR fuel
  - Average cell voltage: 0.7V
  - Fuel utilization: 80%
- Degradation rate: <6%/1000 hours

Cell Performance:

- Power density: 0.3W/cm^2
- Cell LHV efficiency: 51.7% on ATR fuel
  - Cell Voltage: 0.7V
  - Fuel Utilization: 88%
- Degradation rate: <6%/1000 hours

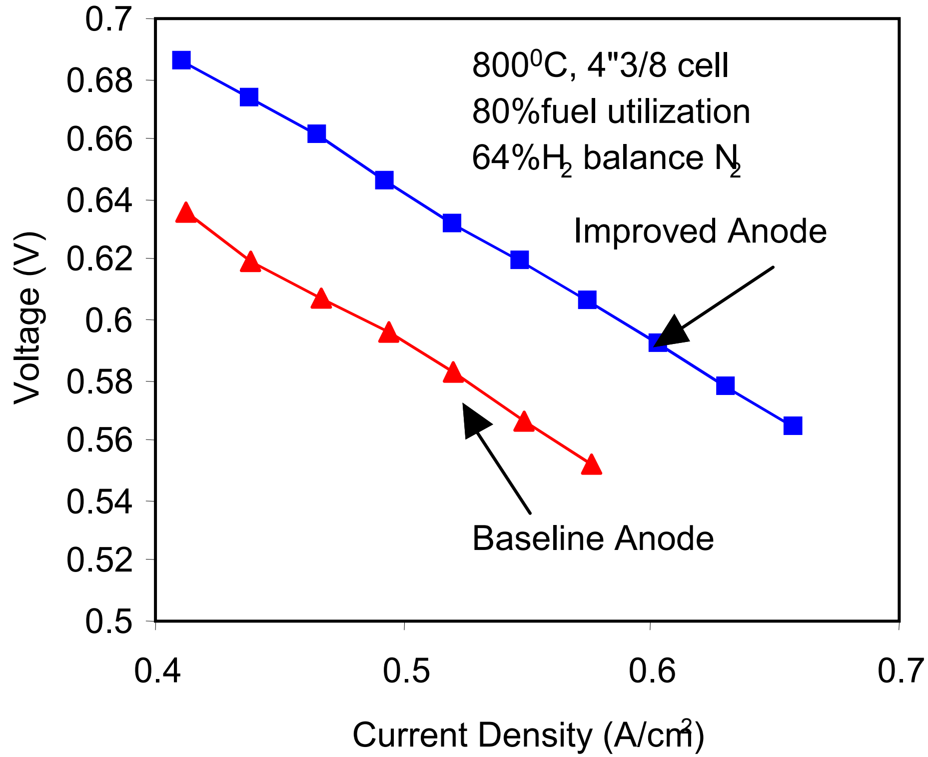
Cell Component:

- Total ASR: < 560 mohm-cm^2

Anode Development

Reduce anode polarization and maintain/improve cell flatness and strength

- Porosity
- Anode thickness
- Microstructure
- Layer configuration

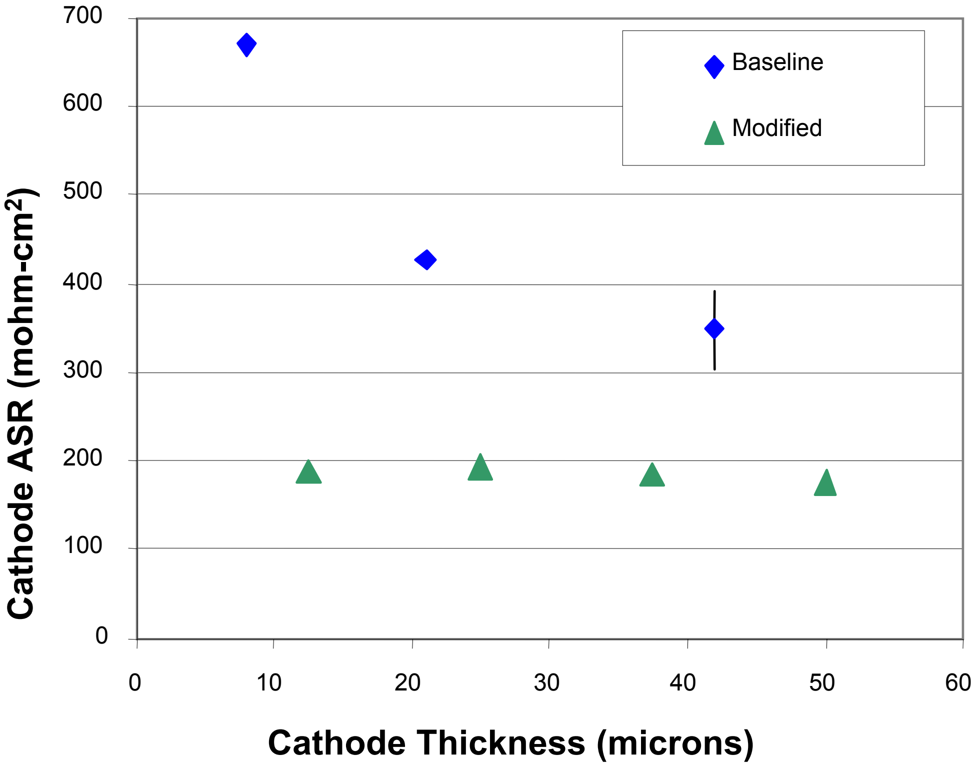


- **10% performance increase with improved anode**
- **To be verified with larger cells**

Cathode Development

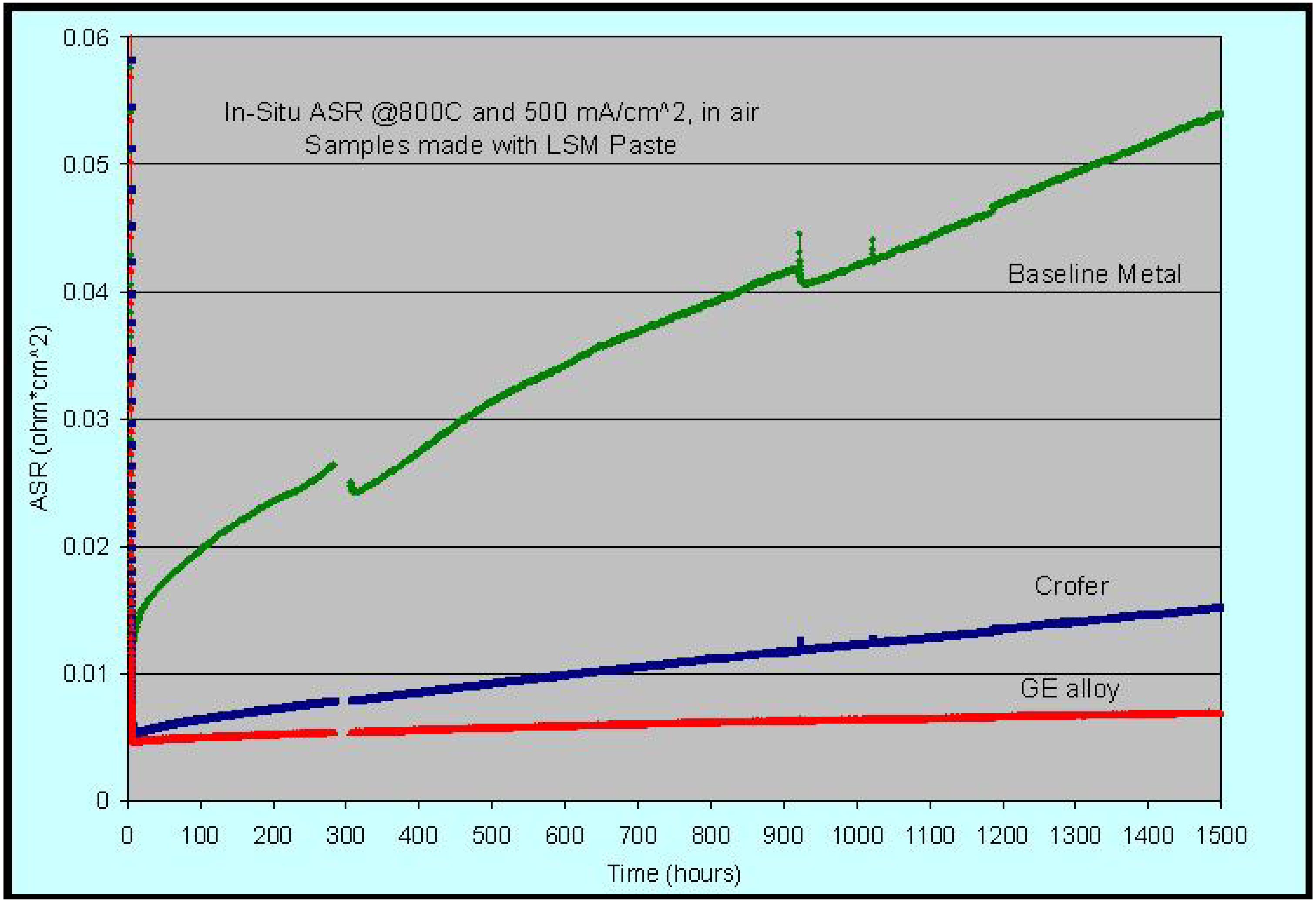
Reduce cathode polarization and reduce thickness

