NATIONAL ENERGY TECHNOLOGY LABORATORY

9^{TH} Annual SECA Workshop
Clean Economic Energy in a Carbon Challenged World

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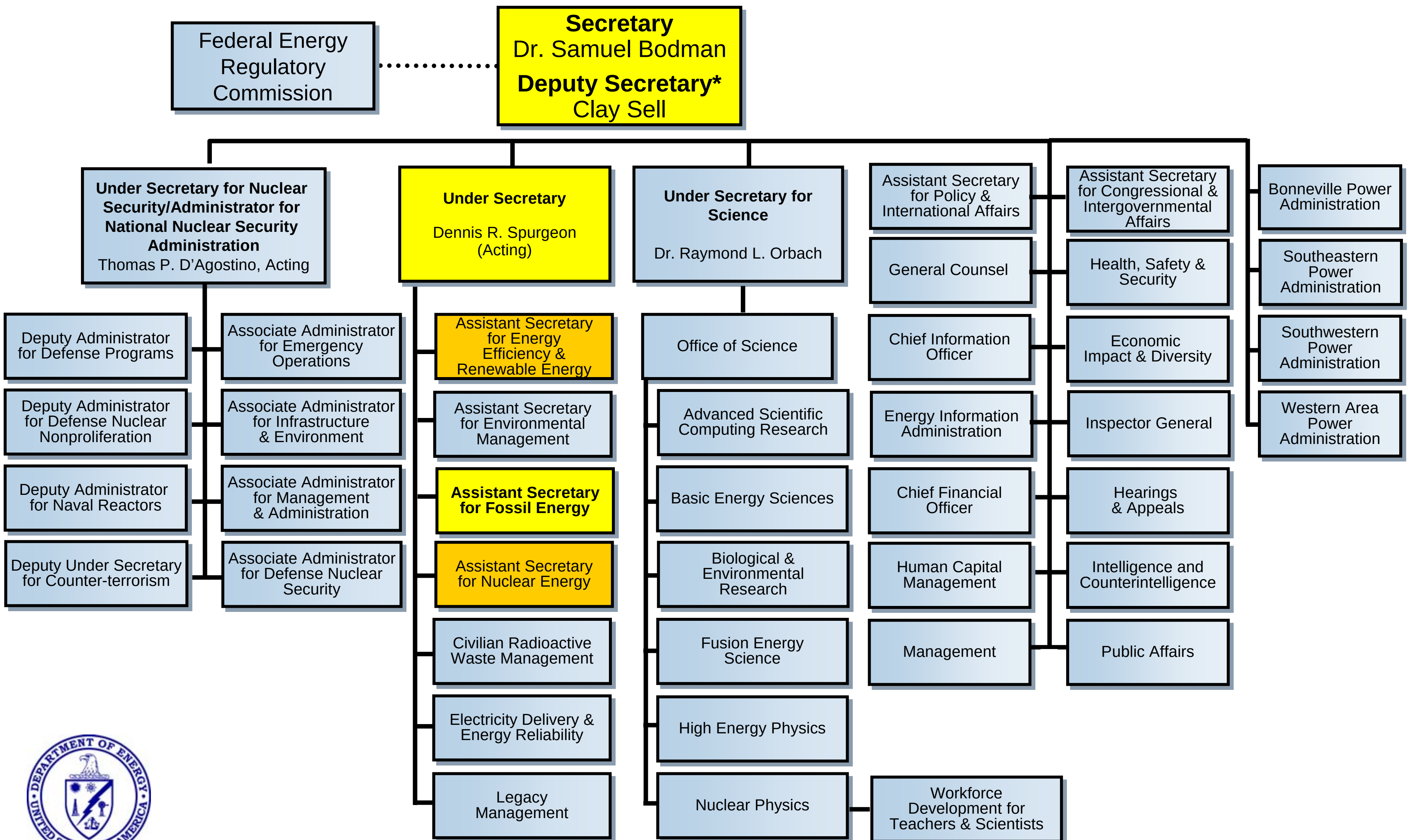
Strategic Center for Coal

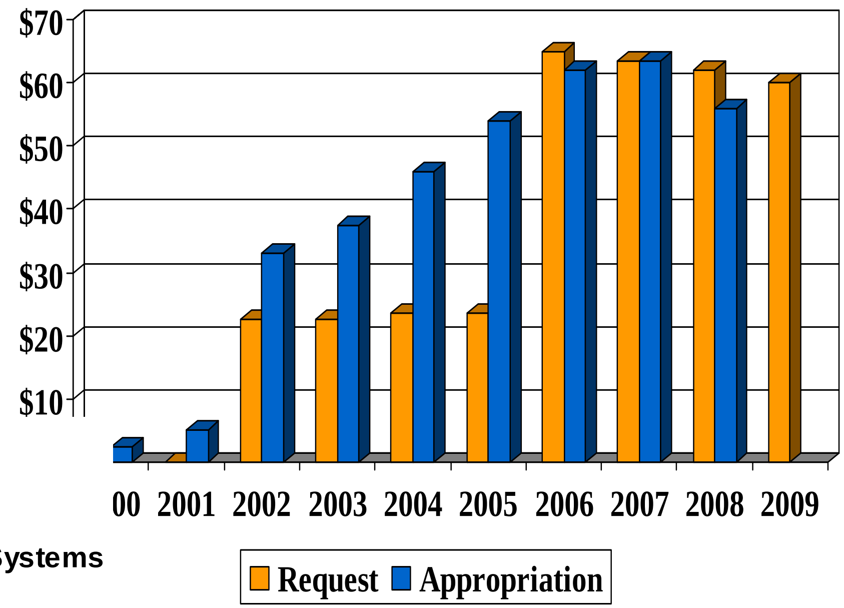
United States Department of Energy

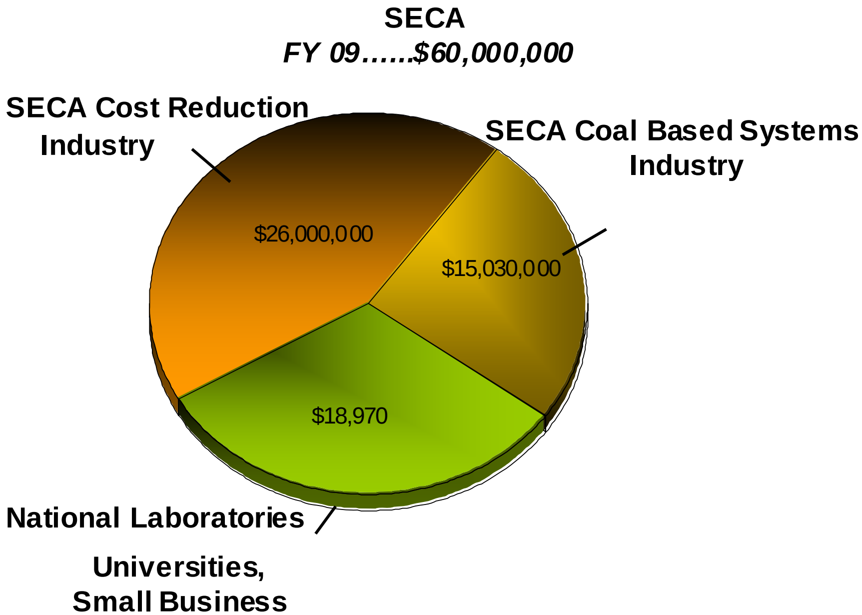
30SEPTEMBER08, International Pittsburgh Coal Conference, Pittsburgh, PA

