Biogas Fueled Solid Oxide Fuel Cell Stack

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Project ID: fc_49_cheekatamarla

Overview

Timeline

- Project start date – 7/1/2008
- Project end date –
  - original 9/30/2009
  - now extended to 12/15/2009
- Percent complete – 30% (as of 3/20/09)

Barriers

- Delayed start date – 10/16/2008
- Technical barriers
  - Cell manufacturing yield
  - Custom manufacturing equipment
- Technical Targets
  - SOFC – 10 watts (W), >0.35W/cm^2, biogas, 70% yield
  - 400W SOFC stack operated on biogas

Budget

- Total project funding
  - DOE share: $984,000
  - Contractor share: $1,419,149
- Funding received in FY08:$146,638
- Funding for FY09: $837,362

Partners

- State University of NY at Buffalo - Surface topography and compositional analysis (not a subcontract)

Objectives - Relevance

- The main objective of this project is to develop and demonstrate a 400 Watt stack module using advanced solid oxide fuel cell (SOFC) technology
  - Electric power generation from different biogas compositions
  - Cost effective SOFC manufacturing
  - Energy efficient
  - Capability to integrate in to commercial systems such as micro CHP and portable power
- Relevance to the DOE Hydrogen program
  - Research and Development of **advanced fuel cell technology** for portable power applications
  - **Renewable energy** - Biogas is a domestic, renewable resource, which offsets the use of non-renewable resources with corresponding emission reduction and energy security benefits
  - Viable, cost effective process for **efficient power generation**

Technical Approach

- New cell fabrication route
  - Fabrication of **light-weight** fuel cells
  - Tailored cell microstructure
  - High energy **efficiency**
  - **Superior performance** compared to the traditional technologies
  - Enables innovative cell designs
  - **Cost effective** manufacturing

- Optimized fabrication process
  - Cell design
  - **>70% fabrication yield**
  - Material **recycling**
  - Thermal shock resistance

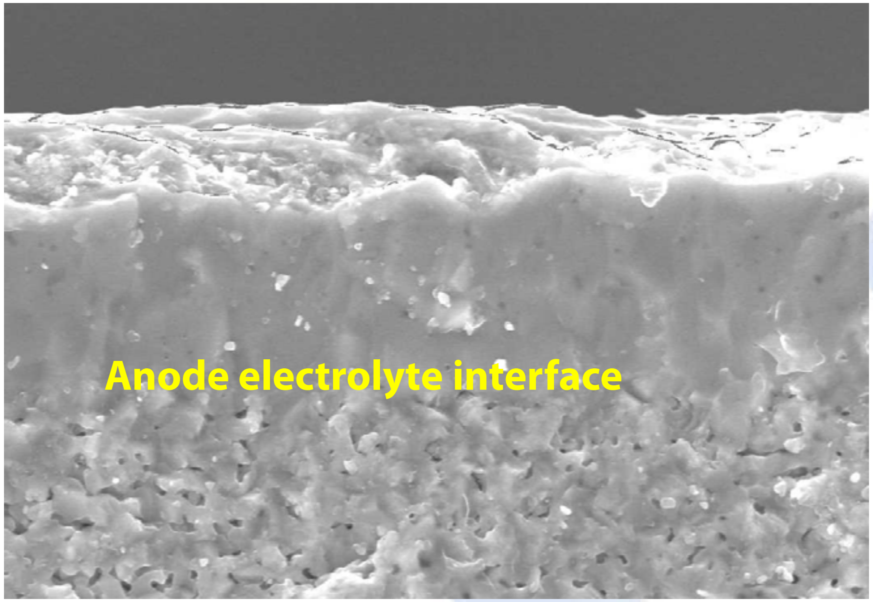
- Evaluation on Biogas
  - Integrated catalytic layer
  - **In-situ biogas reforming** - no fuel reformer
  - Optimize the operating conditions
  - **High power densities** and efficiencies

