SECA Program at Siemens Westinghouse

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April 2003

Siemens Westinghouse Power Corporation
April 15, 2003
Annual Sales Posted by the Siemens Business Segments

Complete solutions from a single source

<table>
<thead>
<tr>
<th>Business Segment</th>
<th>Sales in billions of EUR (FY 1999/2000)</th>
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<tr>
<td>Power</td>
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<tr>
<td>Automation and Control</td>
<td>21.6</td>
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<td>Information and Communications</td>
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<td>Lighting</td>
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<td>Infineon Technologies</td>
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<td>Transportation</td>
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<tr>
<td>Medical</td>
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</tbody>
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Siemens Presence and Employees Worldwide

The Organizational Structure of Siemens
Business Segments and Groups

Managing Board

- Power
  - Power Generation (PG)
  - Power Transmission and Distribution (PTD)
- Automation and Control
  - Automation and Drives (A&D)
  - Industrial Solutions and Services (ISS)
  - Siemens Building Technologies AG (SBT)
- Information and Communications
  - Information and Communication Networks (ICN)
  - Information and Communication Mobile (ICM)
  - Siemens Financial Services GmbH & Co. OHG (SFS)
  - Siemens Business Services GmbH & Co. OHG (SBS)
- Transportation
  - Transportation Systems (TS)
- Finance and Real Estate
  - Siemens Financial Services GmbH (SF S)
  - Siemens Real Estate (SRE)

Regional organization: Regional offices, regional companies, representative offices, agencies
Siemens AG
Power Generation

Power Generation

Fossil Power Generation

Americas
Europe, Middle East, Africa, Asia/ Pacific
Operating Plant Services
Gas Turbine- and Combined-Cycle Plants
Steam Turbine Plants and Electric Generators

Instrumentation & Controls

Industrial Applications

Stationary Fuel Cells
Ceramics and Porcelain
(Carved out in Q4 FY02)

JV Framatome ANP
since Jan. 2001
(Siemens share 34%)

JV Voith Siemens Hydro
since April 2000
(Siemens share 35%)

Siemens Power Generation
Employees 25,000

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Stationary Fuel Cells

- 150 Employees
- Chartered to Commercialize SOFC Power Systems for the Distributed Generation Market
- Focused on Seal-less, Cathode Supported Tubular 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), 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
SOFC Power System Demonstrations with Tubular SOFCs

100 kWe Atmospheric Combined Heat and Power (CHP) System

- 20,000+ hours with no measurable voltage degradation
- 46% electrical efficiency
- Grid and District Heating Connected

200 kWe Pressurized Hybrid (PH) System

- 3000+ hours
- 52% electrical efficiency
Highest Priority for Commercialization

Lower Product Cost ($/kWe)

Cost ↓

Power Density ↑
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.
Projected Fuel Cell Market in 2012

Present Focus

SECA
Focus on New Market Segments; Cost Target < $400 /kW
SECA -10 Year Roadmap

Phase I
- Proof of concept
- 5 kW
- Internal reformation
- Sulfur tolerance < 1ppm
- 45% electrical efficiency

DOE goal
$800/kW

2002
Remote Applications

Phase II
- \( \alpha / \beta \) unit
- > 5 kW
- Partial on cell reformation
- Sulfur Tolerance < 10ppm
- 45% electrical efficiency

DOE goal
$600/kW

2006
Small Stationary, Remote, APU Applications

Phase III
- \( \beta \) and pre-commercial units
- 10 kW
- Large on cell reformation
- Sulfur Tolerance < 30ppm
- 45% electrical efficiency

SFC commitment with stretch target
$400/kW

2008

2012
Small Stationary, Residential, Remote, APU Applications

2008
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SPG SFC
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### Technology Team

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<th>Remote/Residential</th>
<th>Transportation</th>
<th>Military</th>
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<tr>
<td>Siemens Westinghouse</td>
<td>Fuel Cell Technologies</td>
<td>Ford</td>
<td>Newport News</td>
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<tr>
<td>Fuel Cell Technologies</td>
<td>Lennox</td>
<td>Eaton</td>
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<td>Blasch Precision Ceramics</td>
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<tr>
<td>Zircar Refractory Ceramics</td>
<td>Dominion</td>
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</table>

### Customer / Market Team

- **Remote/Residential**: Ford, Eaton
- **Transportation**: Lennox, Eaton
- **Military**: Newport News

**Key Team Members provide Market Access and Industry Specific Expertise To broaden Market Opportunities and New Applications**
SECA Program Technical Approach

- Improve Cell Performance through High Power Density (HPD)
  Cathode Supported Planar Cell - New Cell Geometry
- Improve Cell Performance by Reducing Activation Polarization at Interfaces - New Cell Materials
- Lower Operating Temperature (800°C) - New Cell Materials
- 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
High Power Density (HPD) Cathode Supported Planar Concept

- Maintains Seal-less design
- Reduction in resistance and cell cost
- Increase in cell power (power density and surface area)
- More compact stack
Development of HPD Cell Design

- Computational Thermal Model of HPD Cell Developed to Optimize Cell Design and Dimensions
- Theoretical Performance Estimated by Electrochemical modeling
Evolution of Cell Design