Department of Energy



FY 08 Fossil Energy Fuel Cell Program (SECA)





DOE's Office of Fossil Energy
Advanced (Coal) Power Systems Goals

- **2010:**
  - **45-50% Efficiency (HHV)**
  - **99% SO_2 removal**
  - **NOx< 0.01 lb/MM Btu**
  - **90% Hg removal**
- **2012:**
  - **90% CO_2 capture**
  - ***<10% increase in COE with carbon sequestration***
- **2015**
  - **Multi-product capability (e.g, power + H_2)**
  - **60% efficiency (measured without carbon capture)**

Solid State Energy Conversion Alliance Goals

Stack Cost ~ $100/kW stack

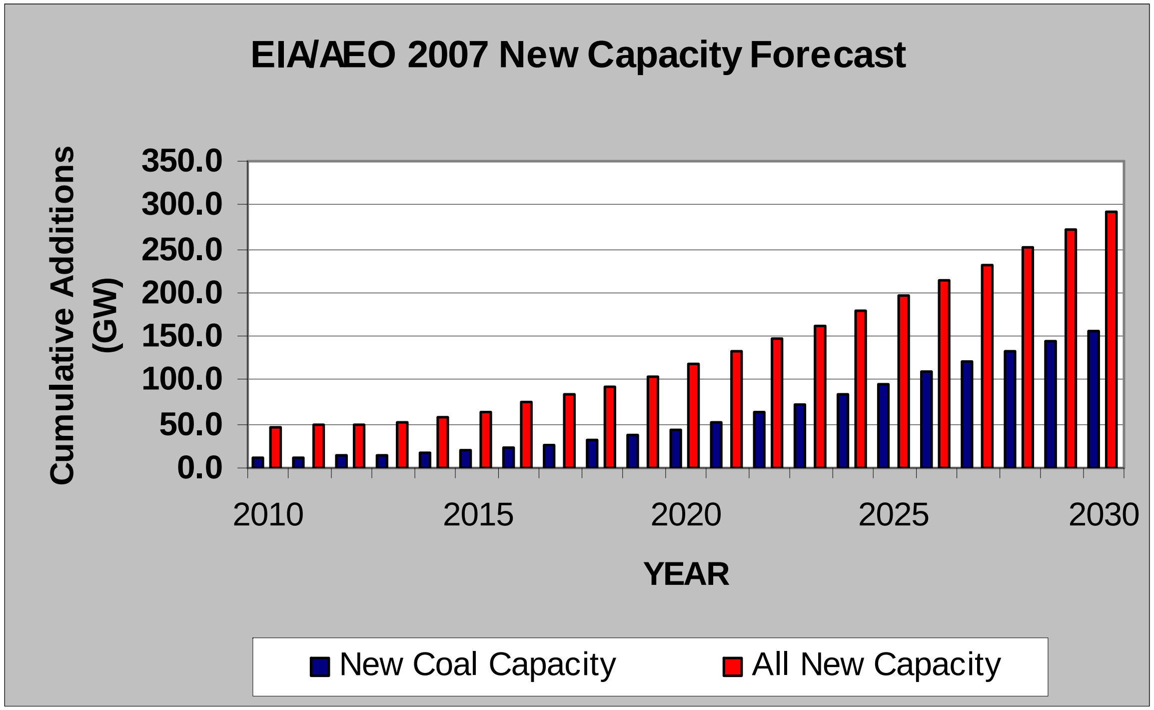
Capital Cost < 400/kW system

Maintain Economic Power Density with Increased Scale ~ 300mW/cm2

Ref: 2002

Mass customization – stacks used in multiple applications….large and small systems