- 400W stack design and build

Milestones

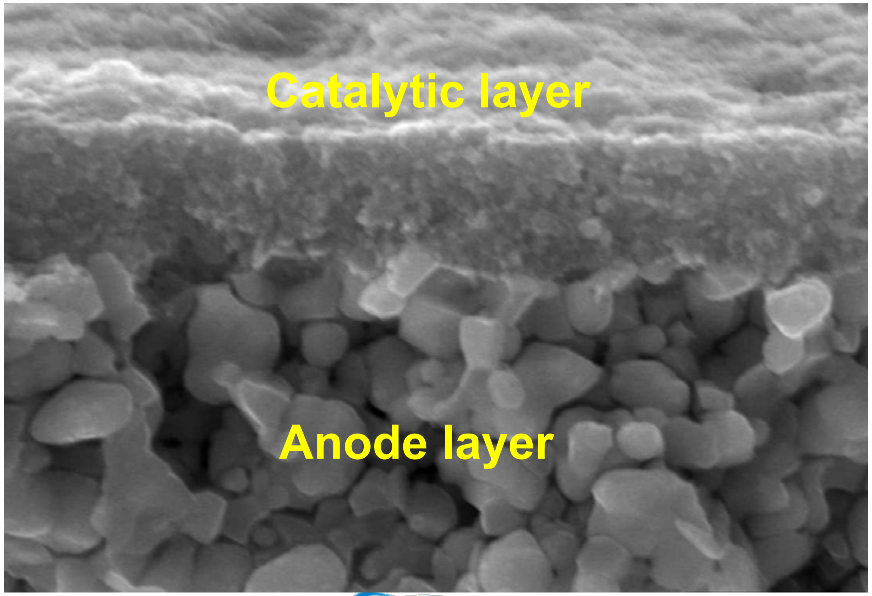
Milestones	Progress notes	% Comp
Determine the cell design		100
Optimize the fab. Process – 70% yield	Achieved 50% yield to date	50
Power density (>350mW$_e$/cm^2)	Achieved > 525mW$_e$/cm^2 producing >9.5W$_e$ on biogas	100
Single cell operation on biogas	Optimized the operating conditions	100
Thermal shock tests	120 cycles conducted	25
Endurance tests	250 hours achieved	25
400W stack design and build	Stack design underway	10

Technical Accomplishments - SOFC

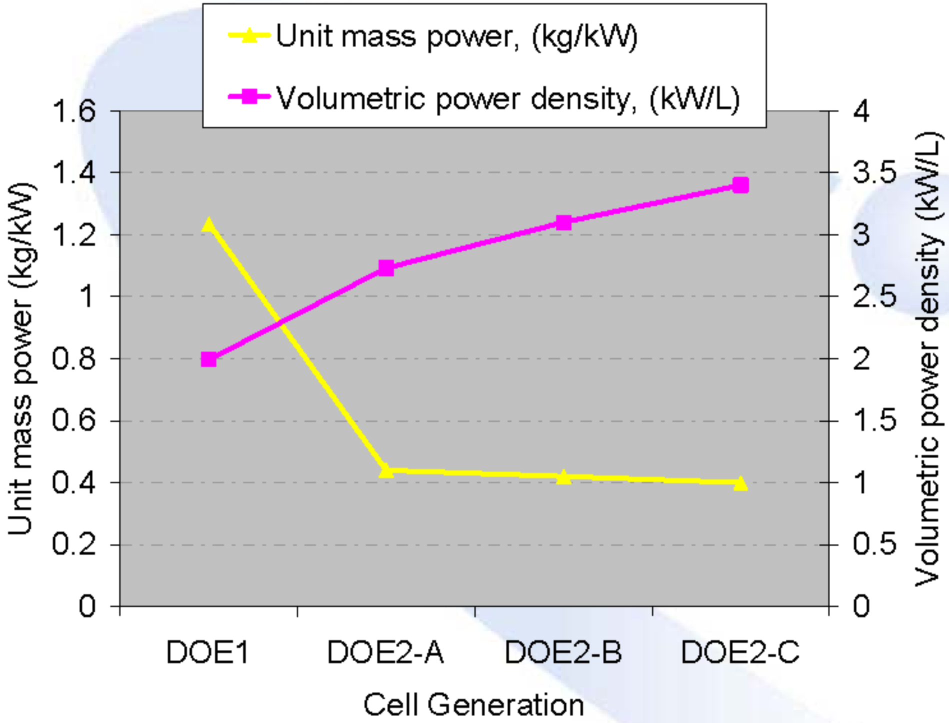


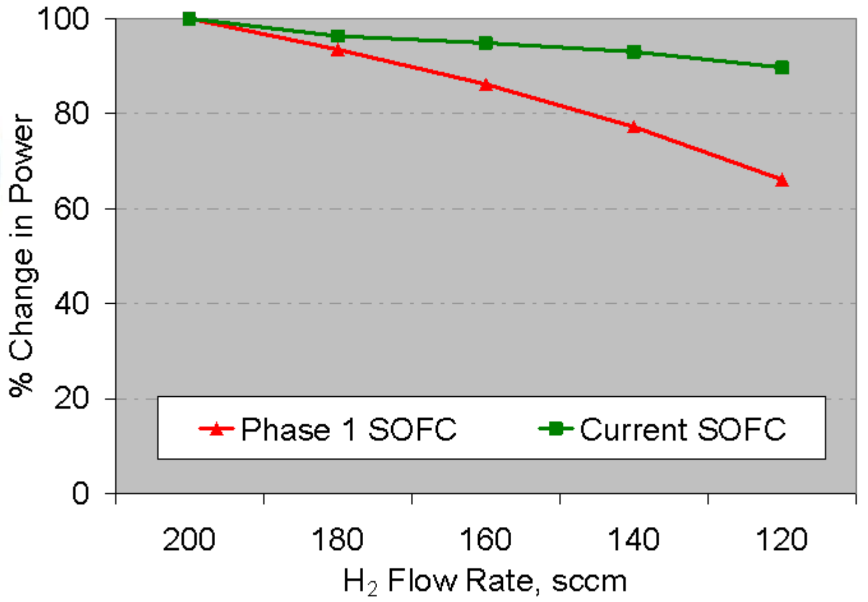
- Materials selection is critical for high performance at reduced temperatures for all parts of the cell
- Need to consider conductivity, chemical stability, TEC mismatch, physical stability, etc.
- Interface between anode and electrolyte shows necking
  - Good bonding
  - Thermal expansion match
- Stronger bond will aid in thermal cycling stability