- Cathode thickness
- Microstructure
- Material characteristics
- Formulation/process

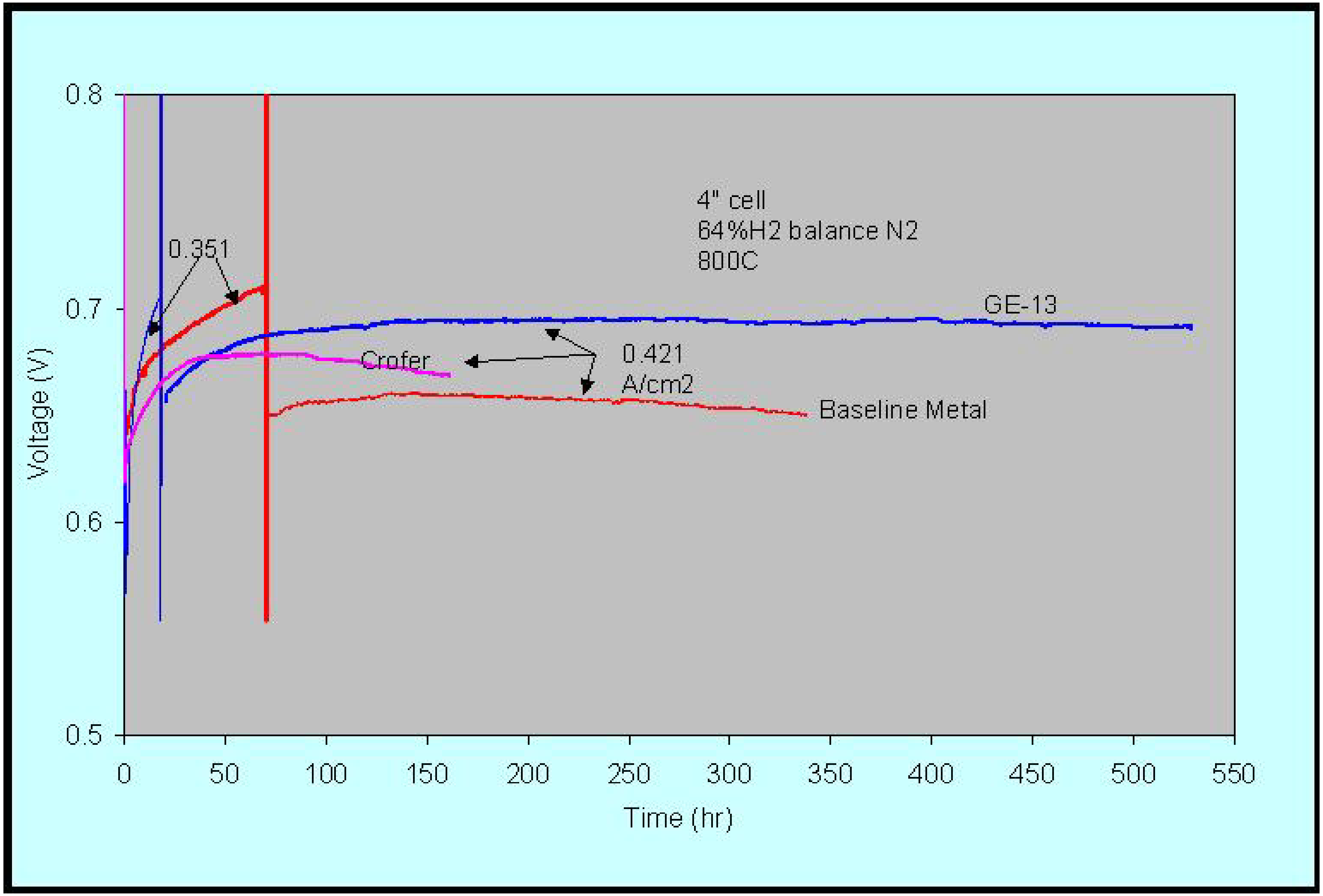


- **Performance improved with modified cathode**
- **To be verified with larger cells**