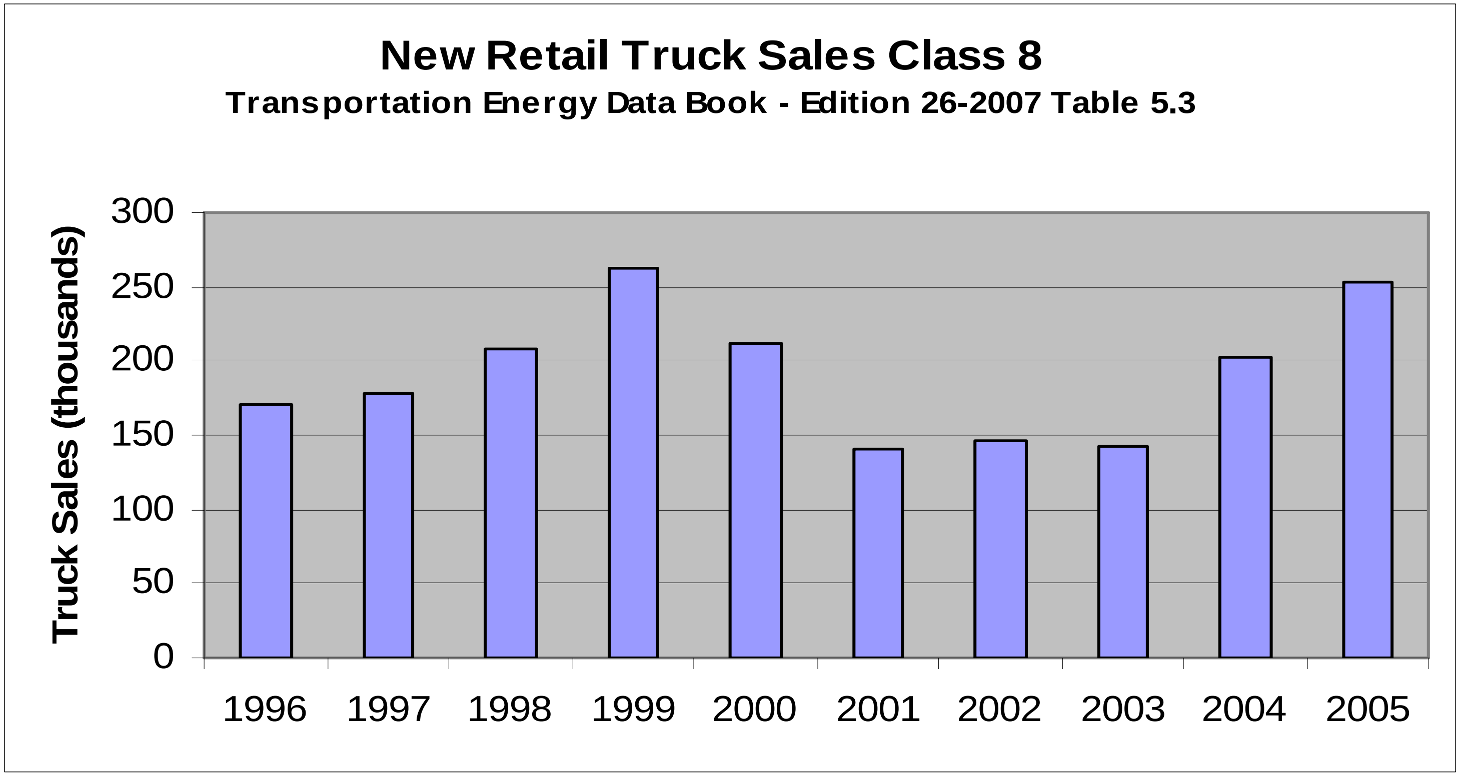
How Big are the U.S. Markets?
Coal



SECA Fuel Cells available for installation in 2018
New Coal Capacity, 2018 – 2030…….110 GW
Average SECA Fuel Cell Production …. 9.2 GW/yr

EIA Annual Energy Outlook (AEO) for 2007 pp. 82-83

How Big are the U.S. Markets? Overnight Trucks



Average Size of a Truck APU – 5kW

Average Annual Production – 200,000 units

Average SECA Fuel Cell Production…. 1 GW/yr

SECA Fuel Cells in DOD Applications

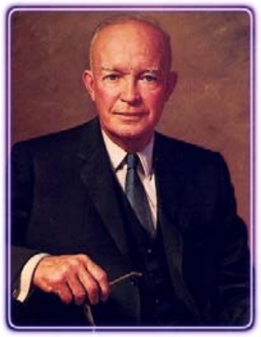
- **DOD Requirements**
  - Extend mission length
  - Quiet
  - Combined functions – power, heat and water
  - ***Volume and weight***
    - Operate with High Specific Energy Fuels – Liquids
- **DOE's power density targets (based on cost) minimize stack size and volume to diminishing returns. Specialized DOD designs will not increase gains.**
- **Further size and weight improvements – Focus on the Balance of Plant**

Atoms for Peace 1953

***October 22, 1953*:** The Atomic Energy Commission announces that an AEC-owned demonstration power plant of 60 MW will be built at Shippingport, PA, jointly by Westinghouse Electric Corporation and Pittsburgh's Duquesne Light Company under the direction of the **U.S. Navy/AEC Naval Reactors Branch.**

The more important responsibility of this atomic energy agency would be to devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind. Experts would be mobilized to apply atomic energy to the needs of agriculture, medicine and other peaceful activities. A special purpose would be to provide abundant electrical energy in the power-starved areas of the world.

Dwight D. Eisenhower, President of the United States of America,
to the 470th Plenary Meeting of the United Nations General Assembly Tuesday, 8 December 1953



Photograph of the Shippingport Atomic Power Station in Shippingport, Pennsylvania, the first full-scale nuclear power generating station in the United States which began operating in 1957.

Clean Coal Power Initiative

"More than half of the electricity generated in America today comes from coal. If we weren't blessed with this natural resource, we would face even greater [energy] shortages and higher prices today. Yet, coal presents an environmental challenge. So our plan funds research into new, clean coal technologies."