- Integrated Catalyst layer for in-situ reforming
- Direct biogas injection
- No external reformer required
- Robust catalyst to address dry, steam and partial oxidation reforming reactions
- High active surface area



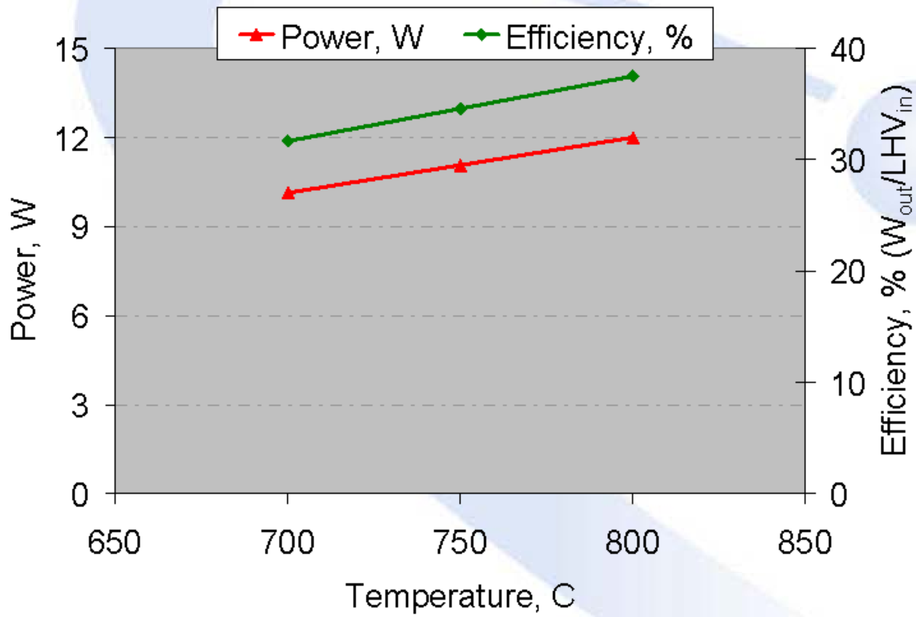
Technical Accomplishments – Cell design

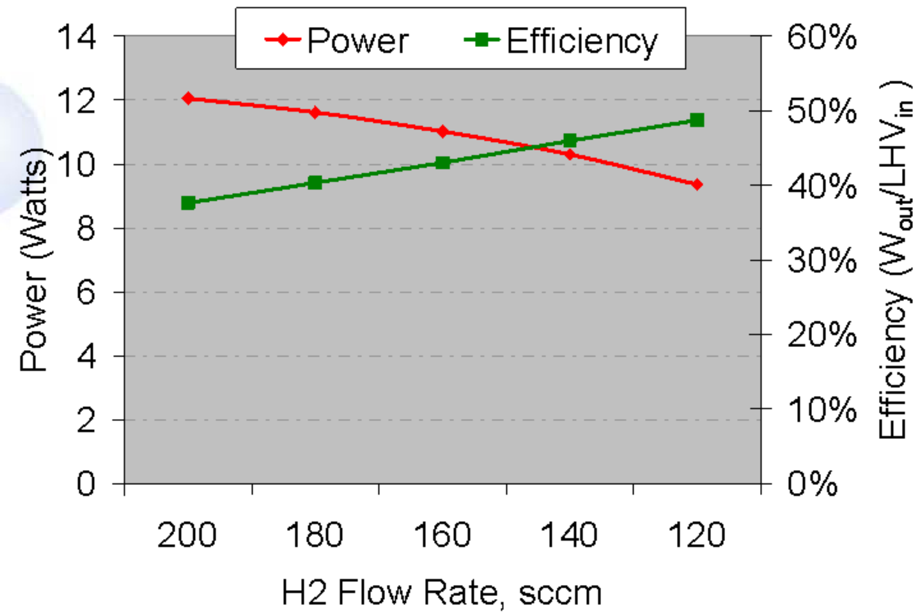




- Cell performance vs. different generation of technologies
- Light-weight
- New approach yields cells packed with <u>more power per unit mass, volume and surface area</u>
- Higher fuel utilization and electrical efficiency at lower flow rates

