DOE FE Distributed Generation (DG) Fuel Cells Program

Sixth Annual SECA Workshop & Core Program Peer Review

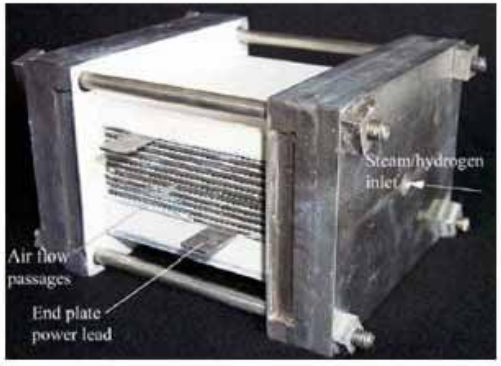
Pacific Grove, CA
April 18, 2005

Dr. Mark C. Williams, Technology Manager
National Energy Technology Laboratory

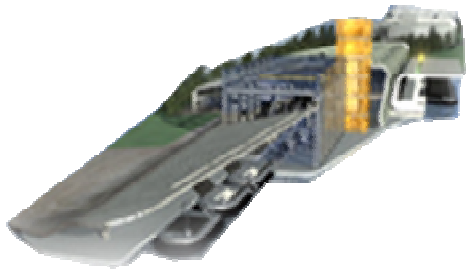
DG Fuel Cells Program Areas (R&D Activity)

FY05 Budget in Millions

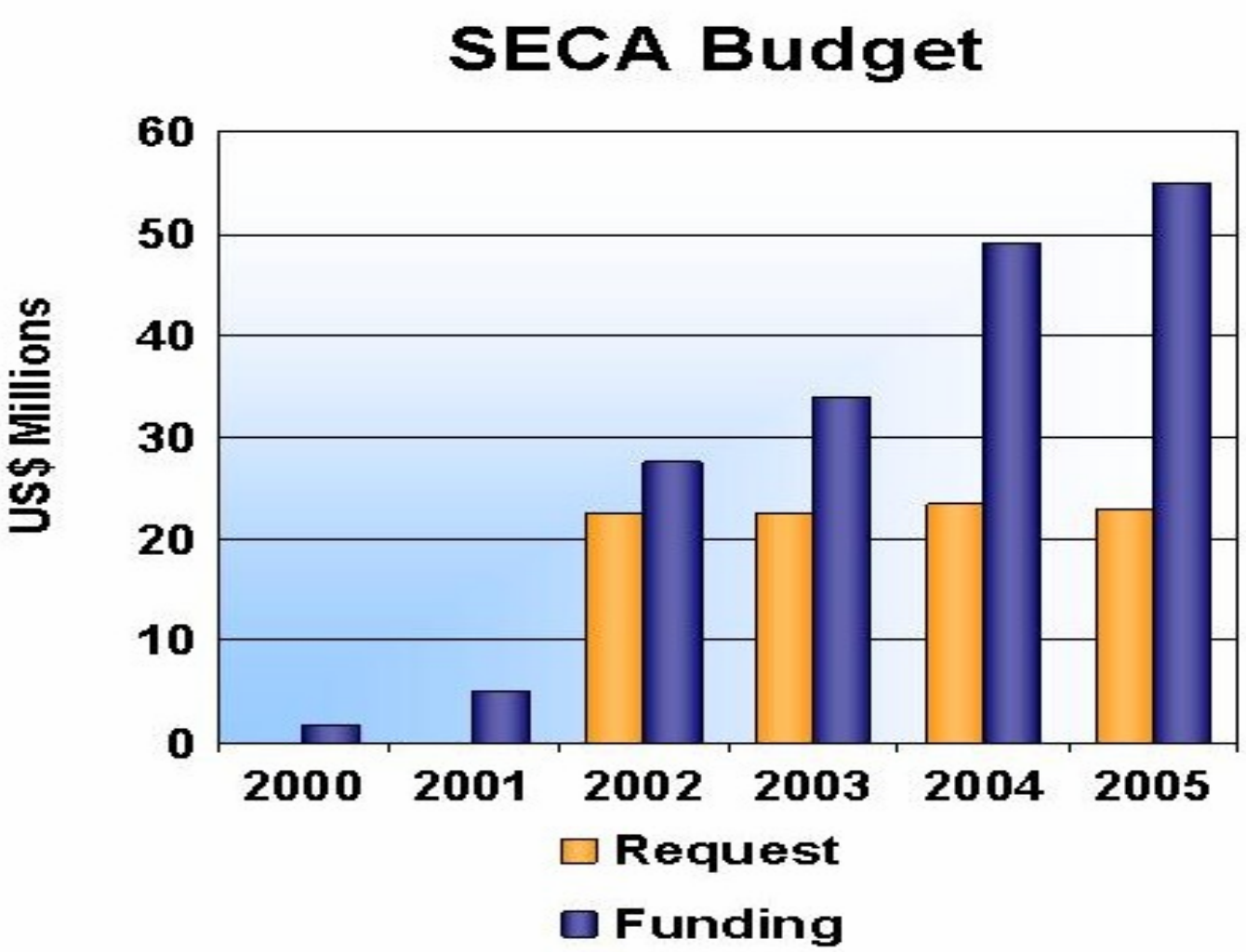
Innovative Concepts SECA $54.2



Advanced Research $12.2
High Temperature Electrochemistry Center (HiTEC)



Coal-based Central Systems – Hydrids - $5.0MM

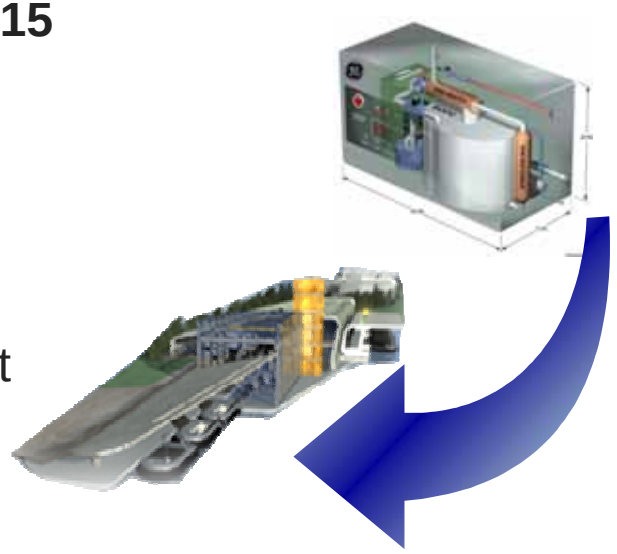

SECA Budget
US$ Millions
60
50
40
30
20
10
0
2000
2001
2002
2003
2004
2005
Request
Funding

DG Systems Program Mission/Goals

- **Mission: Ensure the widespread deployment of fuel cell-based power systems**
  - Lower cost
  - Higher reliability
- **FutureGen Support - 2010**
  - Aggregatable MW-class fuel cell modules
  - Auxiliary & Primary power generation
- **Fuel Cell Coal-Based Systems – 2011-15**
  - 50% HHV efficiency
  - 90% CO_2 capture
  - Coal syngas testing at FutureGen
  - Scaleable to >100 MW
- **Coal/CURC Roadmap – 2018-2020**
  - Fuel cell-turbine hybrids: 60% efficient coal-based power systems

DG PSPG- 2010

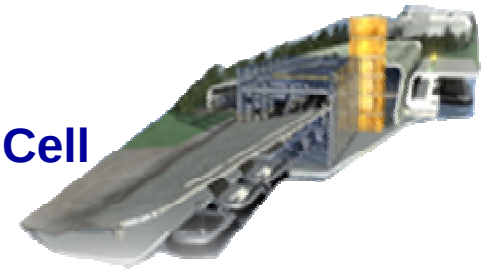
Fuel cell: 10-fold cost reduction to $400/kW with 40 - 60% efficiency & adaptable to zero-emission coal systems