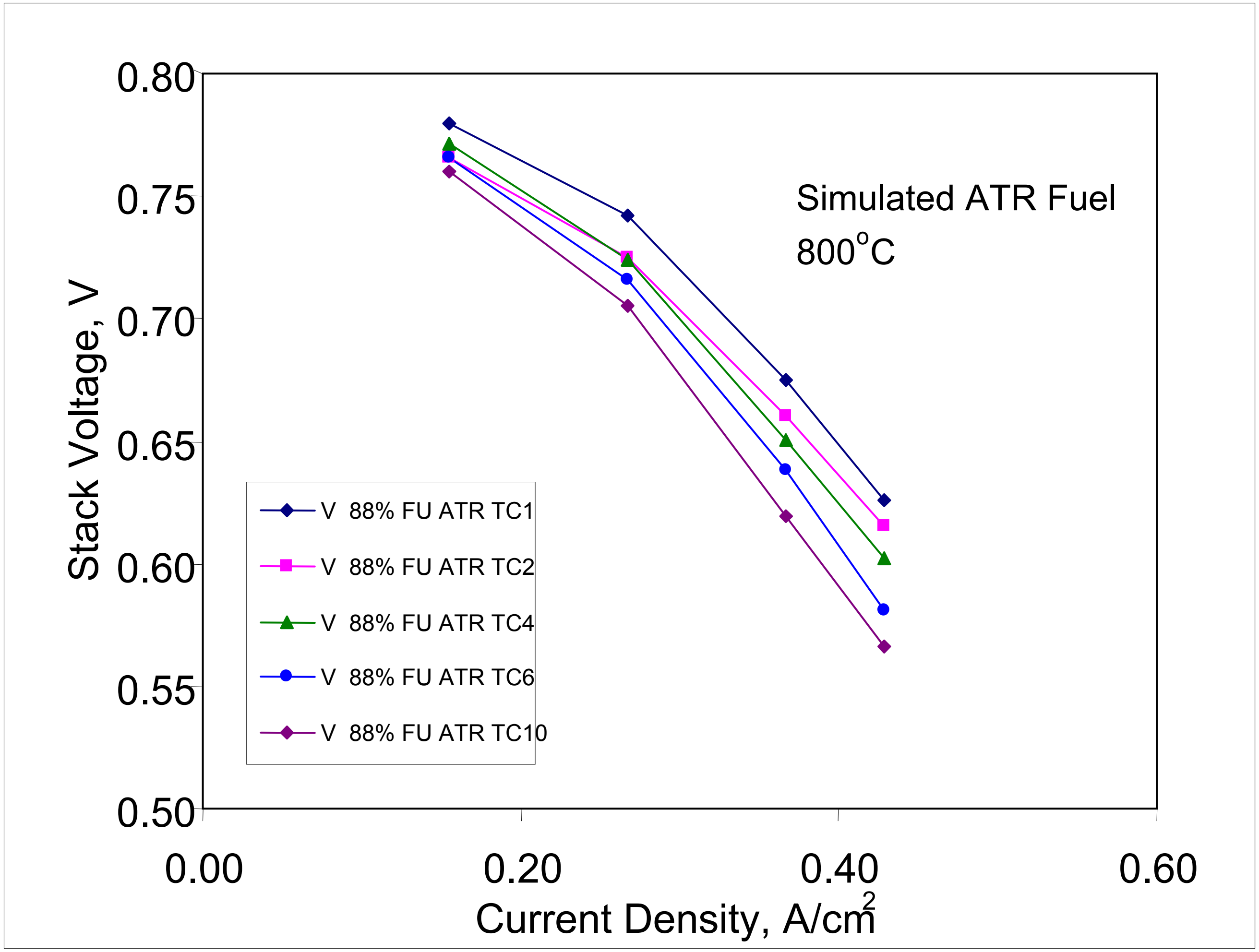
Interconnect Evaluation-Oxidation Test



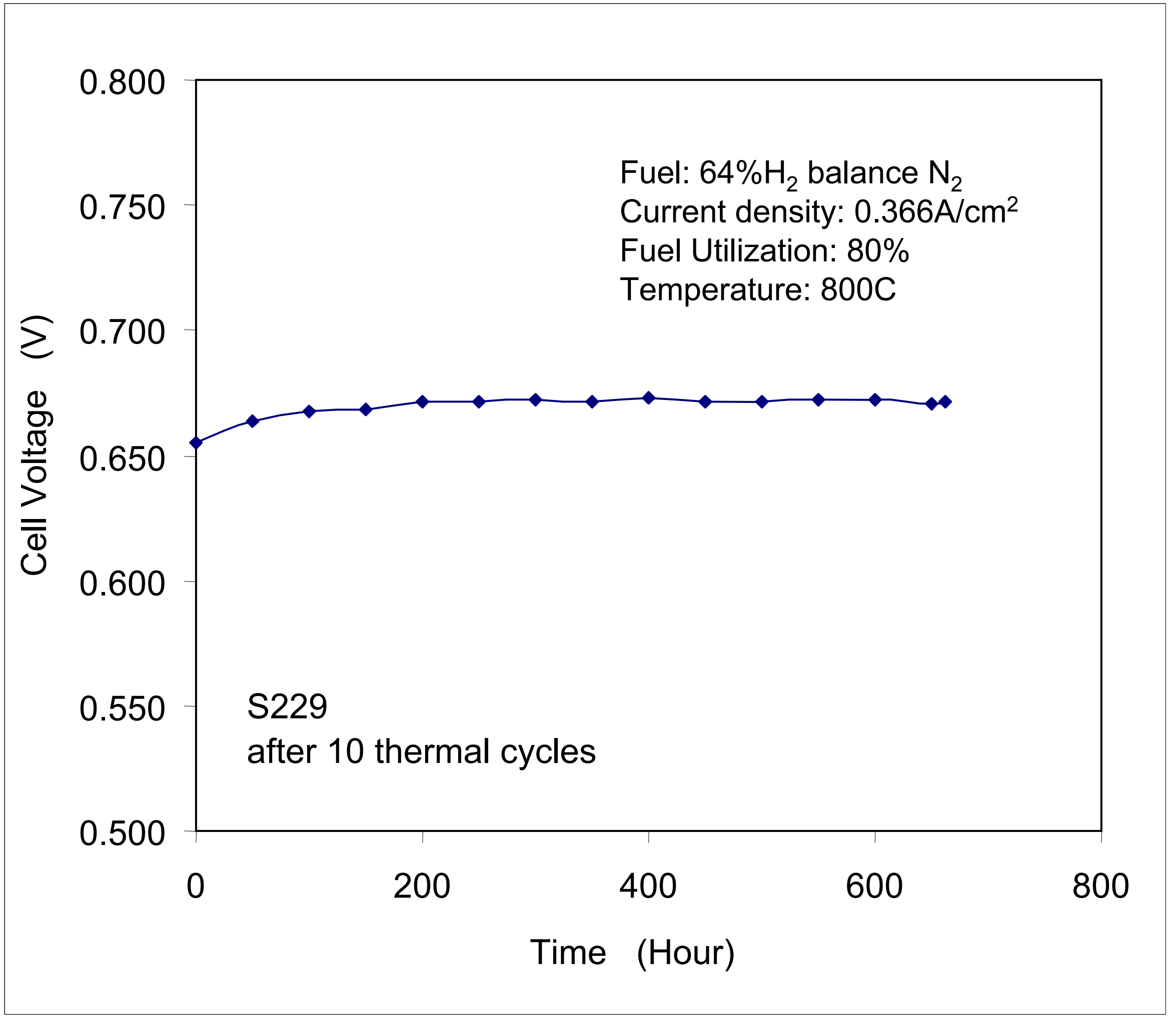
Interconnect Evaluation—Fuel Cell Test