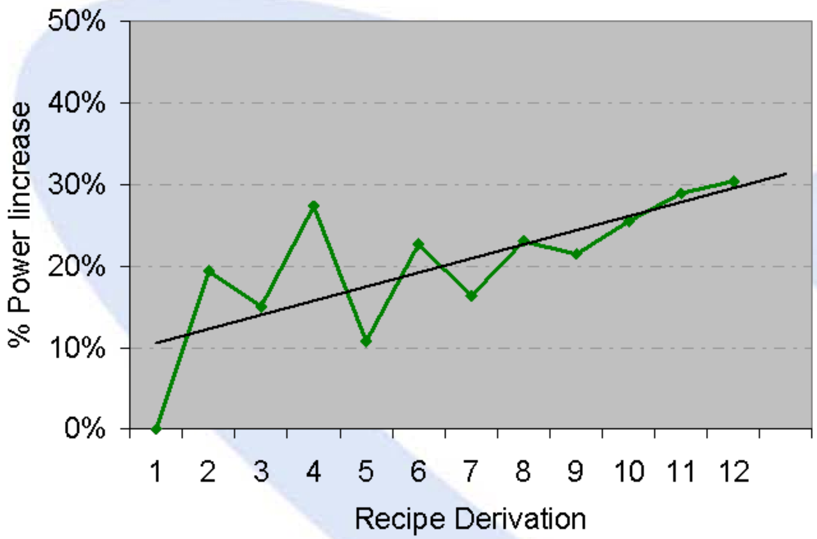
Technical Accomplishments – Cell Performance

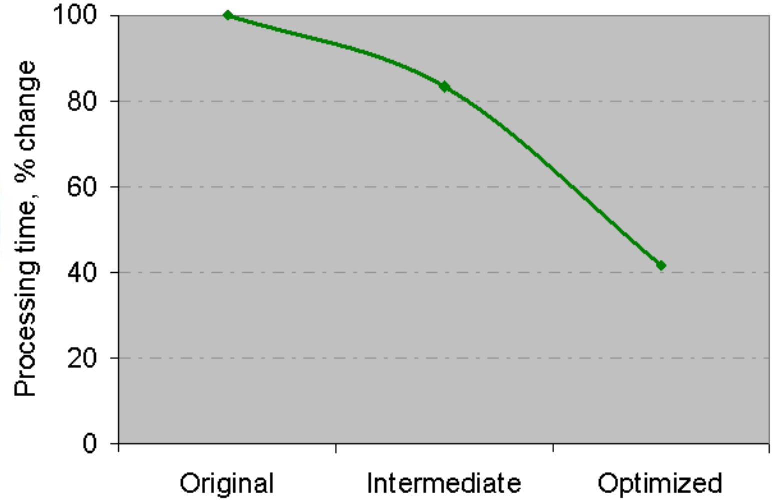




- Efficiency = Power produced vs LHV of fuel supplied: ~ 50% on Hydrogen
- ~10% lower W as the cell temperature decreases from 800 to 700C – increased cell stability