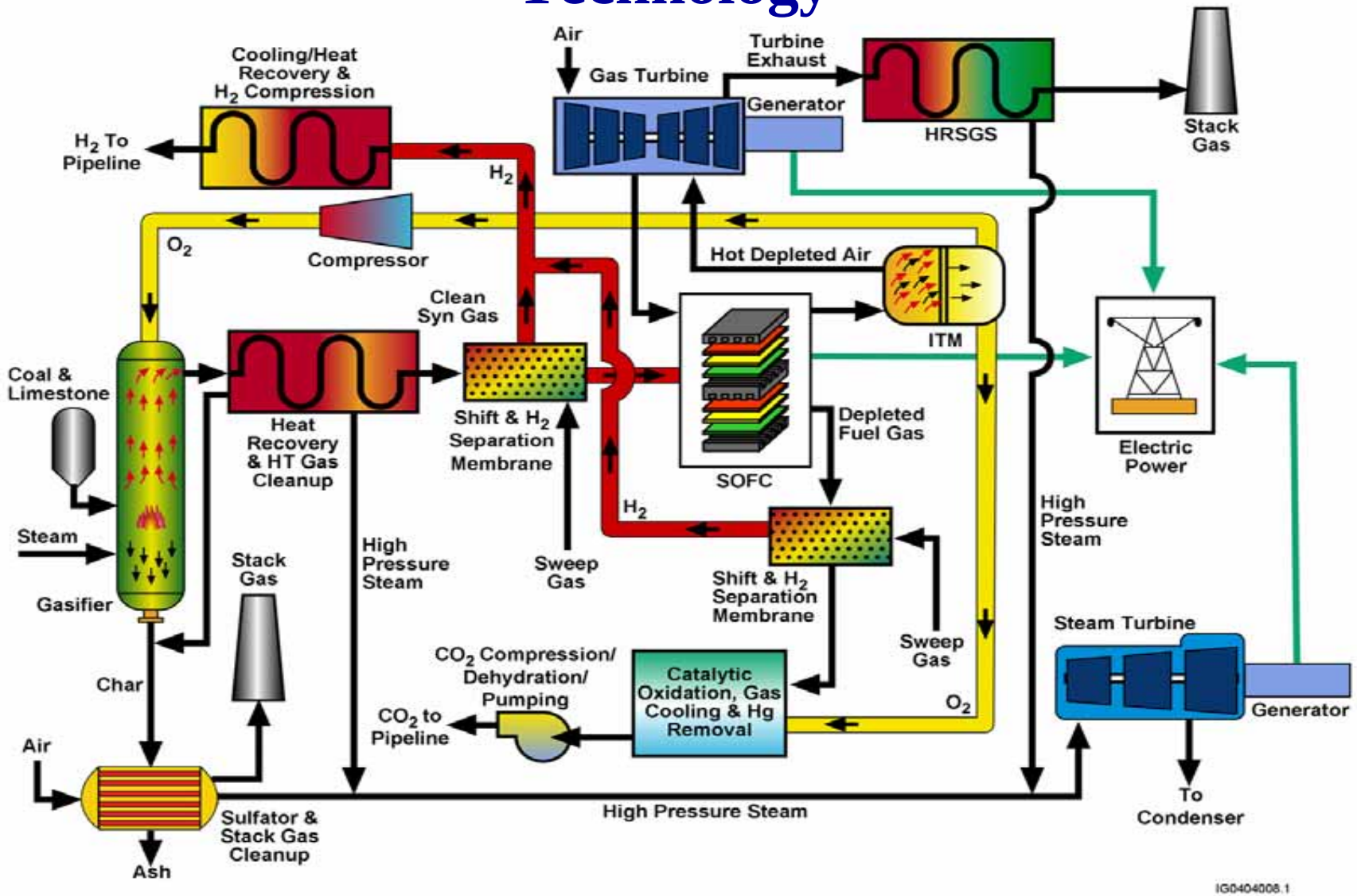
DG Systems Strategy: SECA → Fuel Cell Coal-Based Systems

Fuel cell technology demonstrated in DG applications before use in large-scale Central Power Systems

- **Mass customization through SECA DG applications**
  - High-volume
  - Establish manufacturing and materials base
- **Scale-up SECA-derived fuel cell technology in the form of fuel cell and/or fuel cell-turbine hybrid systems to MW-class**
  - Scale-up
  - Pressurization
  - Aggregation
  - Integration
- **Apply fuel cell-based designs to >100-MW class Fuel Cell Coal-Based Systems**
  - FutureGen
  - Advanced coal-based generation



FutureGen Plant with Solid Oxide Technology



SOFC and Manufacturing

(courtesy CFCL)

SOFC U.S. Markets - 26 GW/yr by 2011

	Range (kW)	Units per year	Size (kW)	Total (GW/yr)
Remote Generators	0.5-10	30,000	10.0	0.30
Telecommunications	2-10	30,000	10.0	0.30
DG Commercial	<100	165,000	50.0	8.22
DG Residential	2-15	1,520,000	10.0	15.20
Back-up Power	<50	80,000	6.0	0.48
SPA (appliances)	0.5	160,000	0.5	0.08
APUs	5-15	121,000	10.0	1.20
			Grand Total by 2011	25.78

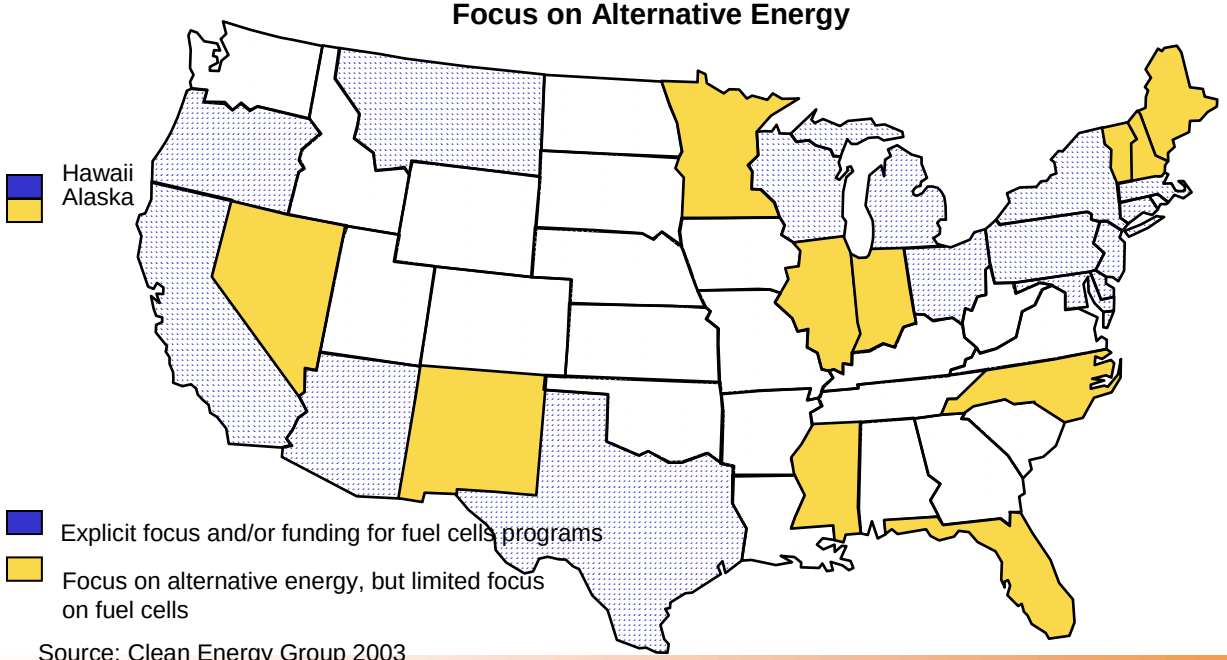
The Sum of the State Incentive Programs Exceed the Federal Stationary Fuel Cell Budget

- **Clearly there must be support of manufacturing capacity development**
- **Developing incentives to support manufacturing development**
  - Production and Employment Retention Grants
  - Loans and Grants
  - Rebates, Price Incentives, Net Metering
  - Tax Incentives, Tax Exempt Financing, Property Tax Exemptions

State Funding Should Support Fuel Cell Manufacturing

At least 21 State Agencies Actively Support RE, Some With Explicit Focus on Fuel Cells