President George W. Bush

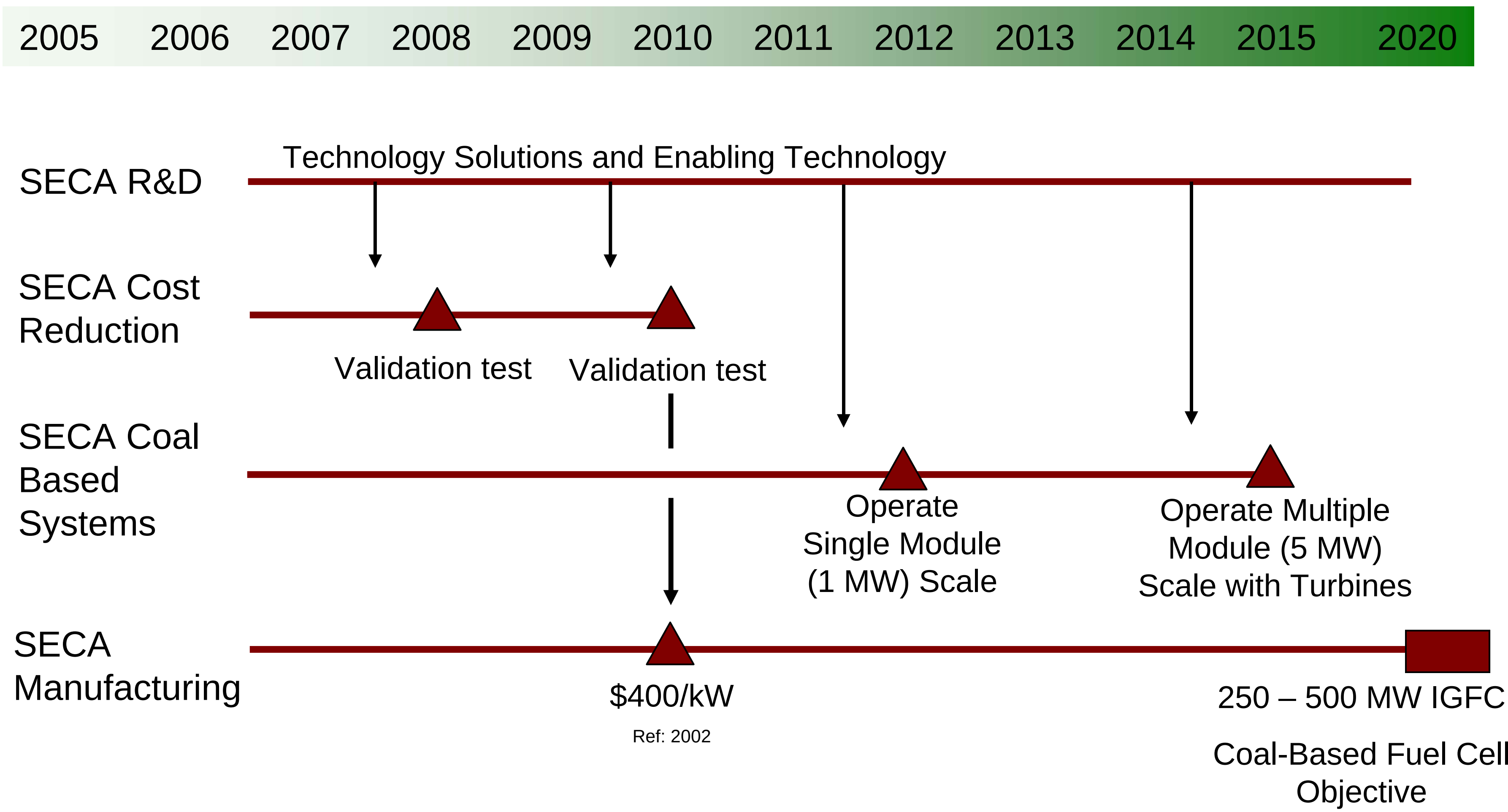
May 17, 2001

"...we're creating the National Climate Change Technology Initiative...to fund demonstration projects for cutting-edge technologies, such as fuel cells."

President George W. Bush

June 11, 2001

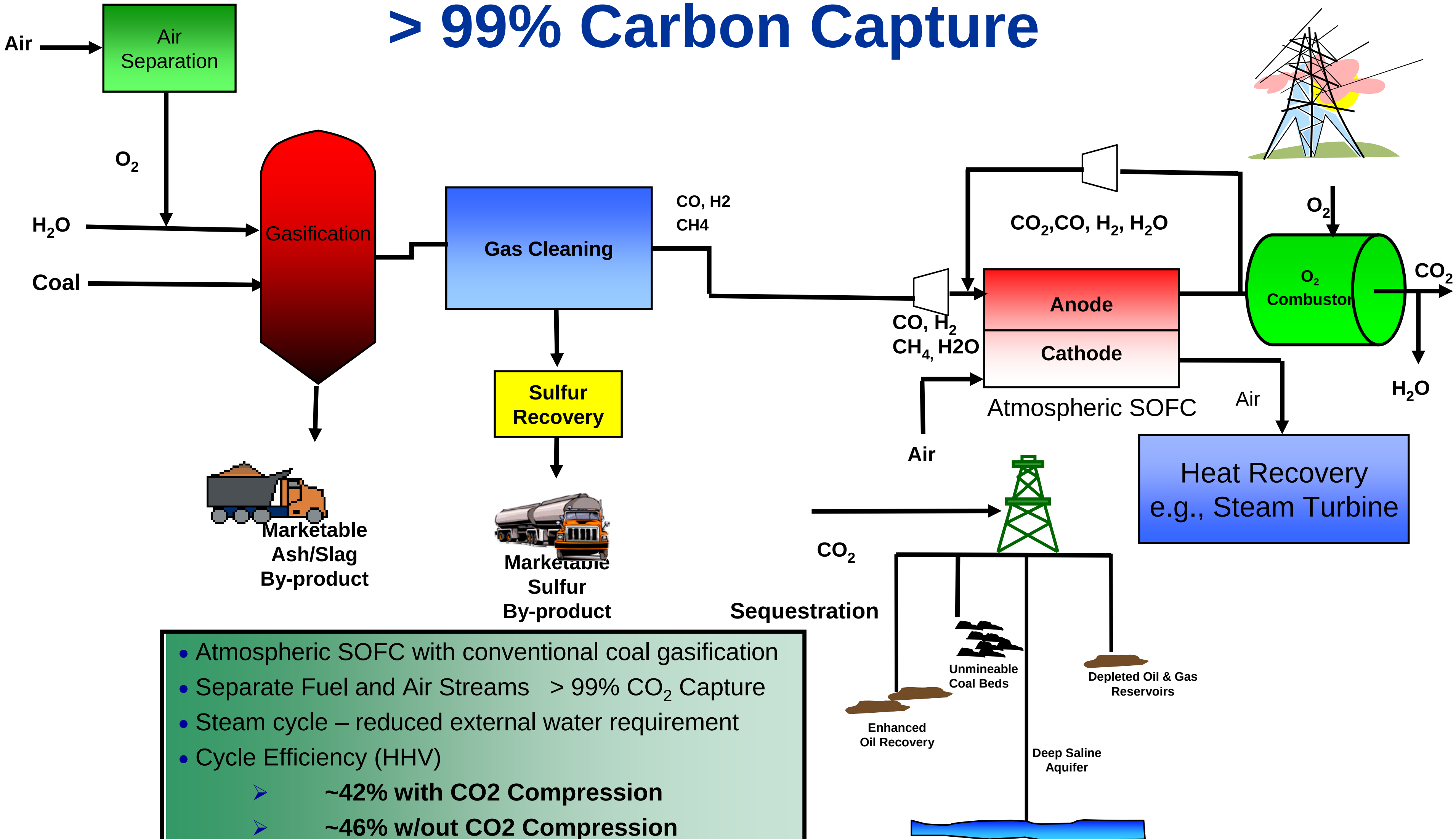
Solid State Energy conversion Alliance (SECA) Fuel Cells Technology Timeline