Technical Accomplishments – Process and Materials



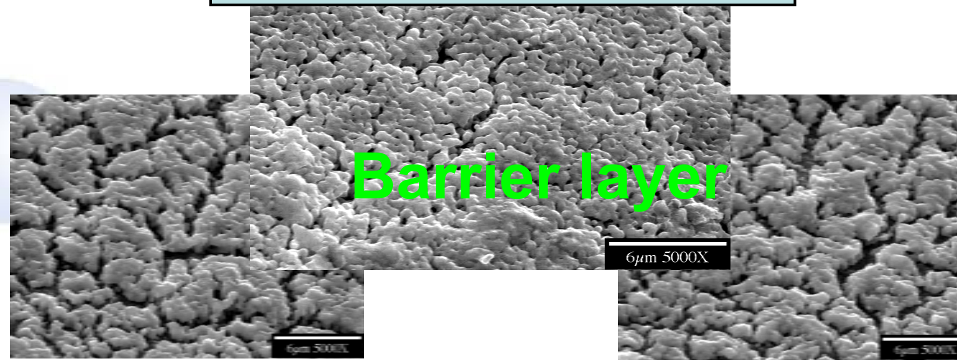


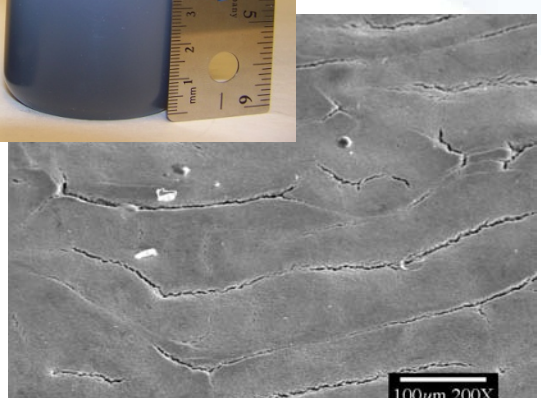
- Anode, electrolyte and cathode materials were optimized for obtaining desired microstructure and composition yielding higher powers.
- Porous anode structures to lower the mass transfer resistance
- 51% reduction in cost of anode (current vs previous phase)
- 58% savings in time due to process optimization

Technical Accomplishments – Material optimization

- New cathode - higher power at lower temperature
- Cathode - electrolyte interaction increases the electrical resistance, leading to degradation and potential mechanical failure
- Barrier layer to prevent this interaction
- Particle size selection creates well packed green layers and sintered bodies - improved long term stability

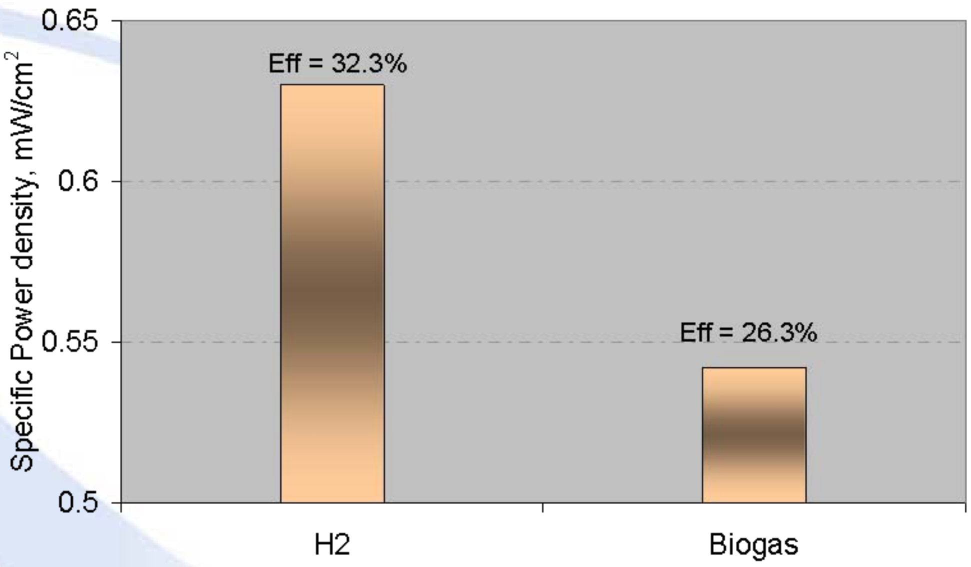
Bimodal powders





- Ink formulation heavily influences the physical and electrochemical properties of the cathode
- Optimization through careful consideration of the type/concentration of solvent, dispersant, binder, viscosity, particle size, etc.
- Stabilized cathode ink results in a power increase of 7.7%, but surface morphology exhibits defects
- Further optimization is in progress

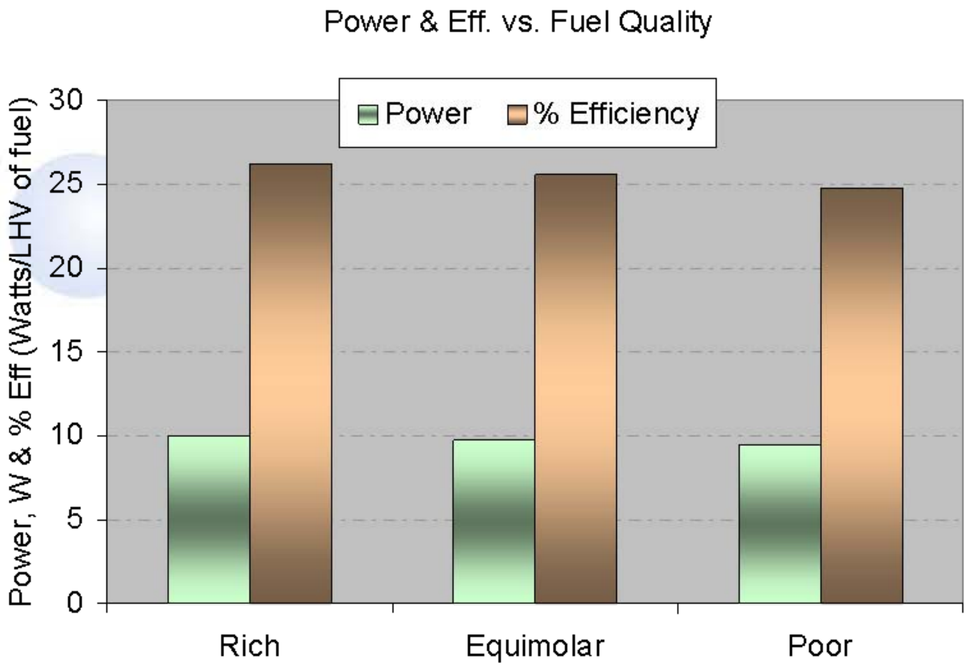
Technical Accomplishments – Biogas tests