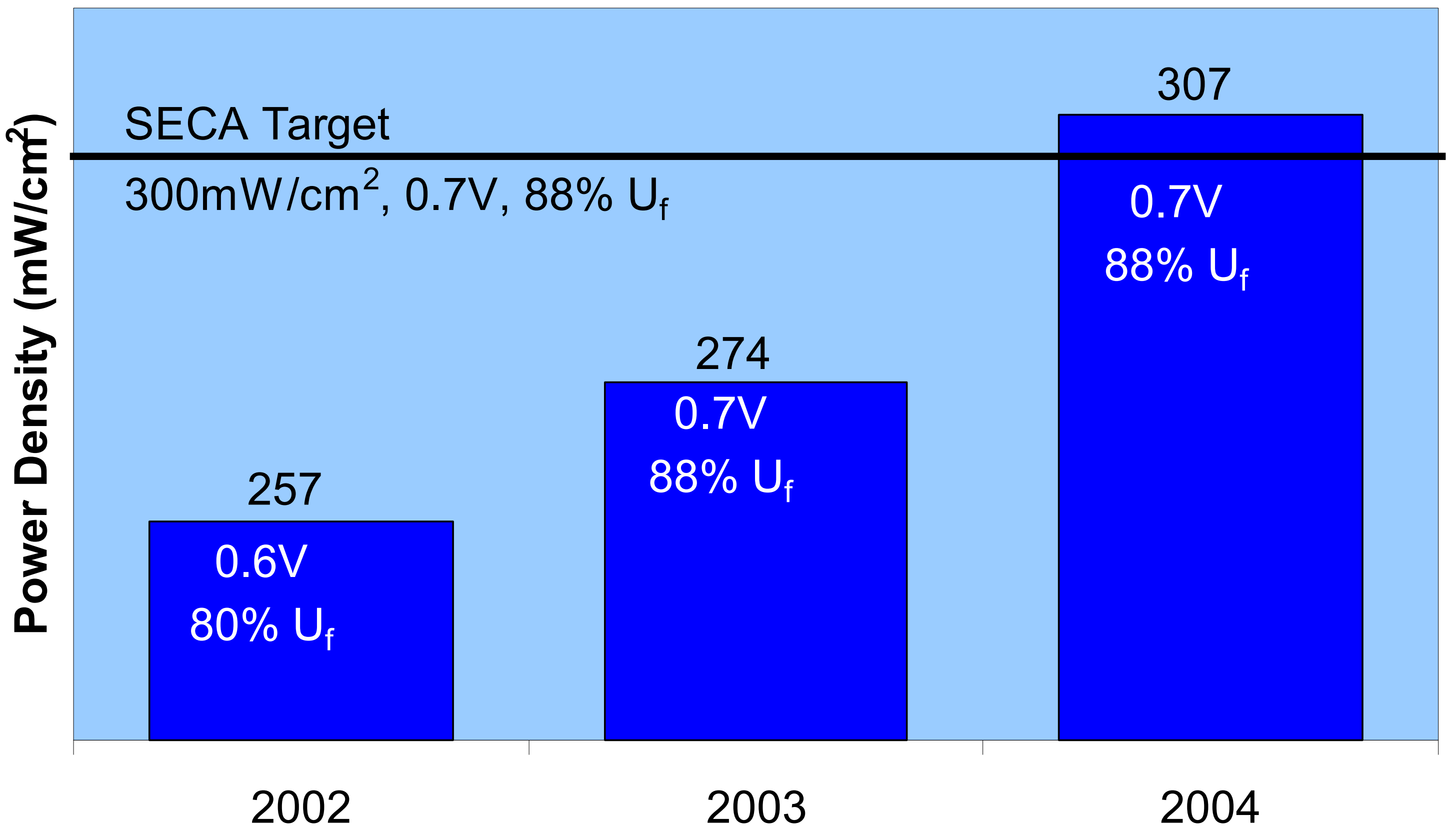
Single Cell Module Thermal Cycling



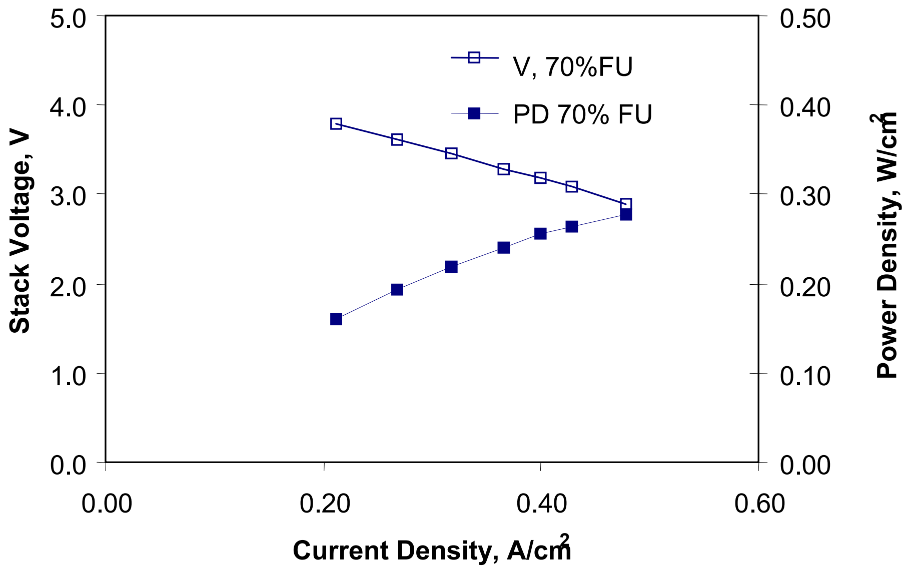
Performance Stability after 10 Thermal Cycles