Impact of Efficiency on COE

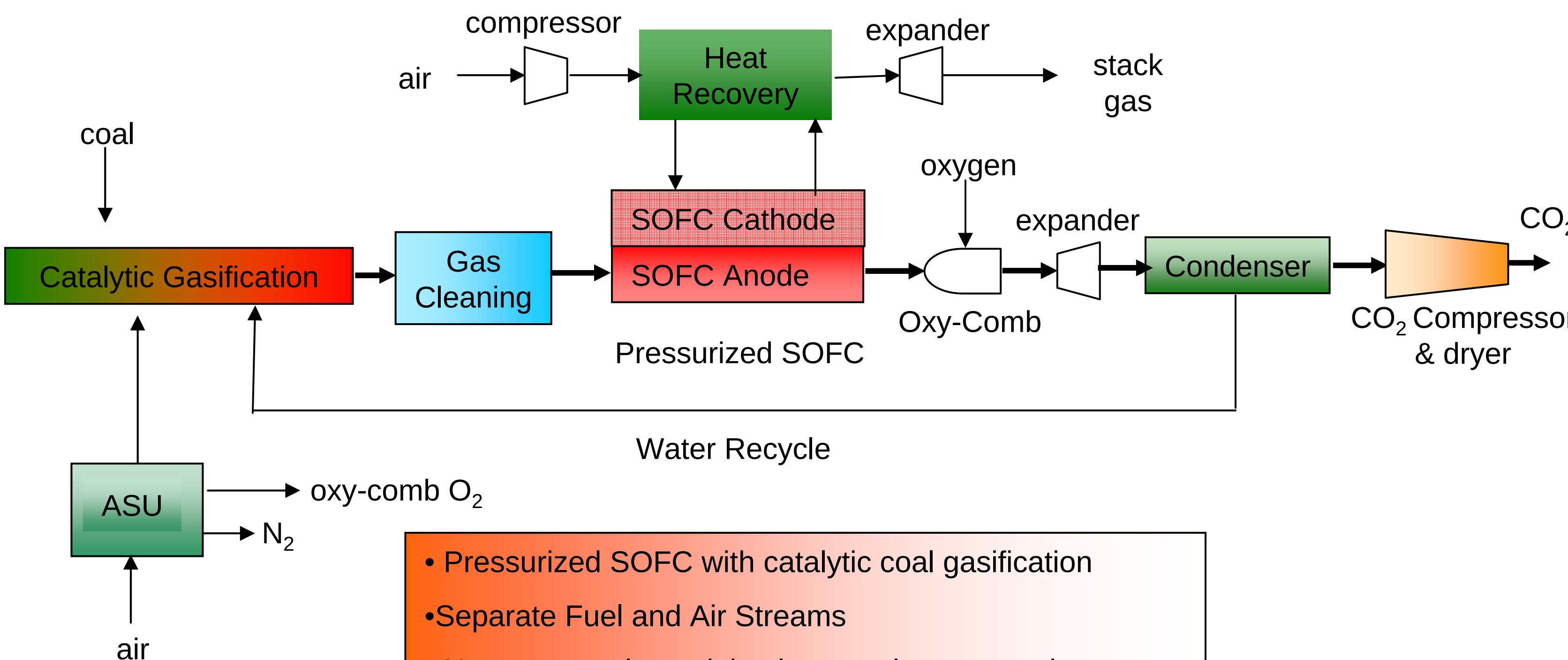
Advanced Power Systems With CO2 Capture, Compression and Storage				
	PC Baseline	IGCC Baseline	IGFC Atmos.	IGFC Press.
Efficiency HHV (%)	27.2	32.5	42.8	57.3
Capital Cost $/kW	2,870	2,390	1,991	1,667
Steam Cycle % Power	100	37	26	2
Cost-of-Electricity ¢/kW-hr	11.6	10.6	8.5	7.3

SECA Coal Based Systems (IGFC) Reduced Water Requirement > 99% Carbon Capture



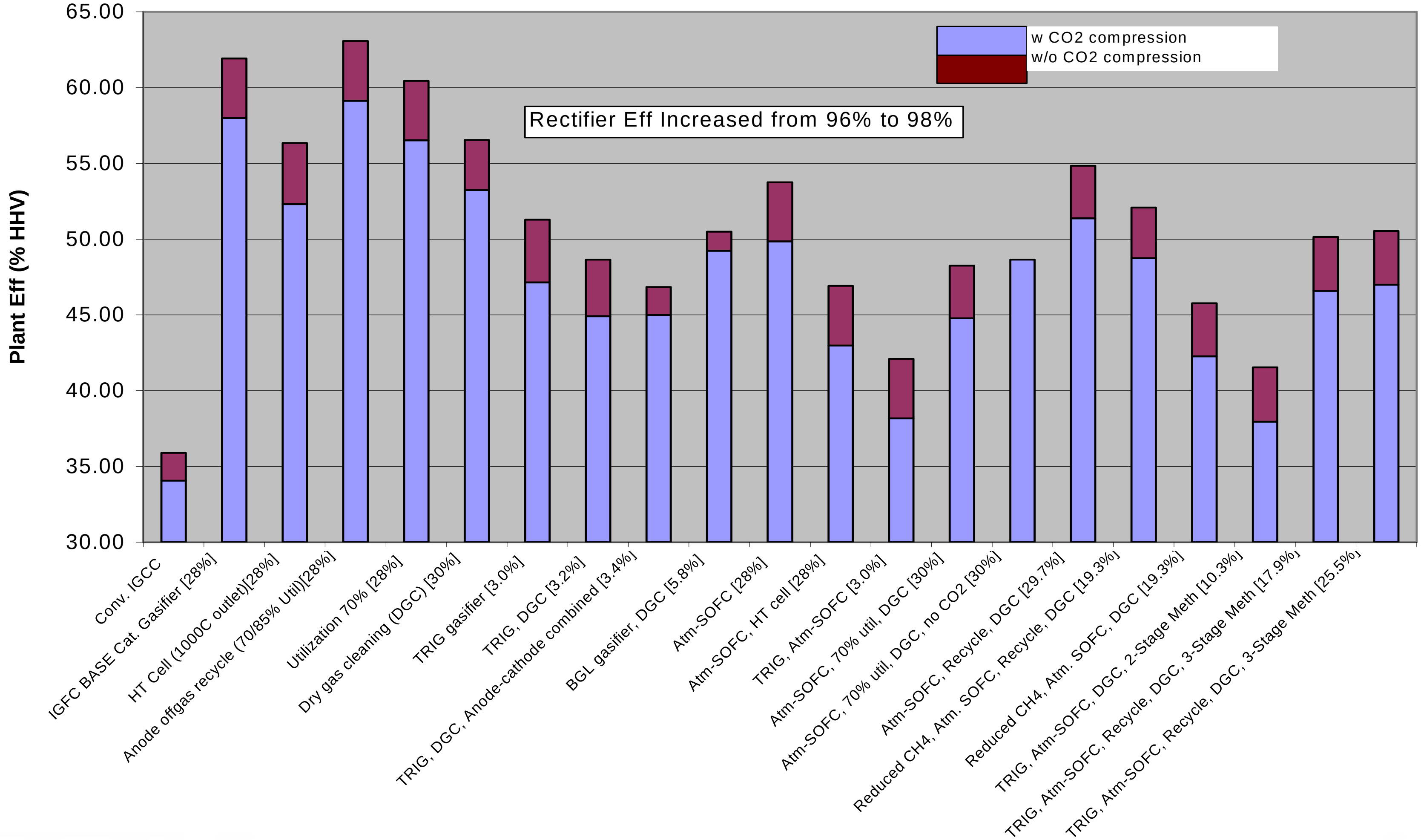
- Atmospheric SOFC with conventional coal gasification
- Separate Fuel and Air Streams > 99% CO_2 Capture
- Steam cycle – reduced external water requirement
- Cycle Efficiency (HHV)
  - **~42% with CO2 Compression**
  - **~46% w/out CO2 Compression**