- 12-16% drop in power with biogas as the fuel
- Slower biogas reforming reaction kinetics compared to hydrogen oxidation
- In-situ biogas reforming on the multi-layer SOFC integrated with catalyst – No fuel reformer required
- Endothermic dry reforming of biogas vs exothermic electrochemical oxidation reaction induces thermal shock on the cell – ΔT = 150-200°C
  - Cell cracks at the fuel inlet immediately after the gas is supplied at temperature
- Addition of air (15% of the stoichiometric requirement) controls the thermal gradient and avoids cell fracture

Technical Accomplishments – Biogas tests

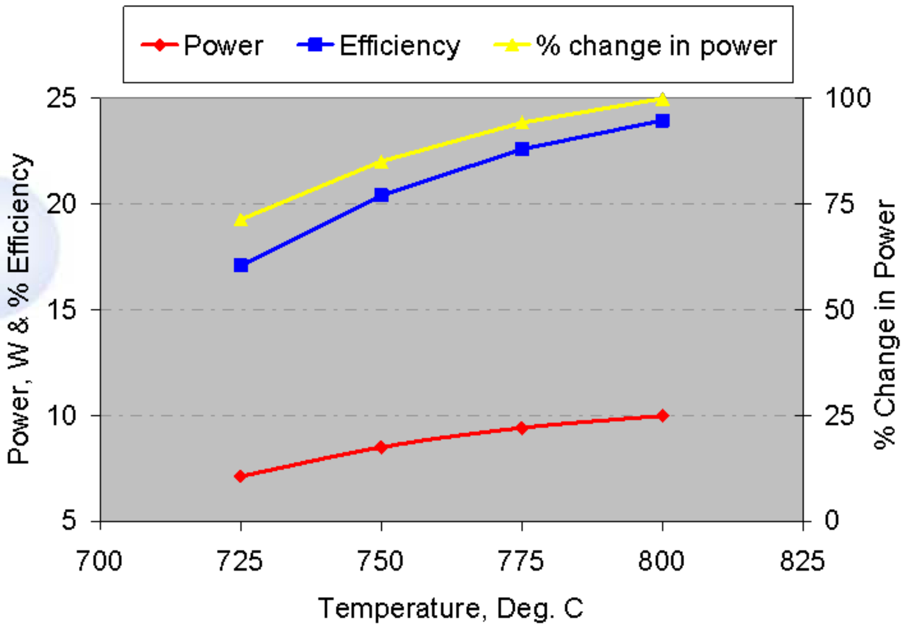
Quality	CH_4 (%)	CO_2 (%)
Equimolar biogas	**50**	**50**
Rich biogas	**62**	**38**
Poor biogas	**40**	**60**