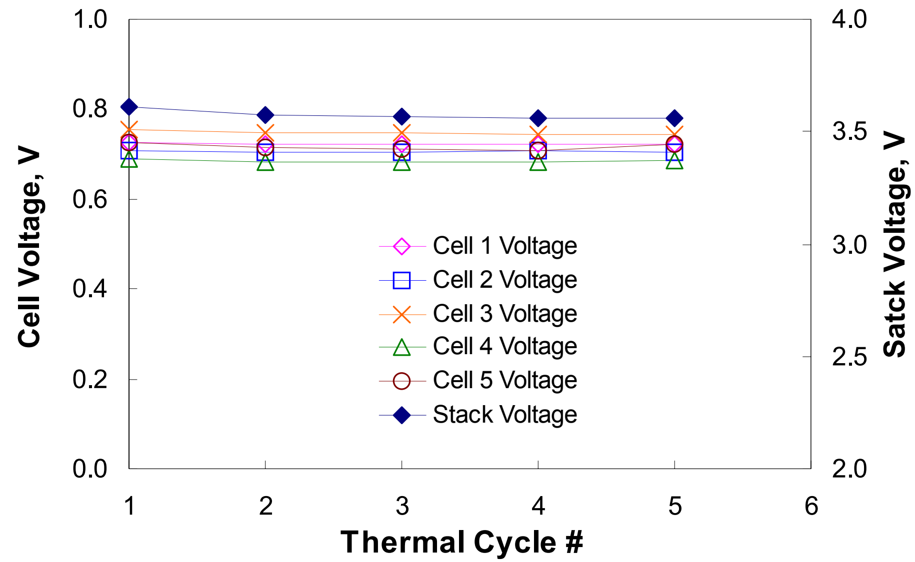


Single Cell Module Performance Improvement



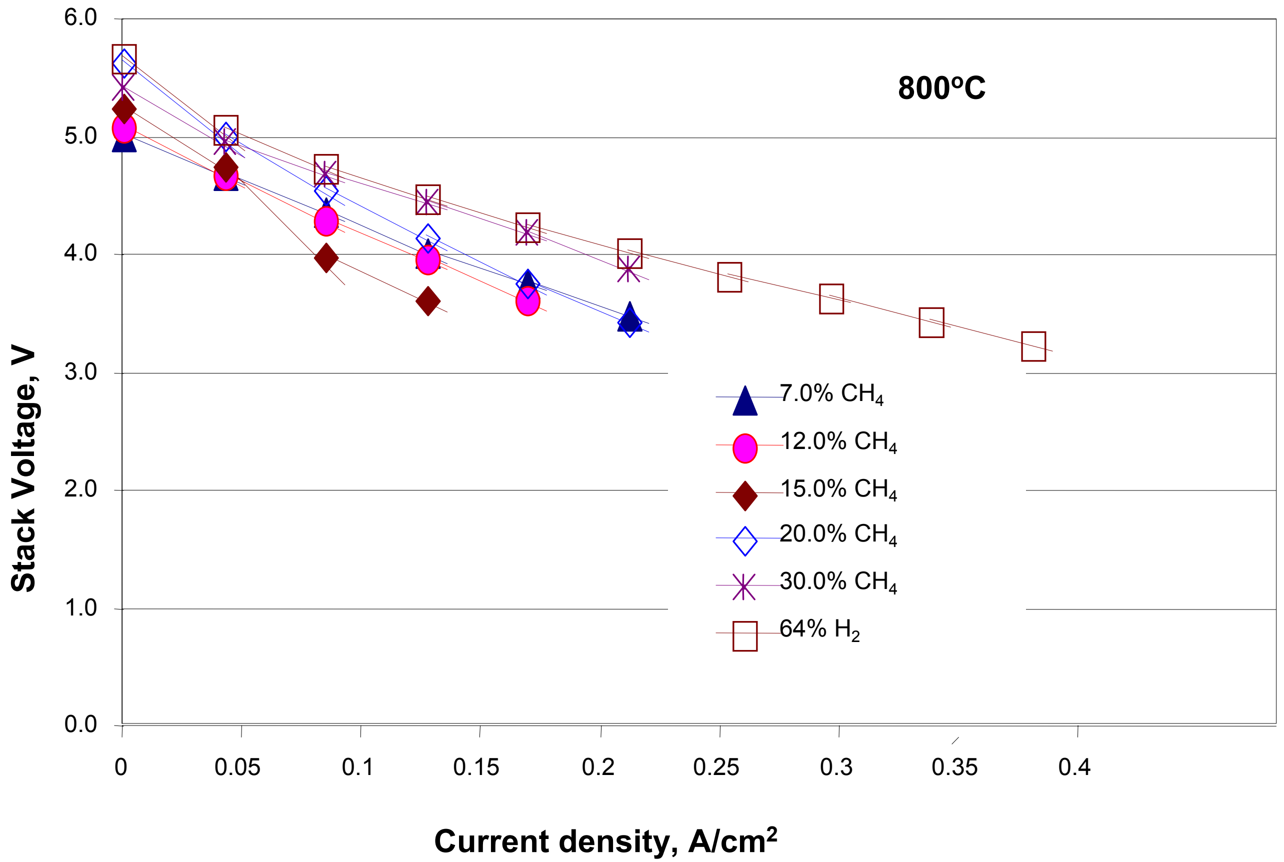
SECA 5-Cell Stack Performance



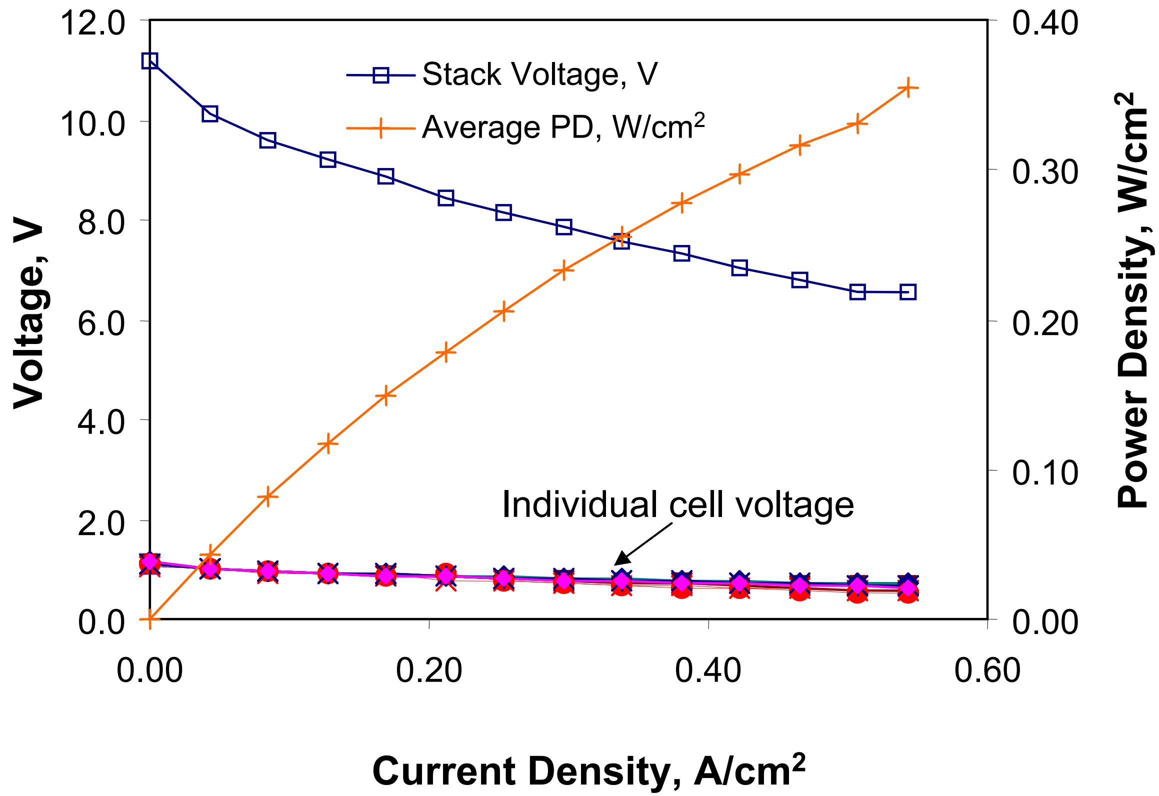


- 265mW/cm² (3.09V @ 0.428A/cm²) with 64% H_2 at 800°C and 70% fuel and 12% air utilization (total power output 188 W)
- No performance degradation after 5 thermal cycles (performance measured at 0.317 A/cm² with 64% H_2 at 800°C and 70% fuel and 12% air utilization)

Five-Cell Stack Performance - Simulated ATR Fuel



Ten-Cell Stack Performance



355mW/cm² (6.6 @ 0.542A/cm²) with 64% H_2 at 800°C and 36.5% fuel utilization (total power output 500 W);

Fuel Processing

- Focus on natural gas
- Autothermal pre-reformer
- Internal reforming

ATR Fuel Processor (Pre-Reformer) - Performance and Characteristics

Ability to Meet SECA System Requirements

✓ Inlet steam-to-carbon ratio
✓ Inlet oxygen-to-carbon ratio
✓ Inlet fuel gas temperature
✓ Methane slip level
✓ Minimum hydrogen production level
✓ Pressure drop
✓ Capacity to support 5 kW_{net} stack
✓ Lifetime

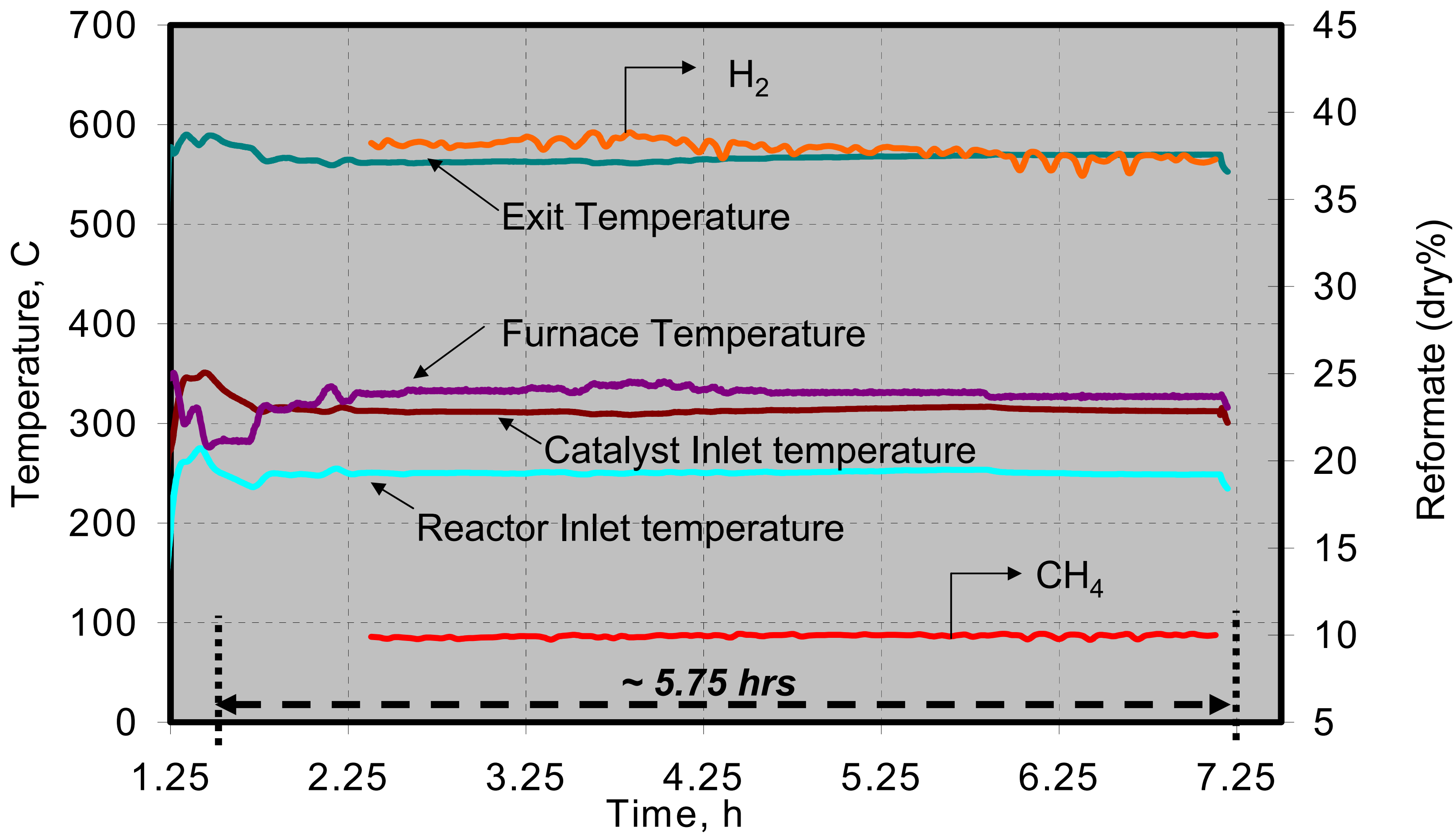
– Outlet reformate gas temperature
– Unit cost