Advanced SECA Coal Based Systems
Minimal Water Requirement
> 99% Carbon Capture



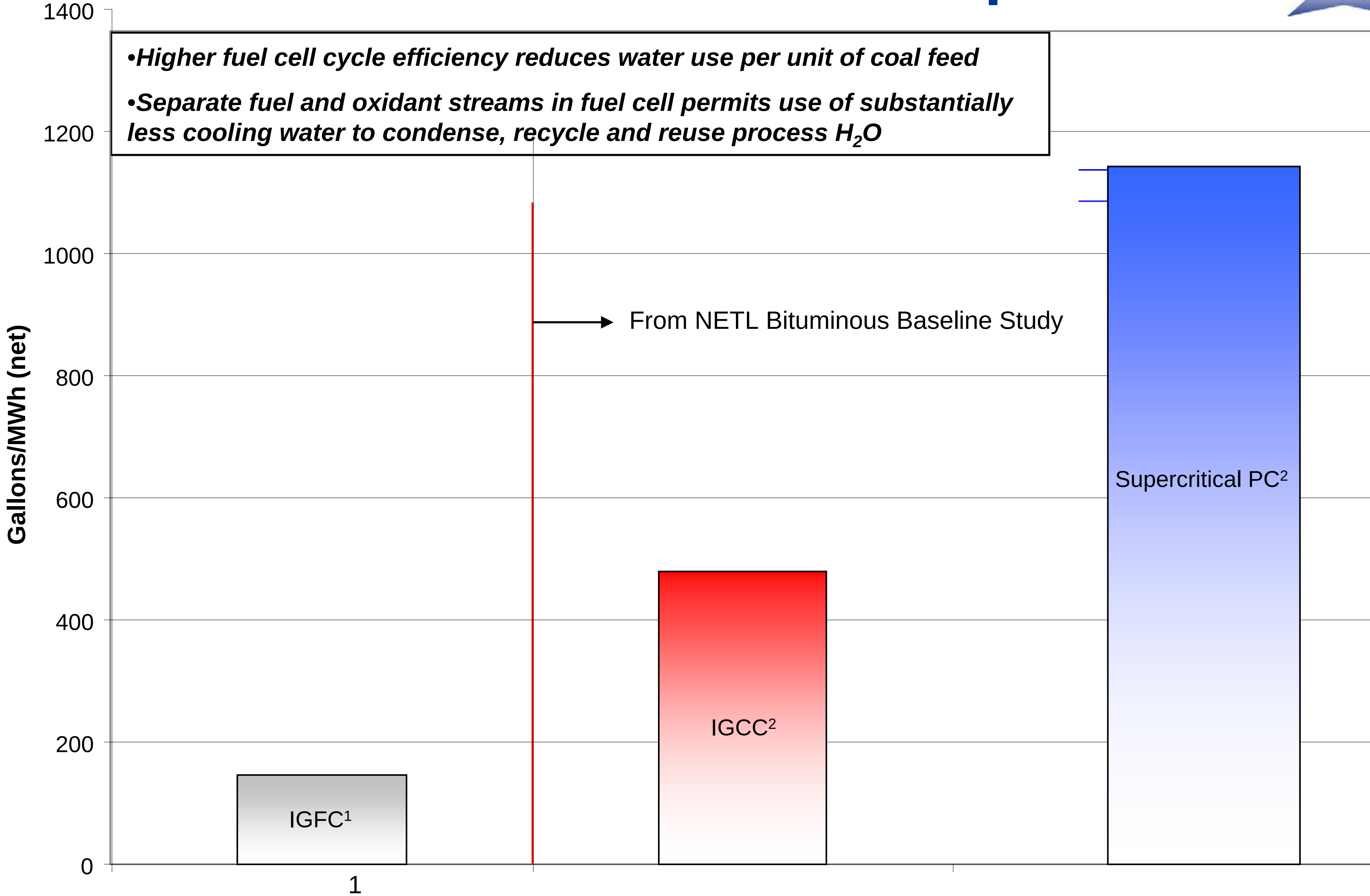
- Pressurized SOFC with catalytic coal gasification
- Separate Fuel and Air Streams
- No steam cycle – minimal external water requirement
- Cycle Efficiency (HHV)
  - **~56% with CO2 Compression**
  - **~60% w/out CO2 Compression**