States with Public Benefit Funds, Active Energy Offices or Economic Development Agencies with Focus on Alternative Energy



Source: Clean Energy Group 2003
aceee, May 2002; CRE interviews

www.cleanenergystates.org/JointProjects/fuelcells.html

Manufacturing

- There are clearly certain states that have taken an aggressive and competitive initiative to be the manufacturing and employment base for fuel cell technology
- As the SECA R&D program achieves its goals to produce cost competitive technology, there needs to be a commensurate growth in manufacturing capacity
- A complete listing of all state and federal incentives for fuel cell technologies can be found at www.dsireusa.org
- Dept. of Commerce SECA Manufacturing Summit planned

Ohio leads the way

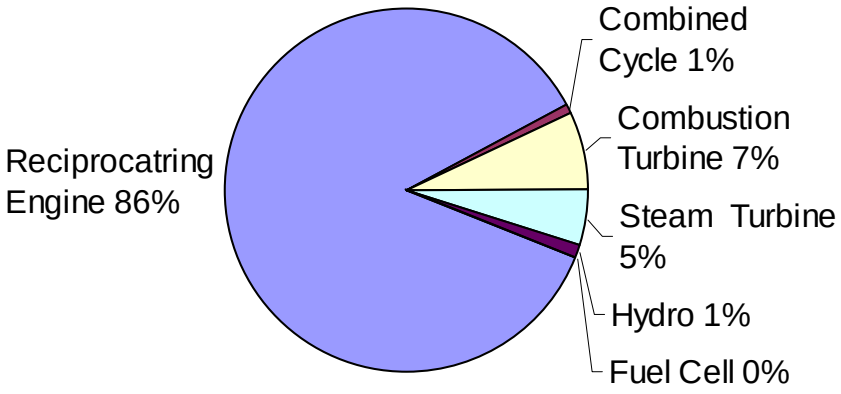
- **Fuel Cell Grant Program**
  - a $100 million, 3-yr initiative to invest in research, project demonstration and job creation. $75M in financing to make strategic capital investments that will create and retain jobs, $25M for fuel cell research, development and demonstration, and $3M for worker training
- **Fuel Cell Loan Program**
  - $15M to finance traditional economic development investments for expansion of Ohio's fuel cell industry through low-interest loans and guarantees. The maximum loan per company is $5M
  - Ohio Dept of Development (ODOD) has set aside $60M in federal volume cap for tax-exempt financing of qualified projects
- **Renewable Energy Program**
  - 11 banks provide reduced interest rates, by approximately half, on loans for those qualifying Ohio residents and businesses for EE, RE and fuel cells

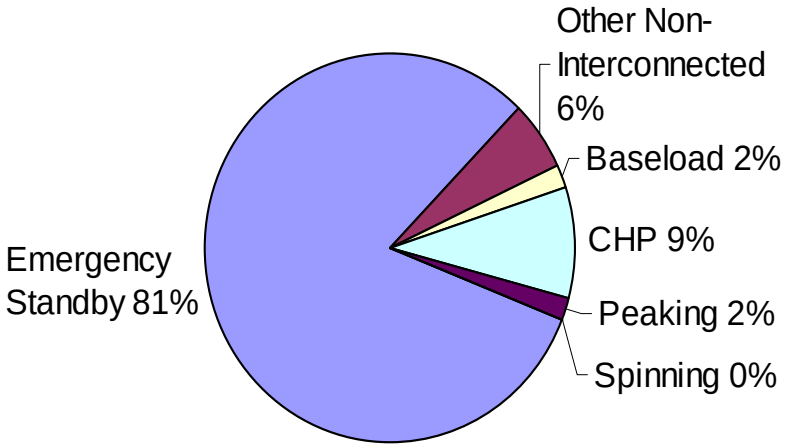
Some Universities/Colleges with Fuel Cell Courses and Certifications

UNIVERSITY	DEPT	# COURSES
Arizona State University	ME	1
Case Western Reserve University		2
Georgia Institute of Technology		UD
Humbolt State University		2
Illinois Institute of Technology		1
Kettering University		2
New Mexico State Naugatuck Valley Community College	CE	1
Pennsylvania State University	ME	1
Rochester Institute of Technology		1
Texas State Technical College Waco		2
University of California Irvine	M&AE	2
University of Connecticut	ME	1
University of Delaware	ME	1
University of Kansas	CE	1
University of South Carolina	CE	1
University of Michigan		UD
University of Washington	CE	1
Virginia Polytechnic Institute and State University		1
Wayne State University		2
West Virginia University	M&AE	1
Worcester Polytechnic Institute	CE	1

DG Percentage Capacity by Application & Technology

(Existing Capacity 2004)





Source: EPRI - Rastler

Importance of DG at SCE in Southern California

- Using the full capabilities of fuel cells and inverters presents some attractive qualities:
  - Voltage Control - (VAR control a.k.a. reactive power)
  - Frequency Control
- Programs such as SCE's Circuit of the Future offers opportunity to test, evaluate, and advance DG (fuel cells, micro turbines, etc.)
  - Circuit of the Future provides a utility test bed for evaluating DG
  - Standardization of circuit design to minimized cost of interconnecting new DG

NETL

International

- Alan Miller of the World Bank-IFC will later address efforts in developing countries
- Escalating fossil fuel prices >$50/bbl is putting an unprecedented premium on system efficiency which favors SOFC
- Poor grid reliability is inhibiting growth in all economic sectors, including IT, and the baseload profiles of these industrial sectors favor SOFC

SECA Industry Teams

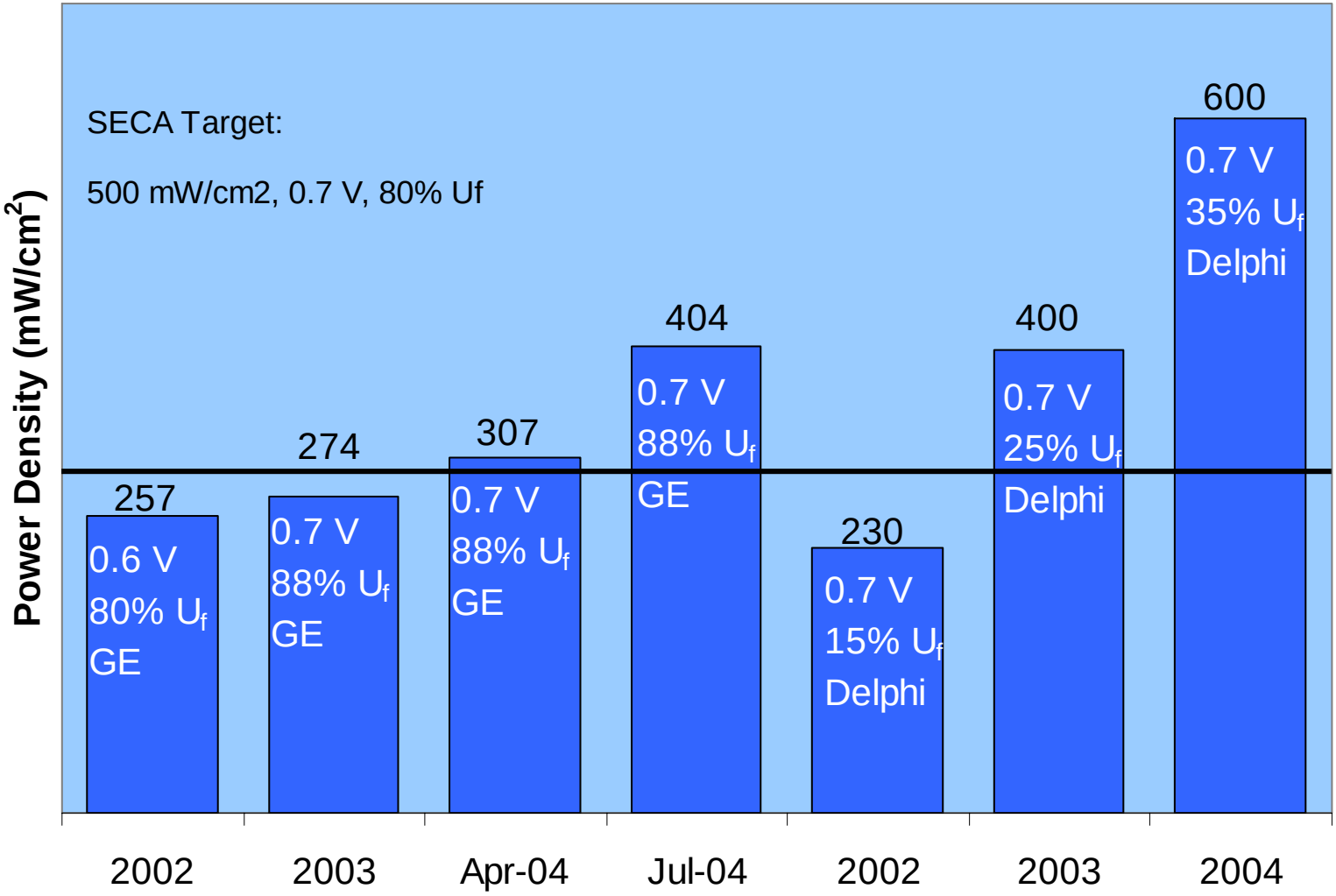
Testing and evaluation of Phase I prototypes for minimal technical requirements is critical for meeting long-term cost and performance targets