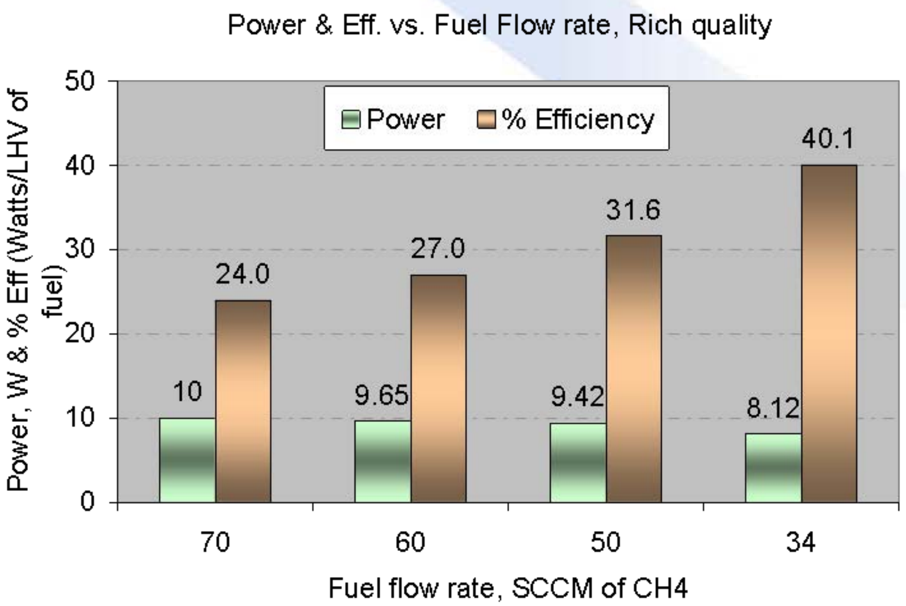


- Effect of biogas fuel quality
- Constant methane supply (W-LHV)
- Rich quality biogas yields higher efficiencies and W
- <5% change in power
- Power generation starts from 470°C on the SOFC

Technical Accomplishments – Biogas tests

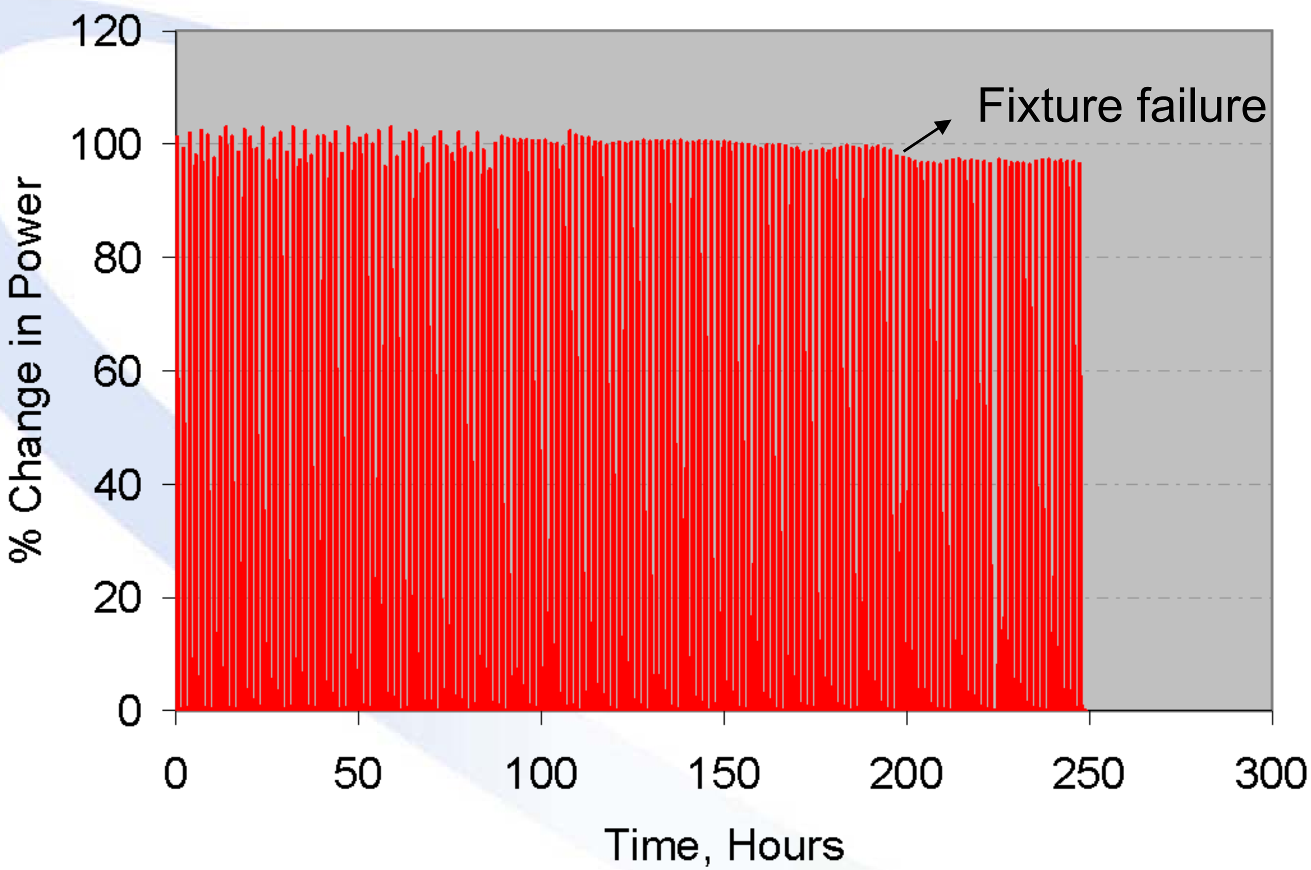
- ~20% lower W as the cell temperature decreases from 800-725C
- Good intermediate temperature performance with biogas