Integrated Gasification Fuel Cell IGFC System Efficiencies



Raw Water Withdrawal Comparison

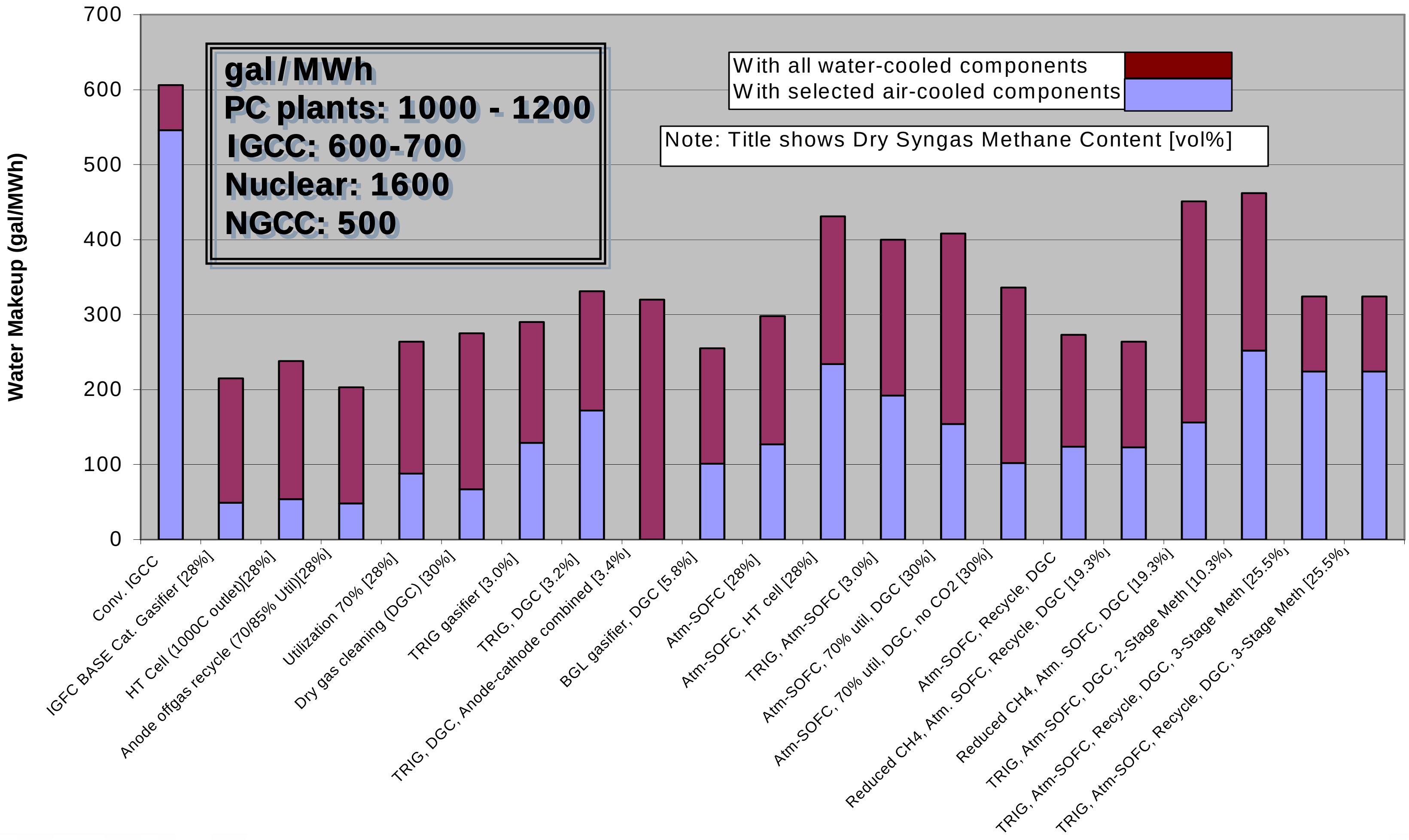
- *Higher fuel cell cycle efficiency reduces water use per unit of coal feed*
- *Separate fuel and oxidant streams in fuel cell permits use of substantially less cooling water to condense, recycle and reuse process H_2O*



[1] System includes 100% carbon capture and CO_2 compression to 2,215 psia
[2] System includes 90% carbon capture and CO_2 compression to 2,215 psia