GE's Phase I prototype qualification testing is scheduled to start in April 2005.

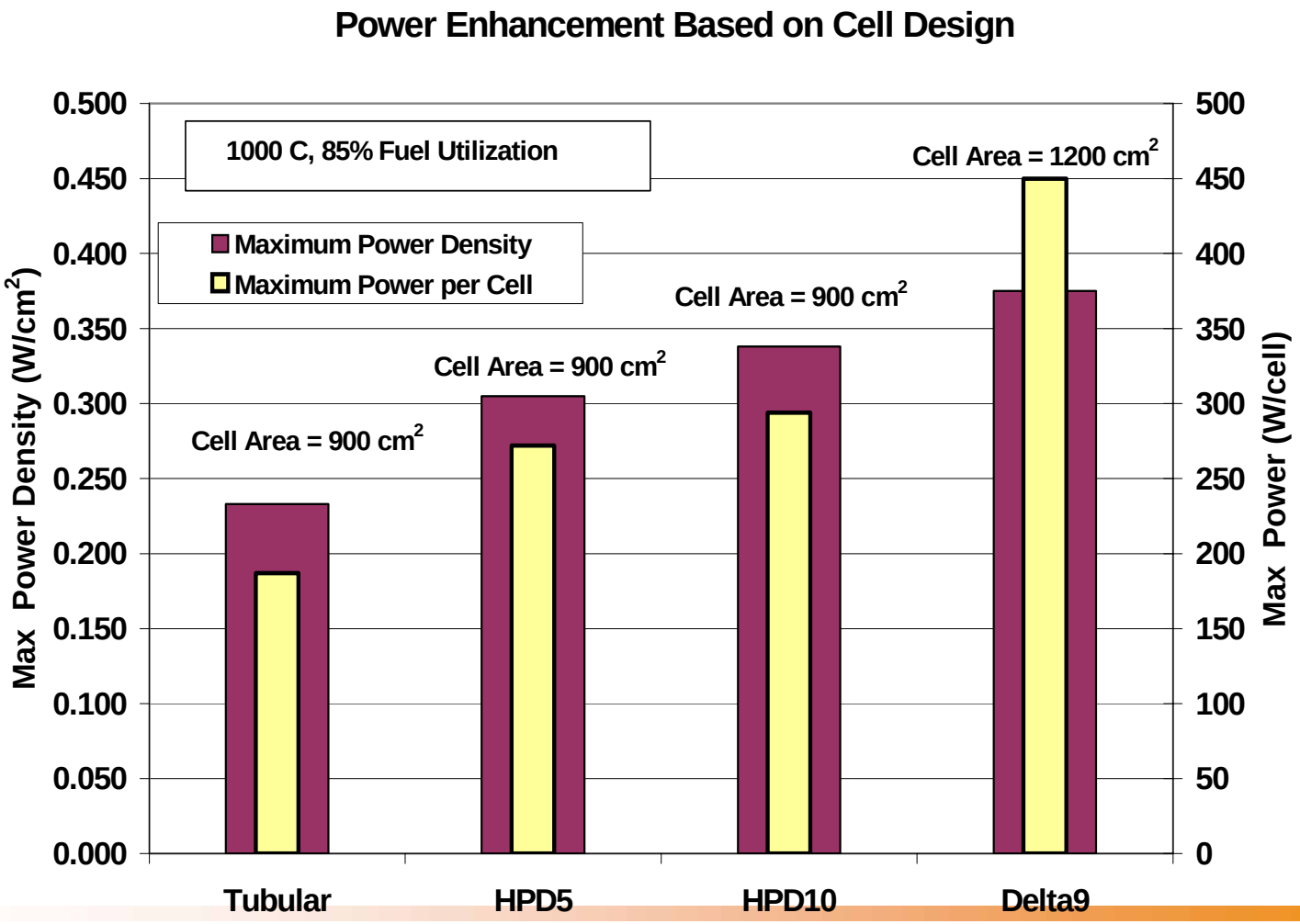
Delphi's Phase I prototype qualification testing is scheduled for start in June 2005.

- Cummins' Phase I prototype qualification testing is scheduled for to start in September 2005.
- Acumentric's Phase I prototype qualification testing is scheduled to start in November 2005
- SWPC Phase I prototype qualification testing is scheduled to start in July 2006
- FCE's Phase I prototype qualification testing is scheduled for completion to start in December 2006.

Single Cell Module Performance Improvement GE & Delphi

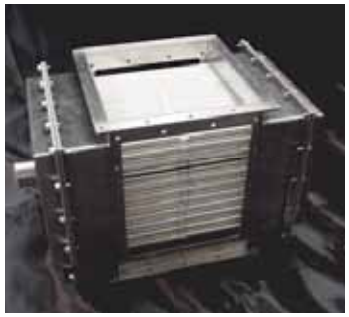


SWPC Maximum Power Density Comparison



SECA Industry Teams

SECA Industry Team Progress and Commitment

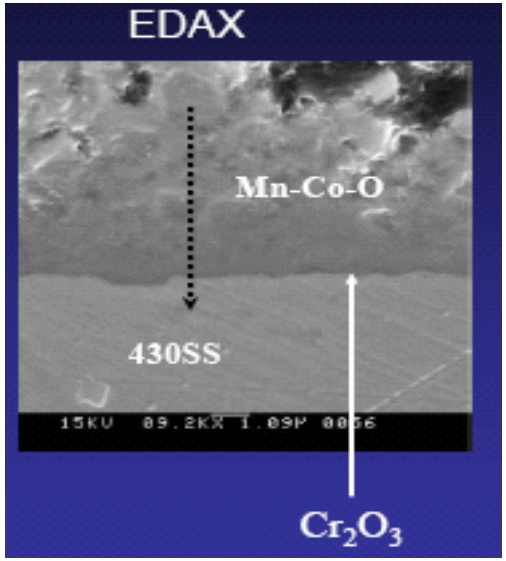


- Acumentric's manufacturing costs may be much lower than some previous fuel cell technologies
- Cummins' may qualify their SECA Project as pilot in VPI program.
- VPS's progress has accelerated wi incorporation of former Global technology and manufacturing capability

Innovative Concepts – SECA Core

Building on Accomplishments

Collaborative system design improvements and technology transfer will help to meet the Phase I cost and performance targets outlined in solicitation. CTP transferred technology helping to solve seals, interconnects, electrodes, fuel processing, etc.