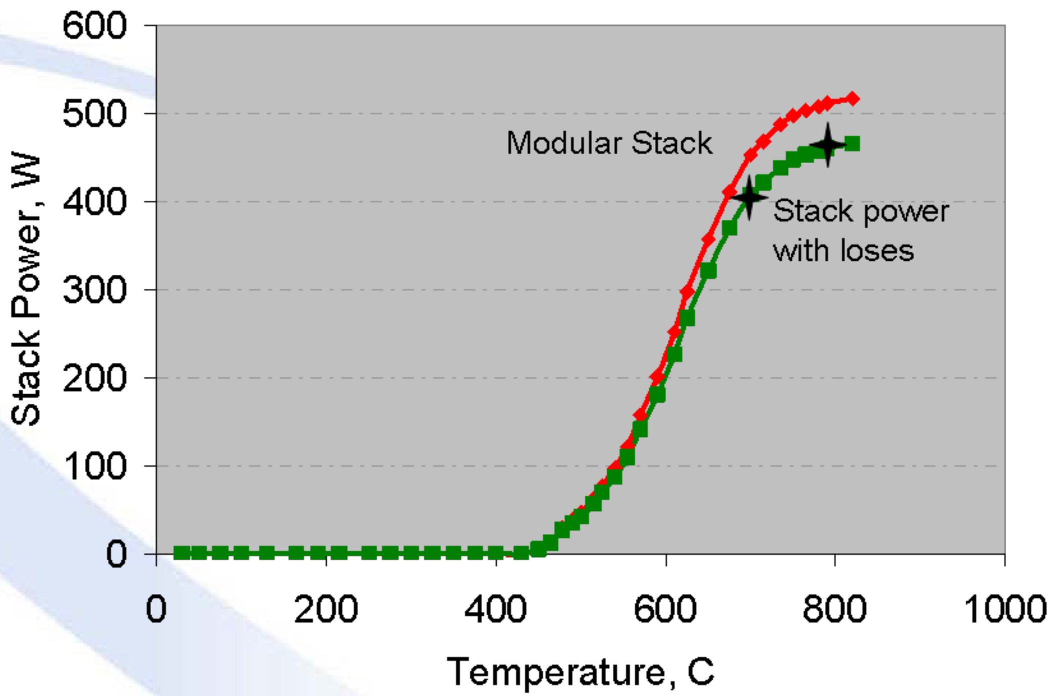
- Effect of biogas flow rate
- Rich quality biogas, 800C
- Efficiency reaches as high as 40% while the cell generates >8 Watts
    - (Methane LHV = 50.06MJ/kg)

Technical Accomplishments - Thermal Cycling



- ~ 120 thermal cycles performed between 25°- 800°C on Hydrogen
- Relatively stable performance, no visual or mechanical defects or abnormalities were found on the cell
- Cell fixture fractured after about every 50 cycles – working on new fixture
- Thermal cycling tests with biogas are being conducted

Technical Accomplishments – SOFC stack



- Projected stack power based on modular stack design
- ~10% loss of power due to loses associated with interconnects, heat and flow distribution etc.
- Potentially 400W on biogas at an operating temperature of 700°C
- Improved stability
- Possible stack power density >500mW/cm^2
- Total projected stack package volume = 1.6 liters
- Potentially scalable to kilowatt range

Collaborations

- State University of New York, Buffalo (Academic) - Surface topography (SEM) and compositional analysis of SOFC materials
    - Not a subcontractor
    - On a need basis

Future Work

Cell fabrication

- Optimize the SOFC fabrication process to achieve >70% overall manufacturing yields – 04/2009
- Fabricate 150 cells with integrated catalytic layer for internal reforming of biogas – 8/2009

Cell testing

- Rapid thermal shock resistance evaluation of the SOFCs – 9/2009
- Perform >200 thermal cycles on the SOFC – 9/2009
- 500 hour endurance test on biogas – 11/2009

Stack testing

- 400W stack build – 11/2009
- CFD analysis of 1.2kW stack – 10/2009
- Stack feasibility demonstration on biogas – 12/2009

Summary

- New SOFC fabrication route was successfully implemented. This process offers numerous benefits over conventional methods: cost effective; automated; light-weight fuel cells; high energy efficiency
- SOFCs with high volumetric (3.4kw/lit.), gravimetric (2.56 kw/kg) and specific power densities (0.63W/cm^2) were fabricated and tested on hydrogen and biogas
- SOFCs demonstrated up to 50% and 40% electrical efficiencies on hydrogen and biogas respectively
- Different biogas compositions were evaluated on the multi-layer SOFC via internal reforming at temperatures of 700-800C
- Future work will focus on thermal shock resistance and long-term endurance of the SOFC operated on biogas
- A 400W stack will be built and tested on biogas