ATR Pre-Reformers

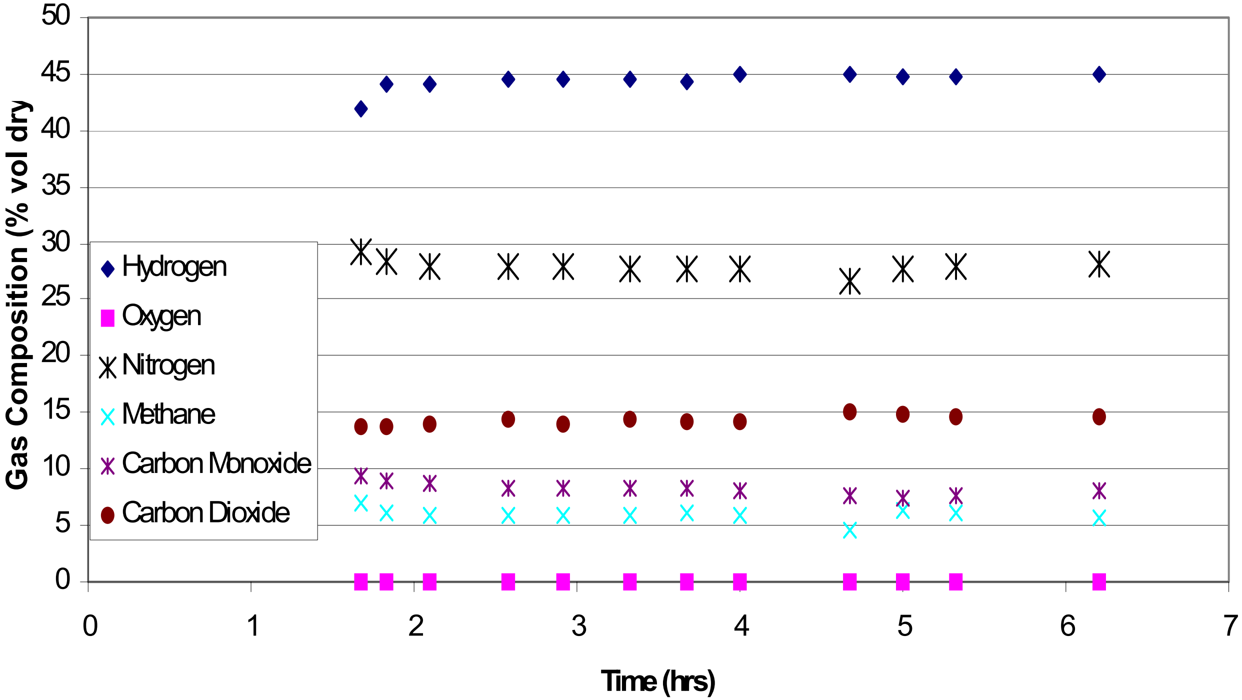
New Design

Earlier Design

ATR Pre-Reformer
Short-Term Performance Stability



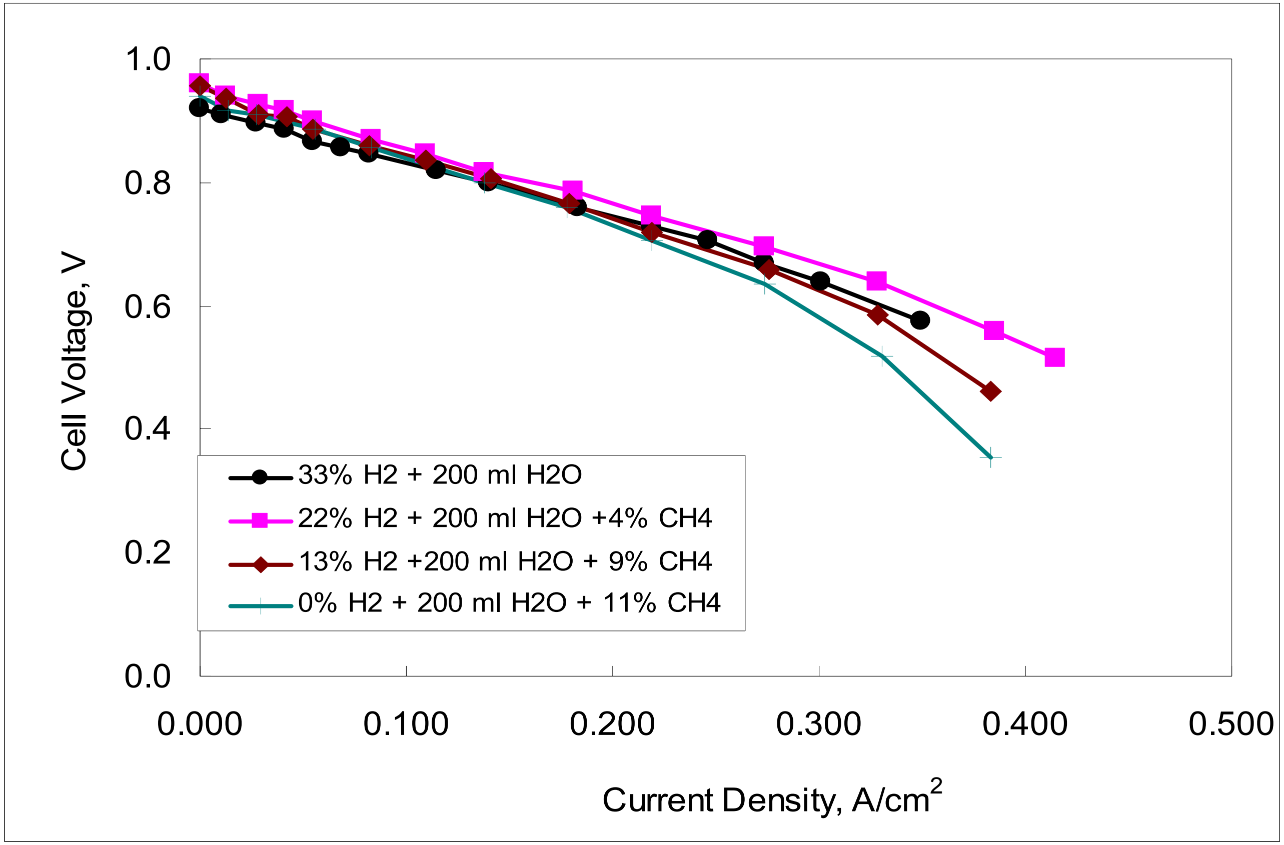
ATR Pre-Reformer Test Using Propane



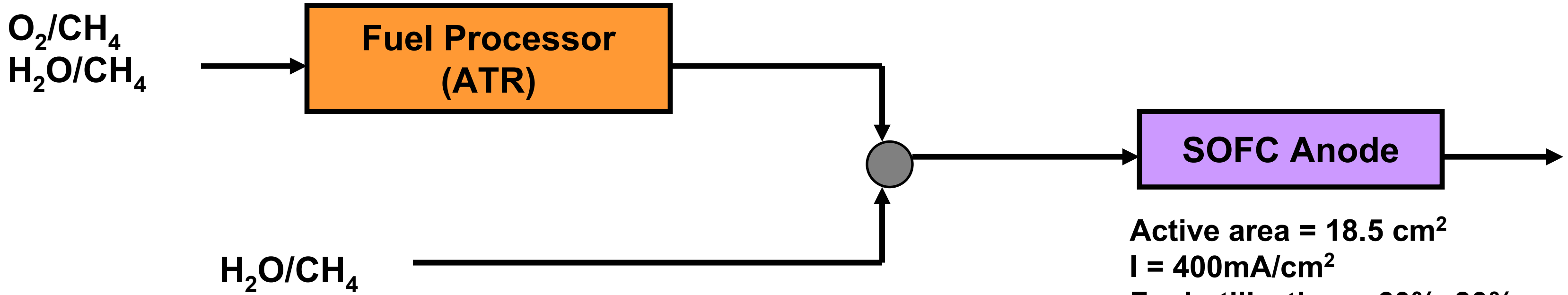
Propane Tests

- Objective was to demonstrate potential operation of pre-reformer with other fuels.
- Propane selected as fuel. Liquid propane fuel used as fuel supply for the test.
- Test conducted on third day of operation.
- Unit operated for 6 continuous hours with no sign of carbon formation.