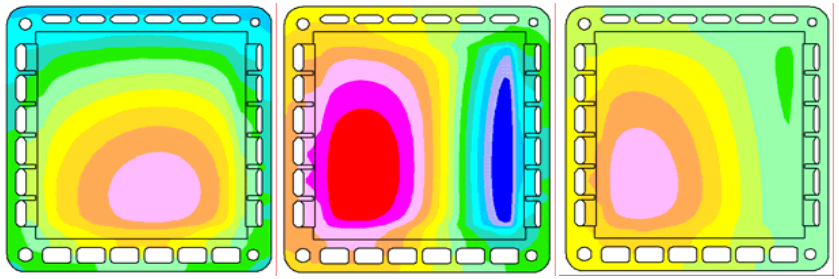
- Determined location and form of Cr deposition and migration in SOFC cathode compositions (PNNL and ANL) Cr Workshop held to formulate a plan to investigate Cr interactions
- FEM based multi-physics MARC code enhanced by GUI - incorporates materials, electrochemistry and empirical flow modules (PNNL and MSC Software) – PNNL reporting results in short course.
- Seal Workshop resulted in a much larger set of seal concepts in development.
  - Mica seal and glass seal composition developed meeting leakage and thermal cycle requirements (PNNL).

Key Core Program Accomplishments

- **Key results**
  - Cathode materials developed permitting 575mW/cm2 @ 0.7 volts in a 30 cell, 106cm2 cell stack (PNNL).
  - Sulfur, carbon and oxygen tolerant anode developed. Performance requires improvement (PNNL).
  - Power electronics/Inverter package – 98% efficient, undergoing tech transfer (Virginia Tech)
  - Available for licensing
  - Integrated SOFC/power electronics integration software, undergoing tech transfer (U. of Illinois)
    - Includes BOP, SOFC, PE – dynamic model for load transients to develop control strategies for any application

SOFC Material Testing

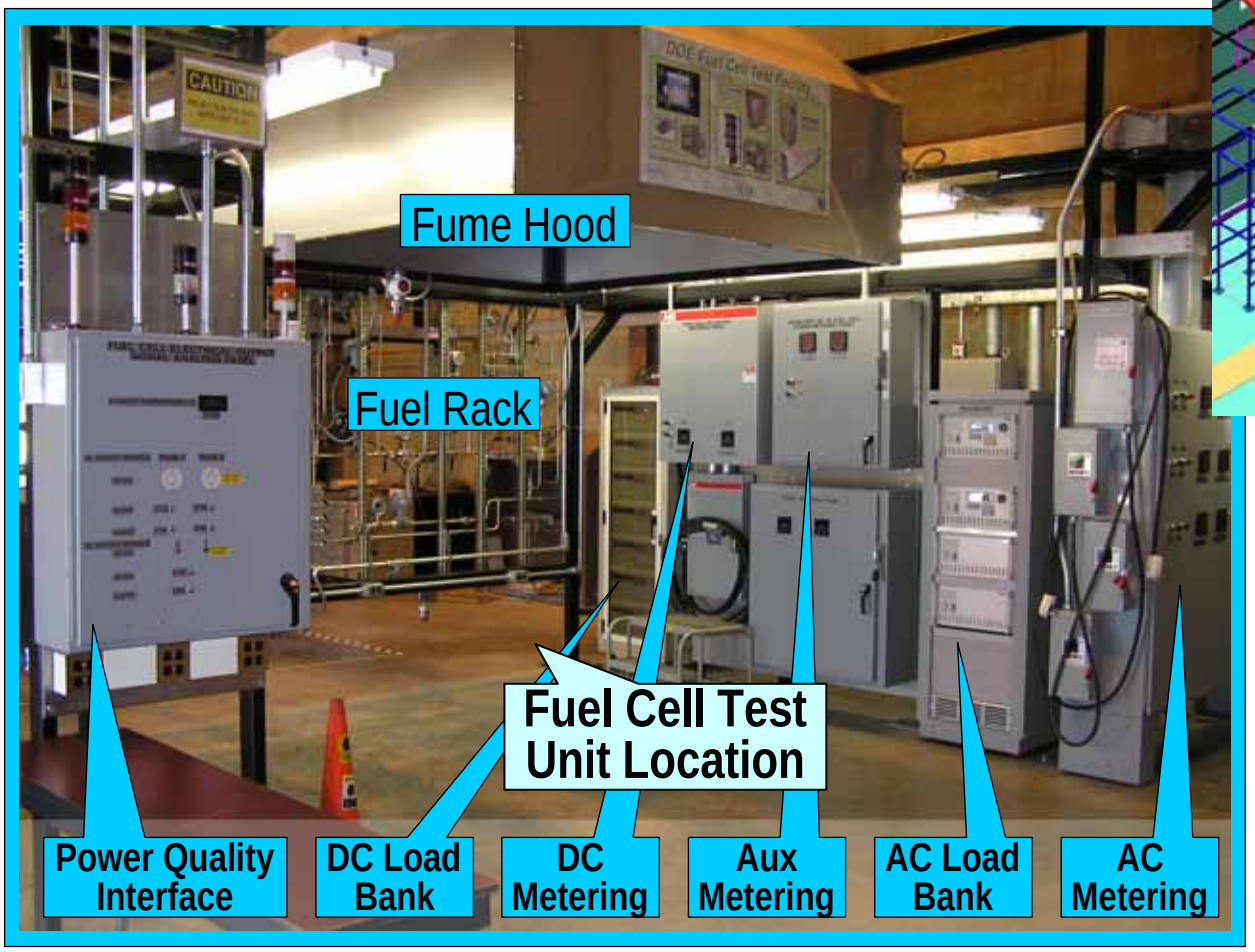
On-Cell Steam-Methane Reforming



SECA Core Solicitation No. 3
10 Phase 1 Awards - $2.25 Million

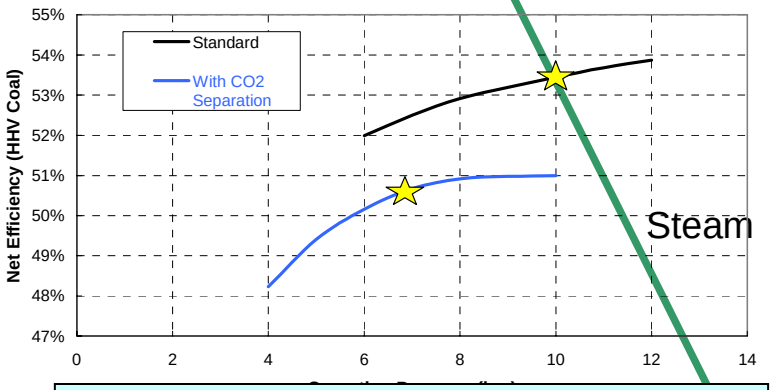
- **Solicitation Announcement – November**
  - Seals, interconnects, electrodes, fuel processing
- **85 Pre-applications – December**
  - Internal merit review for technical approach and teaming
- **28 Full Applications – January**
  - Internal merit review plus external review by SECA Industry Teams and National Labs
- **Selections – April**

NETL Fuel Cell Test Facility



SECA

GE Coal Study: Fuel Cell Hybrid Block Diagram

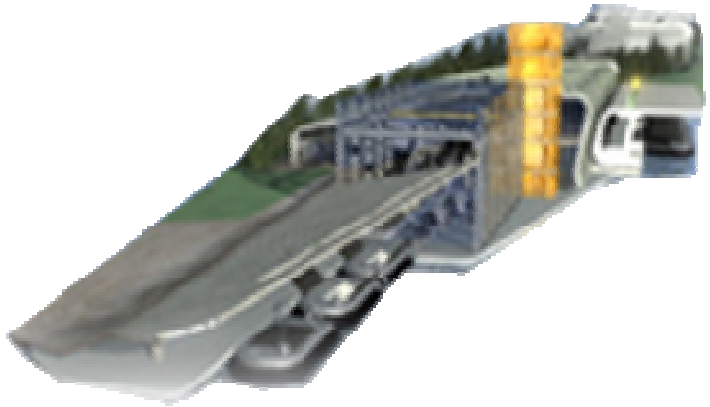


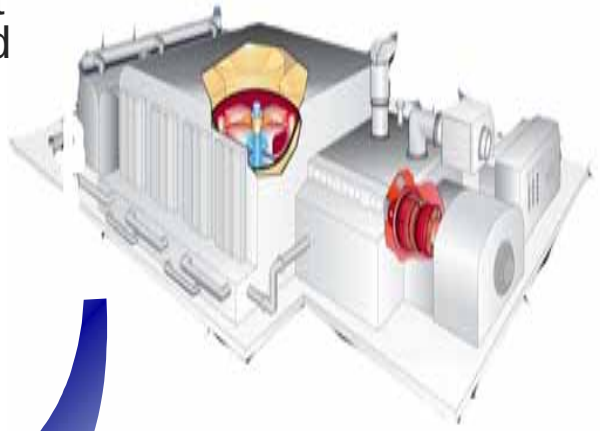
- 53.4% (HHV) Possible with IGFC
- CO_2 Separation penalty 2.7 points

