Siemens Westinghouse Stationary Fuel Cells

- 150 employees
- Chartered to commercialize SOFC power systems for the distributed generation market
- Focused on seal-less, cathode supported SOFC design
- YSZ electrolyte, 1000 ºC operating temperature
- Expertise in
  - High temperature materials
  - Ceramic processing, ceramic powder, cell and module manufacturing
  - Electrochemistry and cell testing
  - Hydrocarbon reformation
  - BOP assembly
  - Systems testing
Stationary Fuel Cells - Accomplishments

- Developed state-of the art, 150 cm active length (834 cm² active area), seal-less, cathode supported tubular SOFCs
- Demonstrated lifetime of >60,000 operating hours with voltage degradation rates < 0.1% per 1000 hours and thermal cycle capability of >100 cycles
- Developed internal reformation technology
- Designed, manufactured and tested complete atmospheric and pressurized hybrid SOFC power systems
- Replaced electrochemical vapor deposition (EVD) process with atmospheric plasma spray (APS) process for deposition of cell components
Stationary Fuel Cells - Accomplishments

Voltage Stability of Tubular APS Cell

Cell Test 675
Total Operation Time - 18,700 hours
Test Stand Changed after 14,400 hours

Temperature = 1000 deg. C
Fuel Utilization = 85%

Cathode
Extruded and Sintered

IC, EL and Anode

APS

Elapse Time (hours)

Potential (Volts)

Current Density (300 mA/cm²)

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APS cell performance

- Demonstrated performance equivalent to EVD cells
- Demonstrated thermal cyclic stability - can withstand multiple thermal cycles
- Demonstrated voltage stability - voltage decline of approx. 0.1% per 1000 hours
SECA Program - Objectives

Develop SOFC system prototypes with a net power output of 5-10 kWe for stationary and transportation applications with a cost target of < $ 400/kWe.
SECA Program - Technical Approach

- Improve cell performance through advances in
  - Materials
  - Processing
  - Cell design
- Lower operating temperature (800°C)
- On-cell reformation - elimination of internal reformers
- Low cost, high volume manufacturing process development
- Low cost module materials - helped by lower operating temperature
- BOP design simplification - parts elimination
Siemens Westinghouse SECA Program - 10 Year Roadmap

**Phase I**
- Cell Development
- Materials Development
- Low Cost Mfg. Processes
- 5 kWe POC and $\alpha$
- Internal reformation
- 40% electrical efficiency

**Phase II**
- Cell Development
- Materials Development
- Low Cost Mfg. Processes
- $\alpha$ / $\beta$ units
- > 5 kW
- partial on cell reformation
- 45% electrical efficiency

**Phase III**
- $\beta$ and pre-commercial units
- 10 kW
- largely on cell reformation
- 45% electrical efficiency

Power System Cost [$/kW]

- 2002
- 2006
- 2009
- 2012

Target $600/kW

Target $800/kW

Target $400/kW

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Cell Power Enhancement
The electrical performance of Siemens Westinghouse cells is primarily influenced by the cathode–electrolyte interface.
Strategies for Cell Power Enhancement

- **Materials**
  - Increase charge-transfer reaction sites
  - Replace existing cerium oxide interlayer with a composite interlayer

- **Cell design**
  - Lower cathode polarization
  - Optimize electrolyte plasma spray process to lower densification temperature
  - Change dopants to increase low temperature conductivity of LSM cathode

- **Processing**
  - Lower EL densification temperature
  - Increase cathode conductivity

- **Cell Power Enhancement**
  - Lower ohmic resistance
  - New cell geometry (High Power Density (HPD) cell with integral ribs)

- **Cell Power Enhancement**
  - Increase cathode conductivity
  - Lower cathode polarization
  - Lower ohmic resistance
Performance Enhancement with Improved Cathode-Electrolyte Interface - Effect of Interlayer

Power enhancement through material change

Over 30% Power enhancement at 0.65 V

Tubular cells

- Ceramic Oxide Interlayer
- Composite Interlayer

900°C
85% fuel utilization

Cell Voltage, V

Current Density, mA/cm²

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Performance Enhancement with Improved Cathode-Electrolyte Interface
Effect of Interlayer + Lower T Densification

Power enhancement through material and processing change

>50% Power Enhancement at 0.65 V

Tubular cells

Cerium Oxide Interlayer
Lower T Densified Electrolyte + Composite Interlayer

900°C
85% fuel utilization

Cell Voltage, V

Current Density, mA/cm²

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Power enhancement through material change

Cathode conductivity increased by 50% at 900 °C

Cell testing initiated

Overall 5-10% power enhancement expected
Radially Graded Anode

Power enhancement through processing change

Cell testing initiated

Overall 3-5% power enhancement expected

- Anode
  - High Ni cermet (80 µm)
  - High YSZ cermet (20 µm)
  - Electrolyte

20 µm
80 µm

Overall 3-5% power enhancement expected

Cell testing initiated

Power enhancement through processing change

Radially Graded Anode
High Power Density (HPD) Cathode Supported Seal-less Planar Concept

- Maintains seal-less design
- Potential to eliminate air feed tubes
- Reduction in ohmic resistance
- Increase in cell power density
- More compact stack
HPD Cells

- Selected HPD5 (five channels) as a baseline to develop cell and bundle fabrication processes and conduct electrical performance testing
- Selected HPD10 (ten channels) to explore the upper bounds of cell fabrication
- Current HPD cell active length is 75 cm
- Optimization/further improvement of cell design ongoing
Tubular and HPD Cells

Active length

Tubular: 150 cm
HPD: 75 cm
Both HPD cells have composite interlayers.

Power enhancement through cell design and materials.

75% Power enhancement for HPD10 over tubular cell at 0.65 V.