SOFC Operation on Hydrocarbon Containing Fuels

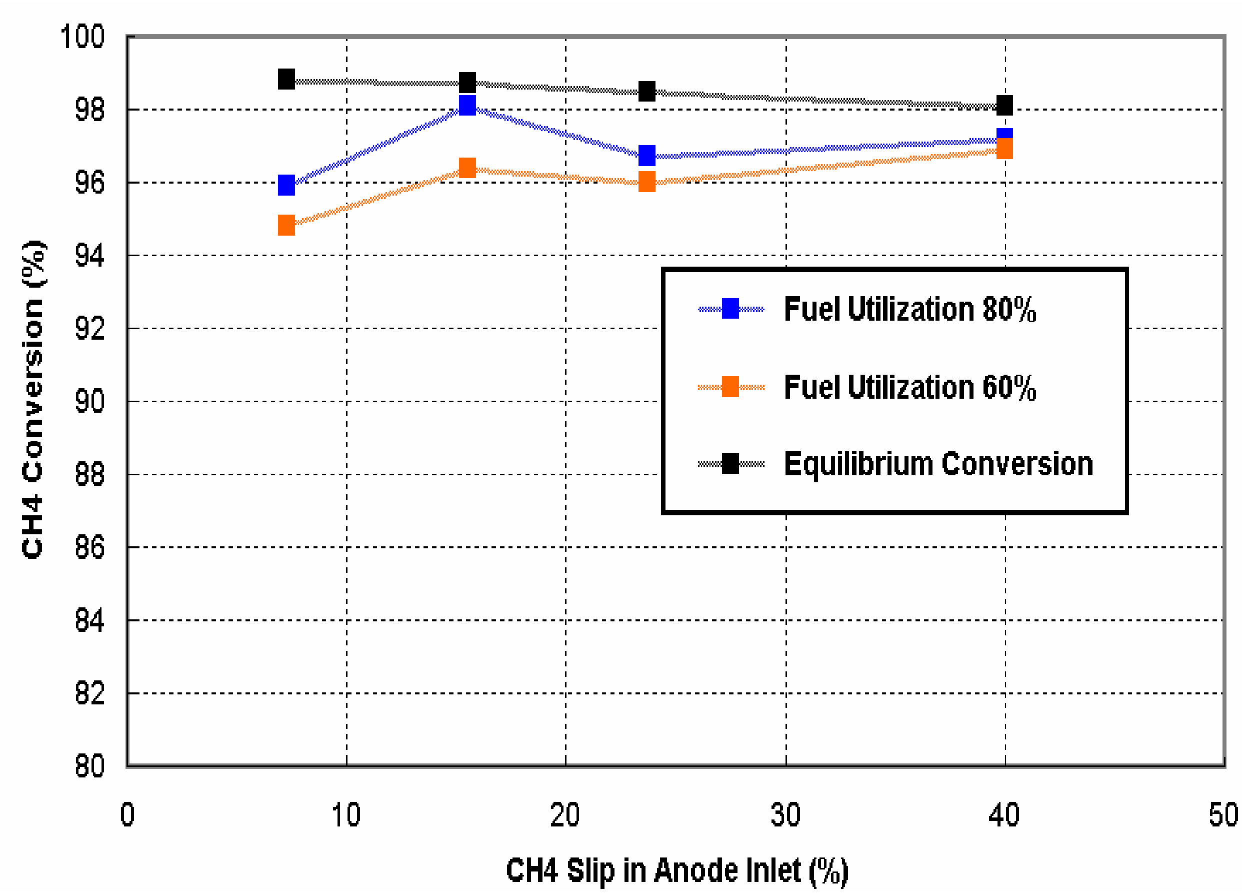


Internal Reforming Capability Test



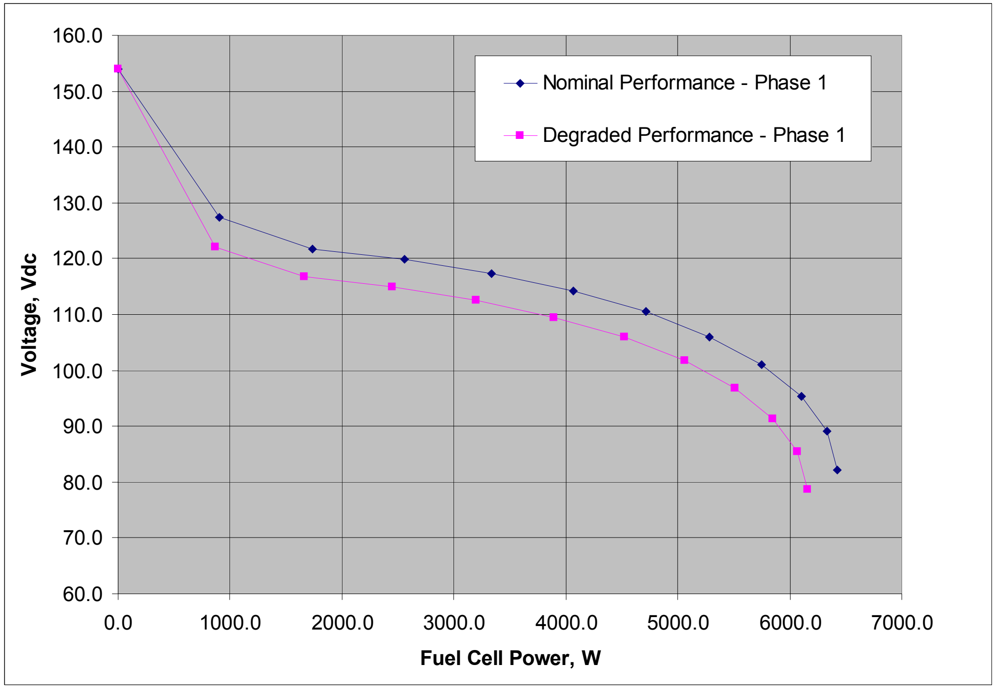
Active area = 18.5 cm^2
I = 400mA/cm^2
Fuel utilization = 60%, 80%

On–Anode Methane Steam Reformation



Inverter Requirements

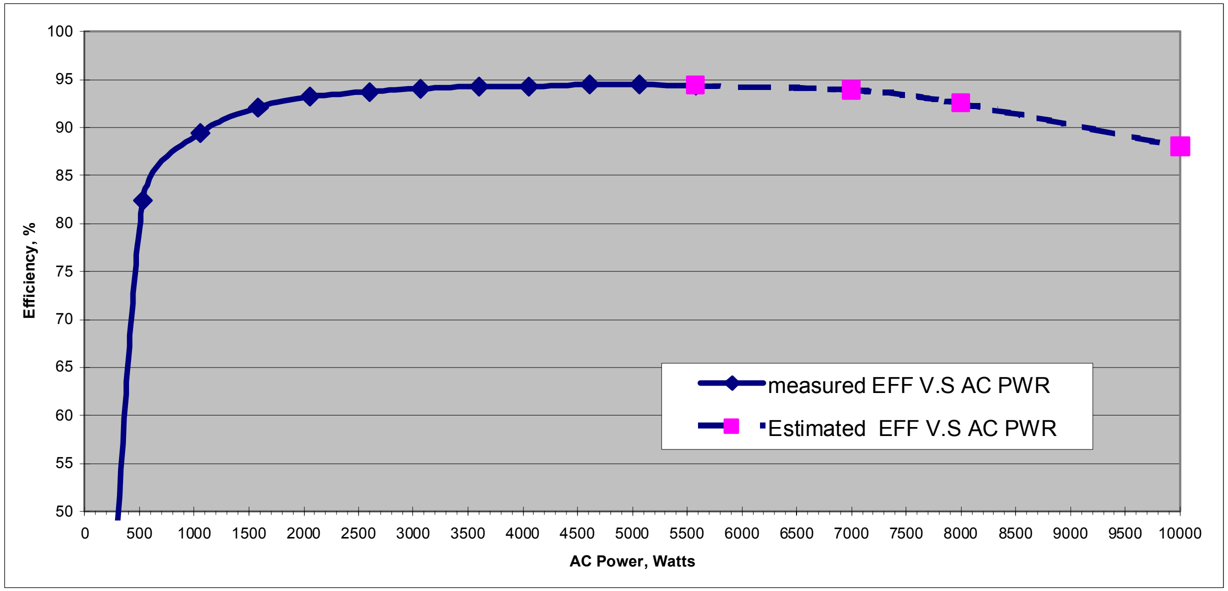
- Efficiency
  - Target = 95 %
  - Low spec limit (LSL) = 92%
- Output
  - 120/240 VAC, 60 Hz
- Voltage Range
  - 88V to 153V
- Current Range
  - 0 to 80A



Design Curves for Inverter

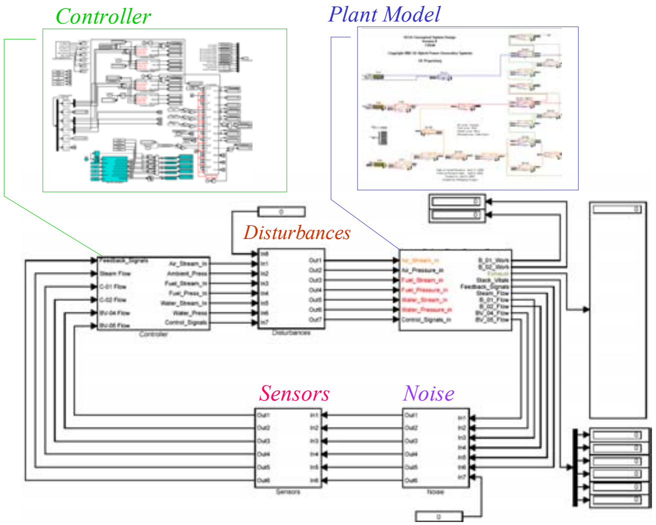
Inverter Performance

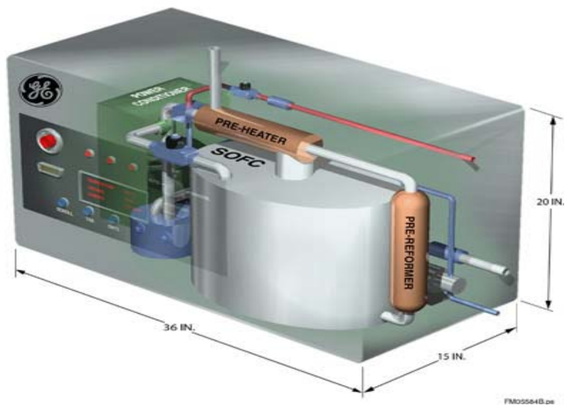
- Demonstrated peak efficiency of 94.5%
- Further testing of unit
  - Assess dynamic performance
  - Assess reliability
- Possible modifications to unit
  - Increase peak power output
  - Increase DC voltage range