Coal
Gasifier
Raw Syngas
Gas Clean-up
Water Gas Shift
CO2 Separation
Spent Fuel Recycle
Fuel Cells
Combustor
Steam
Steam
Steam
Generator
ST
HRSG
GT
C
Generator
Exhaust
Air

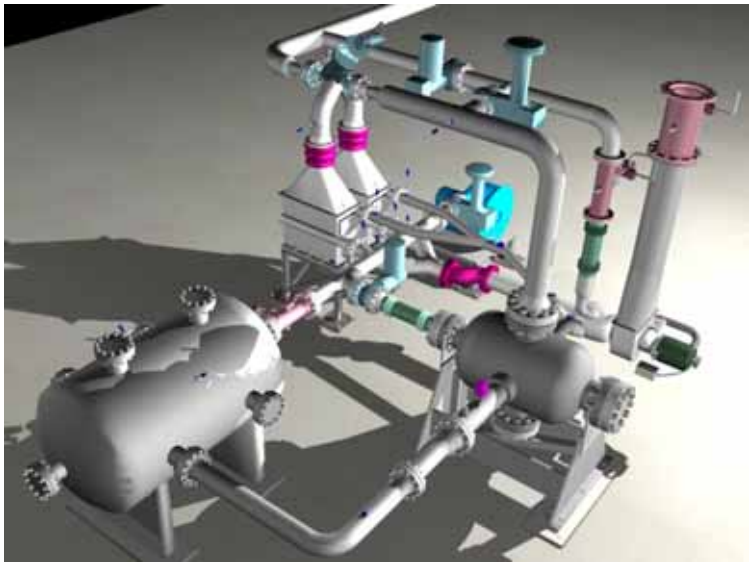
Innovative Concepts – Fuel Cell Coal-Based Systems (FCCBS)

- **SECA Fuel Cell Coal-Based Systems (FCCBS)**
  - Issued a new Fuel Cell Coal-Based Systems solicitation and make selections
  - MW-class SECA fuel cells and hybrids will help meet efficiency, cost, and emissions targets for coal-based power plants
- $5MM Solicitation **(2005)**
- Make selections and negotiate two awards **(4Q/05)**





Hybrid Performance (Hyper) Test Facilities at NETL

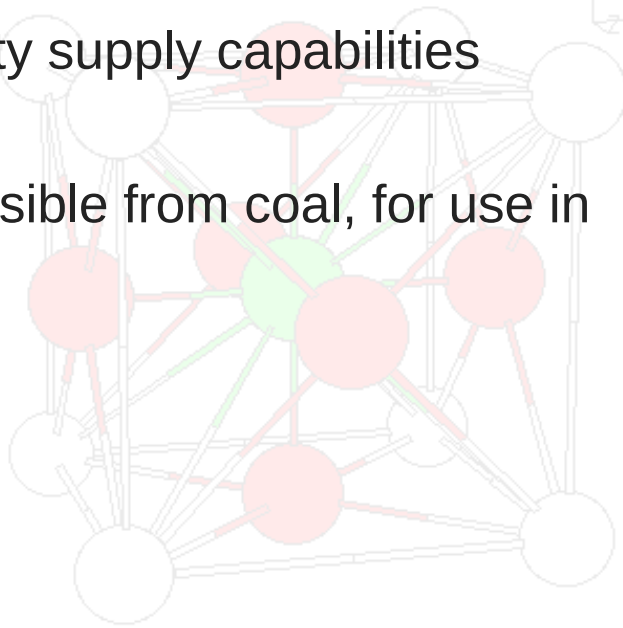


Advanced Research - High Temperature Electrochemistry Center (HiTEC)

Located at Pacific Northwest National Laboratory (PNNL) with Satellite Universities, currently Montana State University and University of FL

HiTEC GOALS:

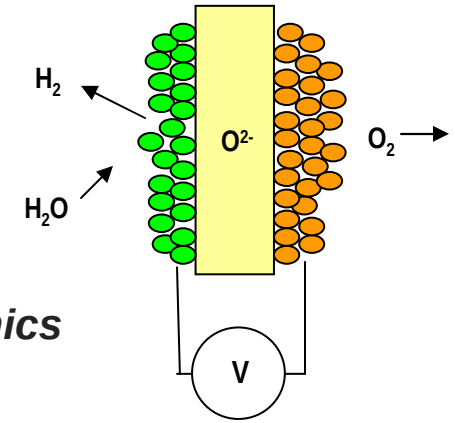
- **Develop energy storage technologies for coal-based central power plants**
  - Enable load leveling and peak load electricity supply capabilities
- **Advanced Fuel Feedstock**
  - Research aspects of alternative fuels, if possible from coal, for use in fuel cells

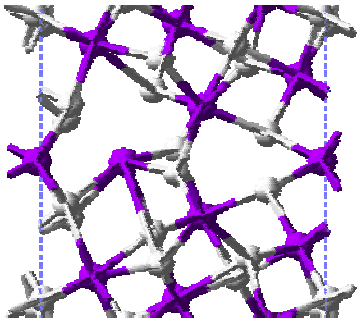


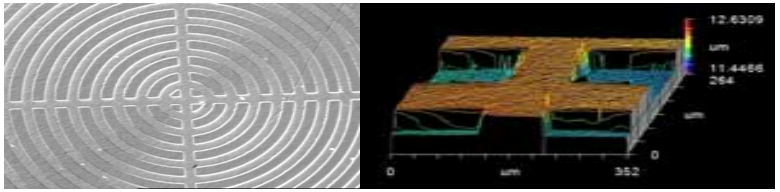
HiTEC Participants and Projects

- **Pacific Northwest National Laboratory**
  Reversible Solid Oxide Fuel Cells
- **Montana State University**
  Study of Buried Interfaces in Fuel Cell Structures
  Development of Corrosion-Resistant Layers on SOFC Interconnects
- **University of Florida**
  Proton Conductors/Hydrogen Membranes
  Atomistic modeling of defects using molecular dynamics
- **University of Utah**
  Determination of Cathodic Inefficiencies in SOFCs Using Patterned Electrodes
  Ultra High Power Density SOFC Concepts

"Reversible" solid oxide fuel cell could produce hydrogen from water during periods of excess grid capacity, and produce electricity later from the stored hydrogen.







Novel electrode structures allow role of microstructure and catalytic activity to be distinguished.