Graph showing:
- Cell Voltage (V) vs. Current Density (mA/cm²)
- Power Density (W/cm²)

Key points:
- 900°C
- 85% Fuel Utilization
- 75% Higher Power density for HPD10 over tubular cell.
Exceeded program goal of stable voltage for 3000 hours at 1000 °C
Stable Voltage for over 1000 hours with increasing current density

HPD10 – Voltage Stability
Cell Power Enhancement - Summary

- Significant power increase relative to state-of-the-art achieved through advances in materials, processing and cell design
- Further power enhancement expected after integration of individual contributions and optimization/finalization of HPD cell design

**Materials**

- Lower ohmic resistance
- New cell geometry
- High Power Density (HPD) cell with integral ribs

**Processing**

- Lower cathode polarization
- Increase cathode conductivity

**Cell design**

- Increase charge-transfer reaction sites
- Lower EL densification temperature
- Optimize electrolyte plasma spray process to lower densification temperature
- Change dopants to increase low temperature conductivity of LSM cathode

- Replace existing cerium oxide interlayer with a composite interlayer
- Optimize electrolyte plasma spray process to lower densification temperature
- Change dopants to increase low temperature conductivity of LSM cathode

Cell Power Enhancement
HPD Cells – Bundling
HPD Cell Bundle Configuration

- HPD5 Cell
- Electrical Connector
- Power Take Off
- Weld Plate
- Spacer
HPD5 Cell Bundle - 6 Cells

Building block for a generator

Active cell length: 75 cm
HPD Cells in a Generator Environment

Proof-of Concept (POC) System

- Primary objective is to successfully demonstrate the operation of an HPD cell generator
- Secondary objective is to gain experience for end of phase 1 system deliverable – Alpha unit
- 36 HPD5 cells – six bundles of six cells each
- Utilizes air feed tubes
- Design of existing tubular generator modified to accept HPD cells
- Stack: SWPC; BOP: FCT
- Target Start-up: May 2005
POC Generator Layout

- Fuel Reformer
- Air Delivery / Recuperation System
- Cell Bundle
- Fuel Delivery System
POC Generator Assembly

- Assembly Fixture
- Support Base
POC Cell Stack

- CELL BUNDLES
- STACK PERIPHERAL BOARDS
POC – Generator and Balance of Plant

**Target Startup**
May 2005

**Generator**

**Balance of Plant (BOP)**

- RECUPERATOR
- CELL STACK

**BOP Developed and manufactured by Fuel Cell Technologies (FCT)**
Low Temperature Electrolyte
Low Temperature (800 °C) Electrolyte - Options

- **Sr- and Mg- doped LaGaO$_3$ (LSGM)**
  - APS selected to deposit dense layer
  - Dense layers obtained on 5 cm long sections – Development needed to scale-up to 75 cm long cell
  - Cathode, interconnection, anode and interlayer compositions compatible with LSGM developed

- **Scandia stabilized Zirconia (ScSZ)**
  - APS selected to deposit dense layer
  - Very similar characteristics as YSZ allows quick adaptation into cell manufacturing
  - Several tubular and HPD cells fabricated
Plasma Sprayed LSGM - Microstructure

LSGM Electrolyte

Cathode
Low Temperature Electrolyte - Summary

- Further development needed to establish feasibility of LSGM electrolyte for HPD cells
- ScSZ electrolyte selected for near-term application
Low Cost High Volume Manufacturing

Feasibility Studies on-going

- Net shape forming of stack components (Blasch Ceramics)
  - Developed structural ceramics with thermal expansion matched to cell materials for greater reliability

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Low Cost High Volume Manufacturing (Continued)

- Higher throughput plasma spray processes
- Sintering of interconnection, electrolyte and anode
  - Higher material utilization
  - Reduced manufacturing steps
  - Higher throughput
  - Lower capital investment

Feasibility Studies on-going
Next Generation HPD Cell – Delta9

• Surface area increased by 40%, further increasing power density
• Built-in fuel channels
• More compact stack
• Active cell length: 75 cm
• Cell fabrication and testing initiated
Volumetric Power Density Comparison

Power Enhancement Based on Cell Design
1000°C, 85% F.U. and 0.65 Volt

Specific Power (W/cm³)

Theoretical
Measured

Tubular HPD5 HPD10 Delta9
Volumetric Power Density Comparison

Six HPD5 Cells
Power Density ~ 200 mW/cc

Nine Delta9 Cells
Power Density ~ 600 mW/cc
End of Phase 1 (Aug 2006) System - Alpha Unit

- Operating Temperature: 900°C
- Reduce component count from POC
- Reduce/eliminate air feed tubes
- Reduce cost relative to POC and show path to $800/kW
- Reduce cost of module components
- Demonstrate advanced cell technologies
- 5 kWe Power output
- Electrical efficiency: 40%
- 0.1%/1000 hrs degradation
- Test duration >1500 hours
- Attended start-up, unattended operation
Summary

- Contract started in September 2002
- Fabricated HPD cells and demonstrated significant higher power density over tubular cells – Met program milestones for power enhancement and voltage stability
- Additional power enhancement expected after materials and processing advancements are incorporated into HPD cells
- POC assembly completed
- Next generation HPD cells under development
- Alternate low temperature (800 ºC) electrolytes under evaluation
- Low cost, high volume manufacturing development in progress
Future Work (Phase 1)

- Integrate individual cell power enhancement results in HPD cells
- Test POC system
- Continue evaluation of LSGM and ScSZ as 800 °C operating temperature electrolytes
- Continue optimization of HPD cell design and HPD cell fabrication
- Incorporate POC system lessons learned and cost reduction developments in alpha unit scheduled at the end of phase 1 (August 2006)
- Pilot production of SECA alpha units scheduled for second half of 2006 for field demonstrations
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