Control System Design

- Fuel Cell Dynamic Component Model Library
  - Rapid development of dynamic system models
  - Design of control systems through simulation
- Rapid prototyping tools
  - Allow for direct transfer of controls designed in simulation to control of fuel cell system
  - Advanced control and sensing techniques can be investigated through simulation trade studies
  - Most promising approaches can be easily implemented in system hardware
- Improved system operation through explicit consideration of dynamics and controllability in design





Design for Control

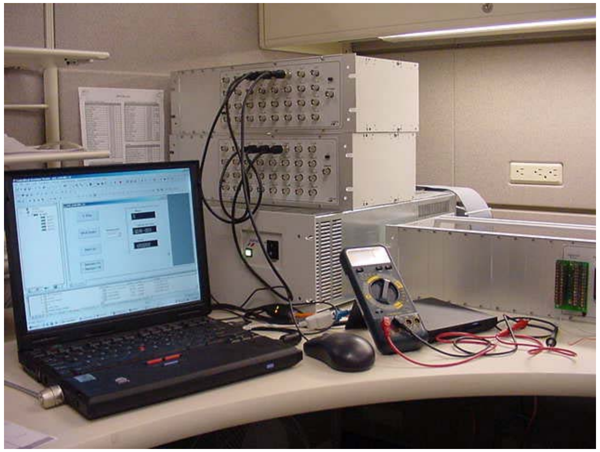
Control Software Development

> Control software from simulation environment updated to support real-time environment

> A full set of software was implemented successfully on real time controller

> Meets real time requirement with significant margin

Software Testing/Verification



Graphical User Interface

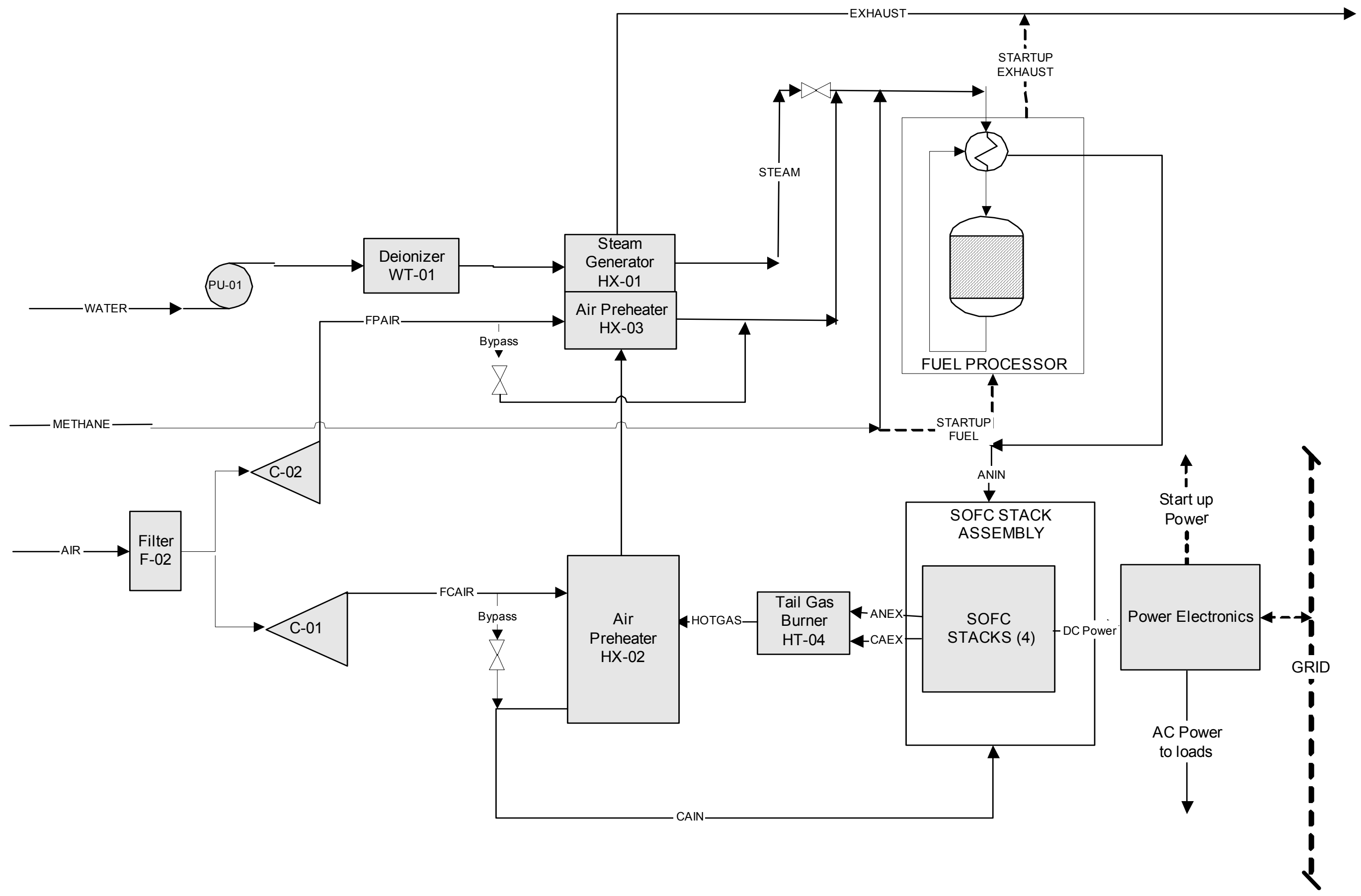
Control Strategy Validation

> Component testing
  - Cells/stacks
  - Blowers
  - Heat exchangers
  - Valves
  - Sensors

> Lower level control loop testing
  - Verify simulation results

> Subsystem integrated testing

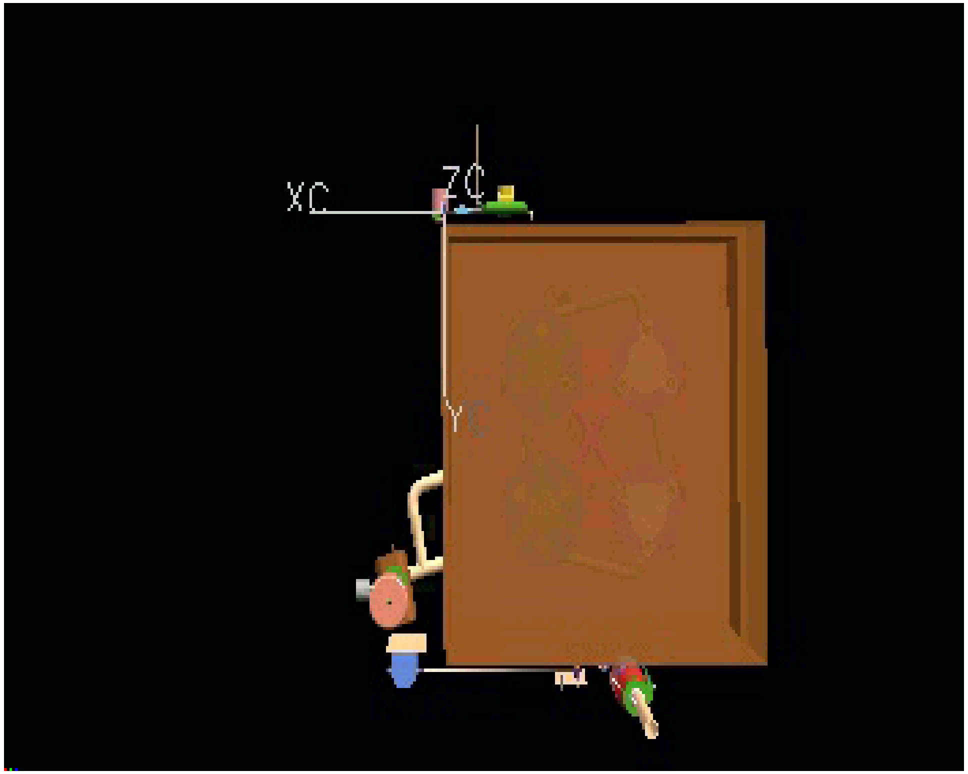
Prototype System Design Diagram



Prototype System Development

- Conduct system design and performance analysis
- Define system component requirements
- Develop prototype system package
- Perform component testing and integration

Preliminary Prototype System Package



Summary

- Progress in several key areas
  - SOFC stack
  - Pre-reformer
  - Controls and power electronics
- Prototype system development
- Plan to demonstrate a prototype system in 2005

Acknowledgments

- **DOE/NETL**
  - Wayne Surdoval
  - Travis Schultz
  - Don Collins
- **GE SECA SOFC Team**