HiTEC Solicitation

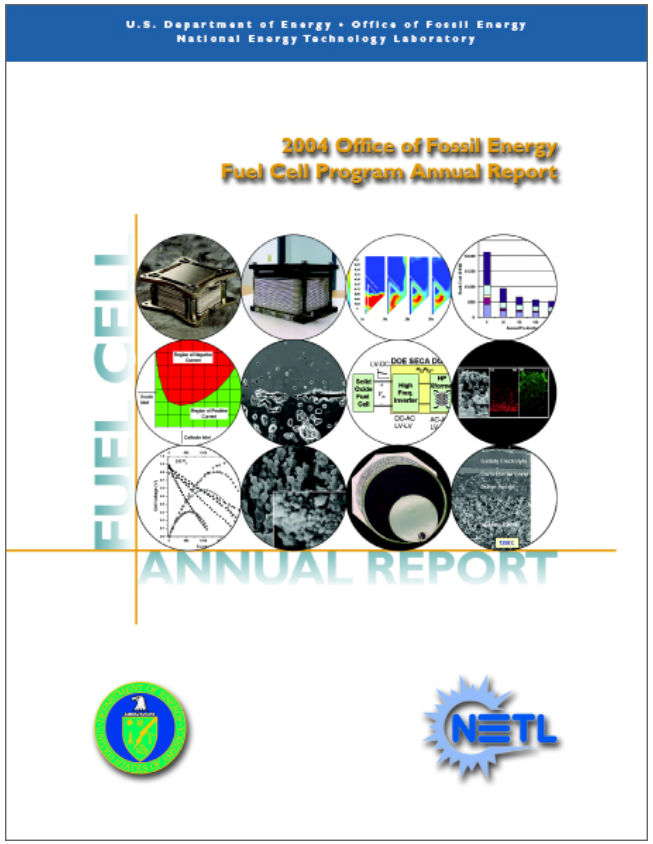
- **$1.75 million**
- **Research Topics**
  - High Temperature Electrochemical Power Generation & Energy Storage Technology
    - Energy Storage Utilizing High Temperature Electrochemical Processes
    - Revolutionary High Temperature Electrochemical Power Technology
    - Thermoelectric-SOFC Hybrid Energy Conversion
  - Advanced Fuel Feedstock
    - Effect of Coal Contaminants on Solid Oxide Fuel Cell System Performance and Service Life

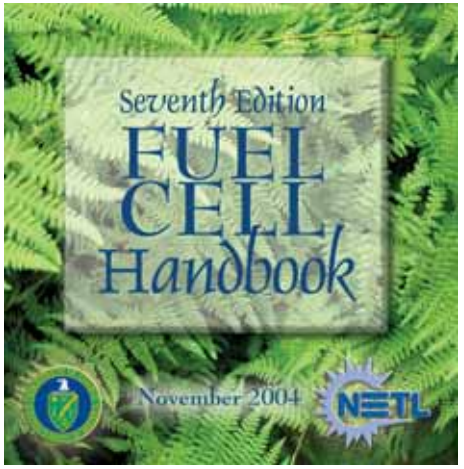
Key Industry Communication Events 2005
(Similar Scenario Expected for 2006)

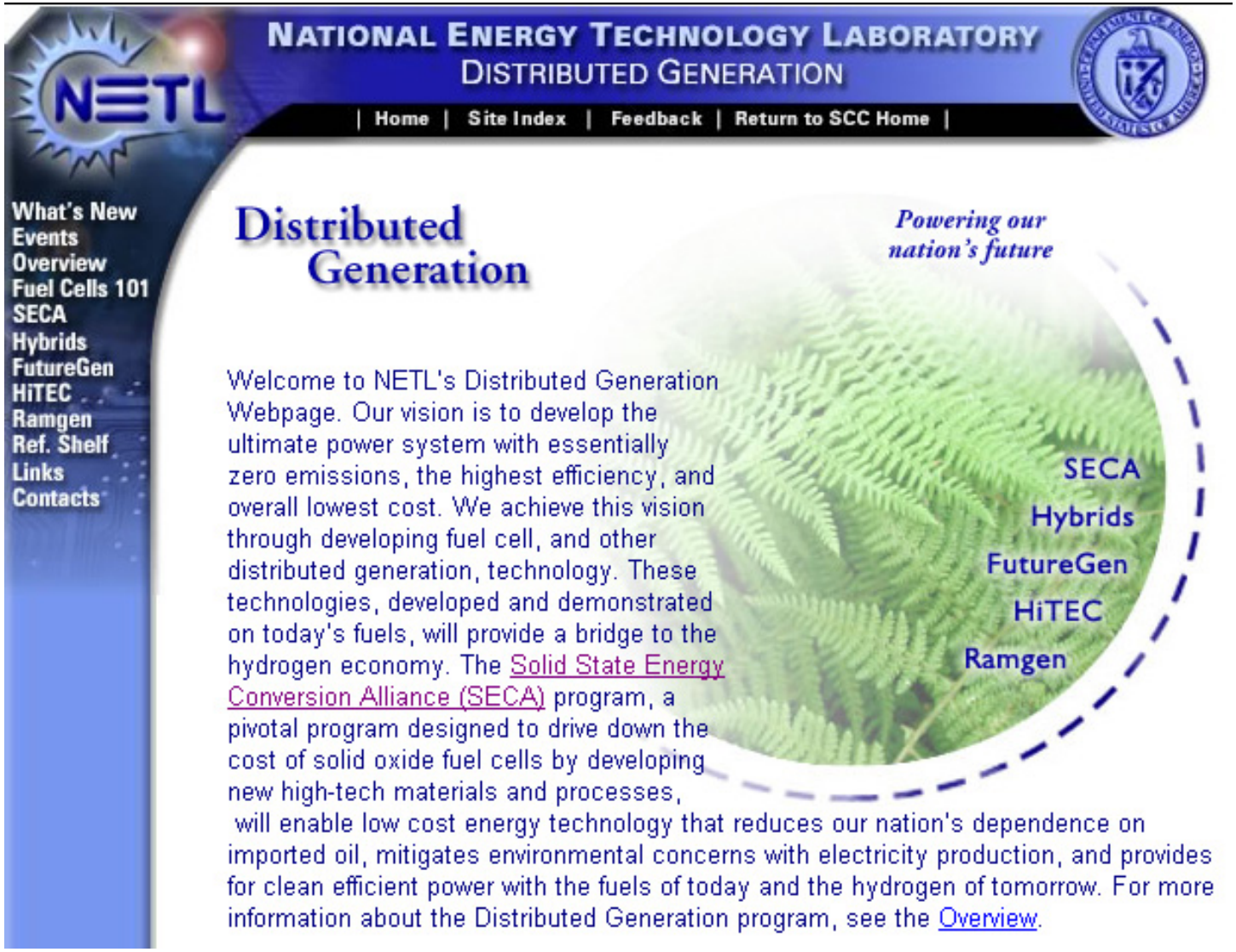
- Semi-Annual SECA CTP Peer Review, Tampa, FL, January '05
  - Peer reviews and stakeholder inputs obtained
- Annual SECA Workshop and Semi-Annual SECA CTP Peer Review, Monterey, CA, April '05
  - Industry Teams detail progress
  - Peer reviews and stakeholder inputs obtained
- Congressional Fuel Cell EXPO, May '05
- Special Topic Meeting: Diesel Reforming, June '05
- NETLFuel Processing (UofMN), Alloys/ Metals, Materials Training(UCSB), July '05
- Balance of Plant Training, August '05
- HiTEC Workshop, August '05
- Fuel Cell Seminar, Palm Springs, CA, November '05
  - World's largest fuel cell informational meetings

For More Information on SECA and other Projects Visit www.seca.doe.gov

- CDs can be order from website
- All projects updated in Annual Report
- Annual SECA Workshops
- Semi-Annual SECA Core Technology Peer Reviews
- Biennial Fuel Cell Handbook







http://www.netl.doe.gov/dgfuelcells

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Key Activity/Component Funding

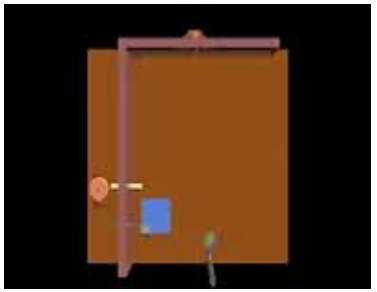
(Thousands of Dollars)

Activity/Component	FY05 Enacted	FY06 President
Advanced Research	11,236	0
Fuel Cell Systems	2,525	0
Vision 21 Hybrids	4,700	0
Innovative Concepts	50,298	60,500
Novel Generation	2,730	0
Other[1]	5,897	4,500
Total	77,386	65,000

Note[1] Hq, SBIR/STTR, DCAA, Contractor Support, Outreach, etc.