Standard Cylindrical

HPD5R0-2002

HPD5R1-2003

HPD10 >2003
Temperature Distribution in HPD10 Cell
Extrusion of HPD Tube
Tubular and HPD Cells
Performance Comparison - Tubular Vs. HPD5

Cell Performance Comparison at 1000°C

Cylindrical and HPD Cells

- Test 779, 85% FU and 25% AU (HPD5)
- Test 558, 85% FU and 25% AU (Cylindrical)
Cell Power Enhancement

- Developed Mixed Ionic and Electronic Conducting Composite Interlayer
- Lowered Activation Polarization at the Cathode-Electrolyte Interface - Enhanced Cell Performance at Lower Temperatures
Performance Comparison - Std. Interlayer Vs. Composite Interlayer (Tubular Cells)

- Graph showing cell voltage (V) vs. current density (J, mA/cm²)
- Conditions: 900°C, air vs. 89% H₂ + 11% H₂O, 83% fuel utilization

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Performance Data
Cylindrical versus HPD5
and SECA Targets

Power Density (W/cm²)

Voltage (V)

Current Density (mA/cm²)

Month 6

Month 25

Month 36

Blue Test 779 HPD5
Red Test 558 Cyl.
Cell Development - Summary

- Reduction in Ohmic Resistance through HPD Design
- Reduction in Activation Polarization through Composite Interlayer
- Target Power Increase for HPD Cells Compared with Tubular Cells - 2X at Half the Length
- Improves Packing Density
Selected LSGM (Mg and Sr doped lanthanum gallate) for Evaluation
LSGM As Low Temperature Electrolyte

- High Electrolyte Oxygen-ion Conductivity: $\sigma(\text{LSGM@800}^\circ\text{C}) = \sigma(\text{YSZ@1000}^\circ\text{C})$
- Excellent Chemical and Structural Compatibility with Perovskite Cathode Substrate
- Higher Cell Performance over a Wider Temperature Range
- Potential Cost Reduction due to Lower Operating Temperature
Characterization of Properties of LSGM and Compatible Materials

- Electrical Conductivity
- Thermal Expansion Coefficient
- Dimensional Stability
- Chemical Reactivity of LSGM with Cathode Substrate at Operating Temperature
- Electrochemical
- Feasibility of Plasma Spraying LSGM Film on Cathode Substrate
Selection of LSGM and Compatible Materials

- Electrolyte: LSGM
- Cathode: Doped Lanthanum Manganite
- Interconnection: Doped Lanthanum Chromite
- Cathode Interlayer: Mixed Ionic and Electronic Conductor
- Anode Interlayer and Anode: TBD

Over 10 compositions of Cathode and Interconnection were selected for Screening
Plasma Spraying of LSGM Layer on Cathode Substrate

As sprayed

- LSGM
- WPC3

SWPC’s LSM tube
LSGM on LSM tube

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Low Temperature Electrolyte - Summary

- Selected Electrolyte and Cathode Compositions
- Prepared Powders for Cell Preparation and Electrochemical Characterization
- Initiated Feasibility Study of Plasma Spraying LSGM on Cathode
Low Cost High Volume Manufacturing

- Initiated Feasibility study of All Sintered Cell
  - Higher Material Utilization
  - Reduced Manufacturing Steps
  - Higher Throughput

- Initiated Feasibility Study of Low Pressure Plasma Spraying (LPPS)
  - Higher Material Utilization
  - Lower Densification Temperature
  - Higher Throughput
- Initiated Development of Low Gas Permeable Ceramic Stack Housing
- Initiated Feasibility Study of Lower Purity Insulation (Possible Due to Lower Operating Temperature)
Generator Design and BOP Simplification (With FCT)

Model Showing FCT Alpha Prototype
Generator Design and BOP Simplification (With FCT)

Oven Testing

FCT Recirculator Design in Testing
Prototype Combustor and Flame Holder Designs
Summary

- Incorporating Lessons Learned from Alpha Demonstration Units.
- Beta Unit with Full Length (834 cm² active area) Tubular Cells Being Designed with an Objective to Maintain Commonality Between Beta and SECA Units.
- Design of SECA Unit with HPD Cells Initiated.
SECA Program Summary

- Contract for First 2 years Signed in September 2002
- HPD5 Selected as Baseline Design for Development and Test
- HPD10 Undergoing Evaluation
- LSGM vs. YSZ Evaluation Initiated
- LPPS, Thin-film Sintering Processes being Evaluated as Alternative to Atmospheric Plasma Spraying
- Low Cost Module Materials Being Investigated
- Generator Design and BOP Simplification Initiated
Future Work

- Continue Development of Cell Design and Cell Fabrication
- Make a Decision on LSGM Vs. YSZ for POC Unit
- Develop Generator Design for POC unit
Siemens Westinghouse Stationary Fuel Cells converted from R&D department to a business unit with a pilot manufacturing facility

First environmental friendly commercial product CHP 250
(no SOx; no CO; NOx < 1ppm)

New Commercial factory (Milestones):
1-Site Selection/Groundbreaking
2-Finalized Manufacturing Building
3-Implemented Manufacturing Equipment
4-Qualified Production Processes
5-Start Commercial Shipments
Stationary Fuel Cells - Manufacturing Facility

Munhall, Pennsylvania Location...180,000 sq. ft. - Phase I Building