General Electric
FY05 – ePME Milestones

- Prepare, for DOE review and approval, a prototype test plan to evaluate performance against SECA Phase I minimum technical requirements. **(1Q/05)**
- Incorporate DOE comments into test plan. **(2Q/05)**
- Initiate cost analysis report for high volume production of Phase I prototype design. **(3Q/05)**
- Initiate Phase I prototype qualification testing. **(4Q/05)**



Conceptual Design

- **Contribution to Cost and Performance Targets**
  - Start 10/1/01- End 9/30/11
  - 5 kW Planar SOFC Stationary
    - >40% Efficiency on NG stationary
  - **Most Hybrid Interest**
    - Effects and issues related to scale-up, pressurization, aggregation are being explored
    - 12-3/4” diameter cells fabricated and tested

Delphi
FY05 – ePME Milestones

- Conduct initial lab testing of Development SOFC System (semi-integrated system) **(1Q/05)**
- Assembly Generation 3 stack subsystem for testing. **(2Q/05)**
- Initiate fabrication of Demonstration System A stacks. **(3Q/05)**
- Perform quality assurance functions in preparation for lab testing of Demonstration System A. **(4Q/05)**

Generation 1 SOFC APU
155 Liters, 204 kg

Generation 2 SOFC APU
60 Liters, 70 kg

Contribution to Cost and Performance Targets

- **Start 7/1/02- End 12/31/11**
- 3 - 5 kW SOFC Power Unit
- Stationary and transportation APU markets
- CPOX or endothermic reforming of gasoline or natural gas
- >40% efficiency NG residential

Generation 3 SOFC APU
Under Development

Cummins
FY05 – ePME Milestones

- Fabricate proof-of-concept reformer. **(1Q/05)**
- Test the control system readiness for proof-of-concept system. **(2Q/05)**
- Prepare test facility for test of pre-prototype proof-of-concept system. **(3Q/05)**
- Report initial proof-of-concept test results. **(4Q/05)**

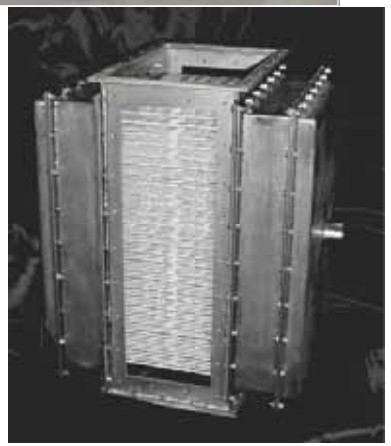
Two 55-cell Stacks

Contribution to Cost and Performance Targets

- **Start 1/1/02 - End 12/31/11**
- 6 kW Planar SOFC APU
- Reforming on natural gas and propane for approximately 2,000h
- 10:1 Turndown
- 2 Stacks, 110 cells, 6”x6”
- Largest manufacturer of generators to RV market

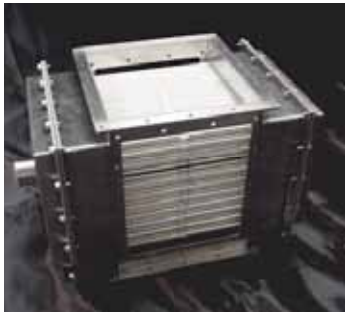
Acumentrics Corporation
FY05 – ePME Milestones

- Demonstrate effectiveness of a Blasch ceramic heat exchanger. **(1Q/05)**
- Test and evaluate power gain from anode improvements. **(2Q/05)**
- Investigate approaches to reduce tube drying time. **(3Q/05)**
- Prepare draft test plan and operating documentation for SECA Phase I prototype. **(4Q/05)**



Contribution to Cost and Performance Targets

- **Start 7/28/03 - End 1/31/12**
  - 2-10 kW Tubular SOFC
  - NG, Propane & Diesel for stationary and APU markets
  - Rapid start-up
  - 40% Efficient NG
  - 800C



Siemens Westinghouse
FY05 – ePME Milestones

- Conduct test of YSZ electrolyte based high power density cell at high fuel utilization and 1000 °C. **(1Q/05)**
- Assess various HPD cell designs for alpha (pre-prototype) unit. **(2Q/05)**
- Conduct experiments to quantify extent of power density and stability improvements. **(3Q/05)**
- Select key design features for the alpha (pre-prototype) unit. **(4Q/05)**

Contribution to Cost and Performance Targets

- **Start 9/1/02 - End 8/31/12**
- 3-10 kW Planar SOFC Stationary/APU/Military
- 5-7kW, >40% Efficiency on NG, internal reforming stationary
- 3-10kW APU on gasoline or diesel

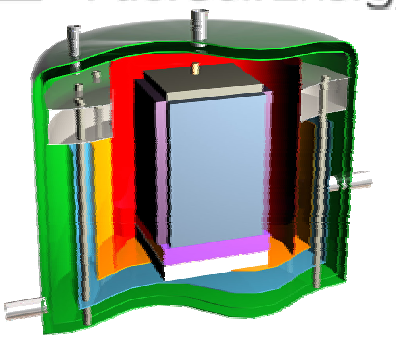
At half the length, the seal-less planar cell will produce 50% more power.

5kW Prototype

Innovative Concepts – SECA Industry

(60% funding for Industry)

FuelCell Energy



DELPHI
Driving Tomorrow's Technology

Battelle

General Electric Company

SIEMENS
Westinghouse

Acumentrics
Advanced Power & Energy Technologies

Cummins Power Generation

SOFCo

NETL

FuelCell Energy, Inc
FY05 – ePME Milestones.

- Conduct trade-off analysis for cell area, number of cells per stack against the power conditioning design. **(1Q/05)**
- Initiate large area cell evaluation. **(2Q/05)**
- Review preliminary design of multi-stack module. **(3Q/05)**
- Initiate procurement of long-lead BOP components for the 1st prototype. **(4Q/05)**

Contribution to Cost and Performance Targets

- **Start 2/27/04 - End 2/26/13**
- 3-10 kW Planar SOFC Generator
- Natural Gas for stationary markets
- Propane & Diesel for remote and transportation markets

80-Cell Tower (Peak Power: 3.5 kW DC)

Fuel Cell Systems (FCE)

- **Contribution to Cost and Performance Targets**
  - Operational data from FCE hybrid to be used to further SECA/FCCBS hybrid development
    - resolution of hybrid integration issues
    - provide critical data which identifies the areas and plans for further integration, simplification, control, cost reductions and performance improvements for subsequent hybrids
  - Input from design and testing of Alpha unit will result in field testing of beta-unit MCFC Hybrid in Montana during FY06 for 303 kW with 56.3% efficiency LHV gas and 3,000 hours testing planned from January to June

Vision 21 Hybrids
FY05 – ePME Milestones

- Assess SOFC subsystem sizing and sensitivity analysis for a megawatt-class SOFC-hybrid plant concept **(GE).** **(1Q/05)**
- Assess cell production quality for first CHP125 SOFC plant **(SWPC).** **(2Q/05)**
- Characterize Blasch ceramic materials with matched thermal expansion properties **(SWPC).** **(3Q/05)**
- Initiate assembly of SOFC bundle test to evaluate/qualify selected new design features **(SWPC).** **(4Q/05)**

Note: No Planned Program Activity in FY2006

Contribution to Cost and Performance Targets

- Transition SWPC tubular program entirely to SECA program
- Address technical issues that have stagnated tubular SOFC technology
- Resolve issues at 800 C vs. 1000 C using SECA HPD SOFC

SECA Fuel Cells
Solution for Today & Tomorrow

- ✓ Fossil Fuels Today
- ✓ Hydrogen Tomorrow

Key DG Program Milestones (FY)

Coal --- Red
FutureGen --- Blue
SECA/Fuel Cell Coal-Based Systems --- Black

- **2005** Initial SECA prototypes
- **2005** Select Fuel Cell Coal-Based Systems Teams
- **2008** Aggregatable fuel cell stack test on coal gas
- **2010** SECA $400/kW modules
- **2010** MW-class (>250-kW) aggregated, $400/kW fuel cell module test on coal gas at NETL/PSDF
- **2011-2015** MW-class scaleable fuel cell or fuel cell /hybrid on coal at 50% HHV efficiency at FutureGen (Testing FY2013-2015)
- **2018-2020** Test MW-class hybrid system on coal at 60% efficiency (CCPI)
- **2020** 100 MW-class fuel cell systems