IGFC Plant Water Makeup

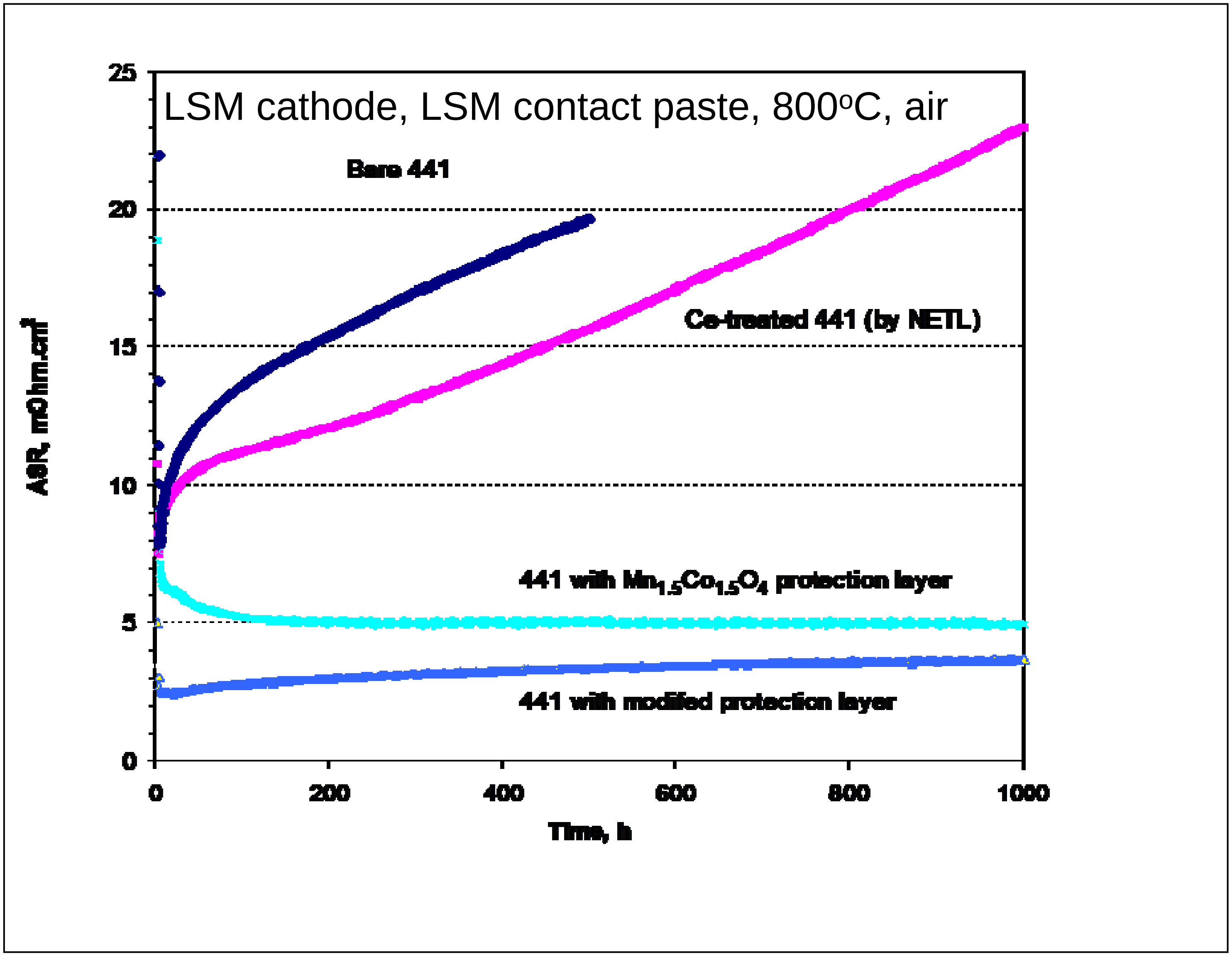
SECA



Current Priorities:
SECA Core Technology Program

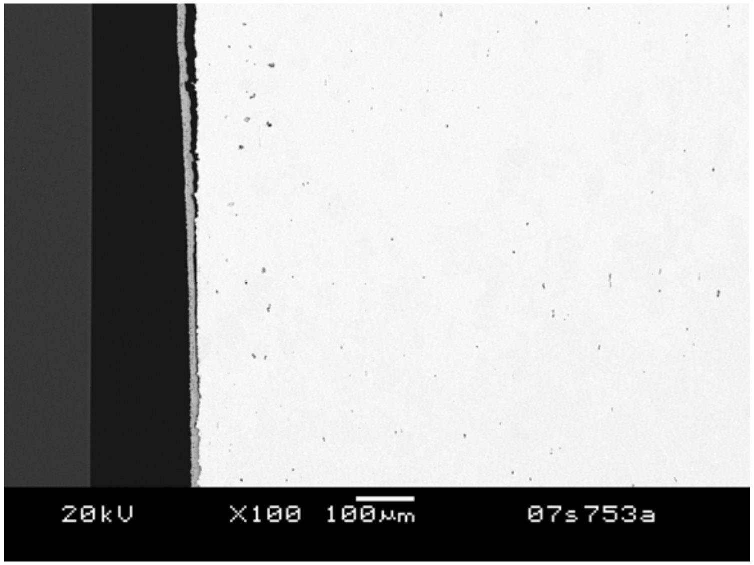
1	Gas Seals	▪ Compliant Seal - Self-Healing Materials ▪ High Temperature Seal – Monolithic Structure
1	Cathode Performance & Stability	▪ Surface Dissociation – Mobility-Surface Modification ▪ In-Situ/Ex-Situ Correlation ▪ Impact of Potential ▪ Solid-State Understanding - Mechanism ▪ Integrated Cathode Studies ▪ Electrode to Interconnect Interface – Contact Material
1	Structural Analysis	▪ Design Basis –Material Data, Analysis & Failure Modes ▪ Design Tools – Engineering Design ▪ Transients- Control System ▪ Manufacturing Tolerances- Cost ▪ Thermal Profile and Gradients – Structure
2	Interconnect	▪ Alloy – Composition – Cost ▪ Coatings ▪ Electrode to Interconnect Interface - Contact Material
2	Anode / fuel processing	▪ Purity Requirements - Fuel ▪ Characterize thermodynamics/kinetics - Contaminants ▪ Multi-component catalysts ▪ Carbon & Sulfur Strategy
2	Heat Exchangers/ High Temperature Blowers	▪ Cost and reliability

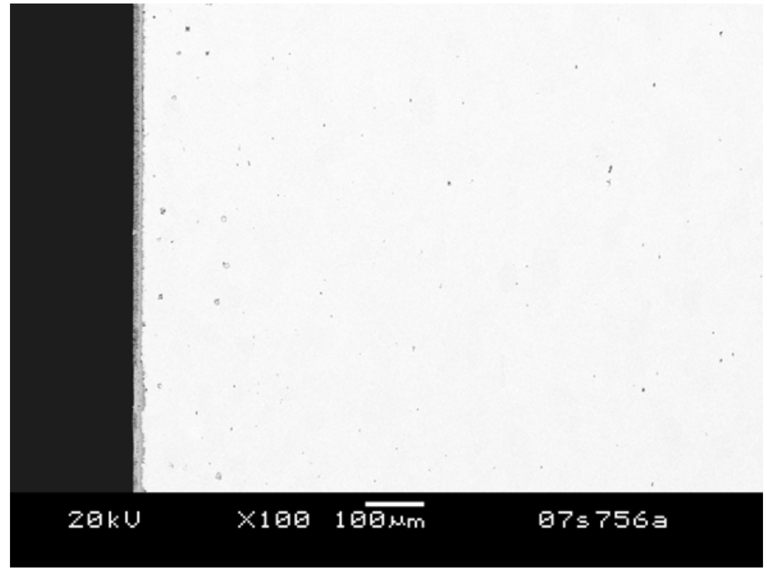
Electrical Performance of Surface Treated 441

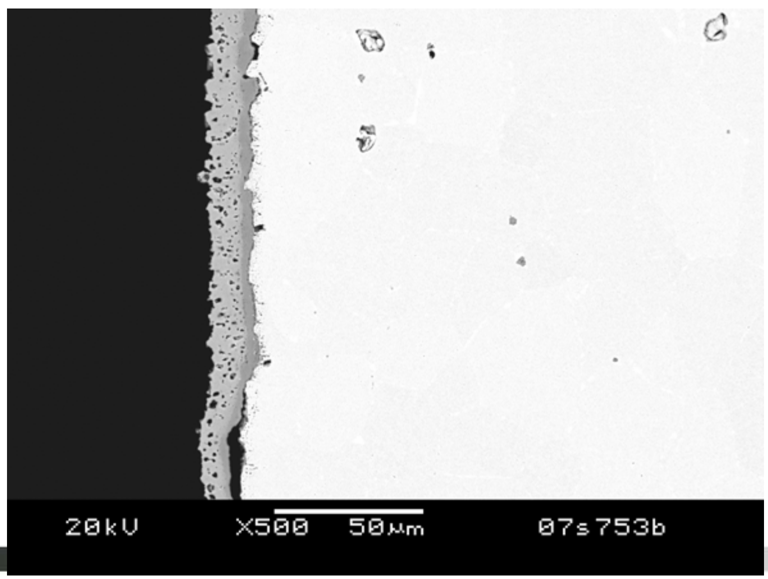


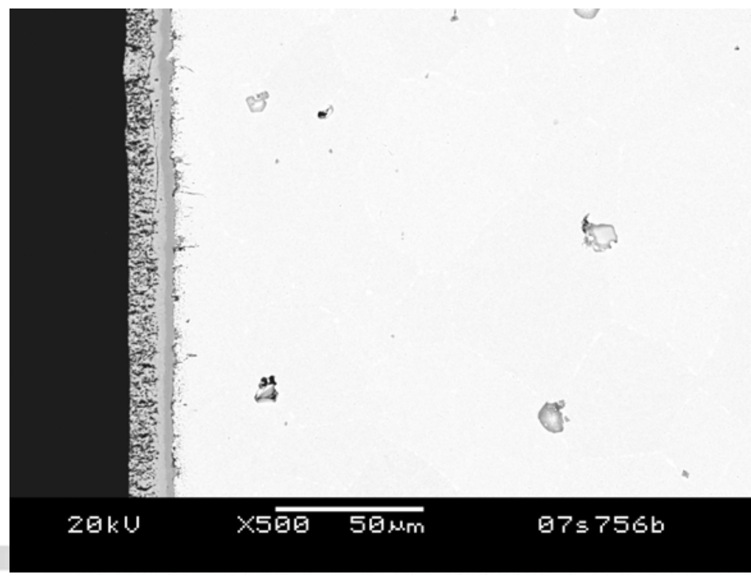
Improved Scale Adherence with Modified MC Coatings

850ºC, 900 hours, air









Original MC spinel

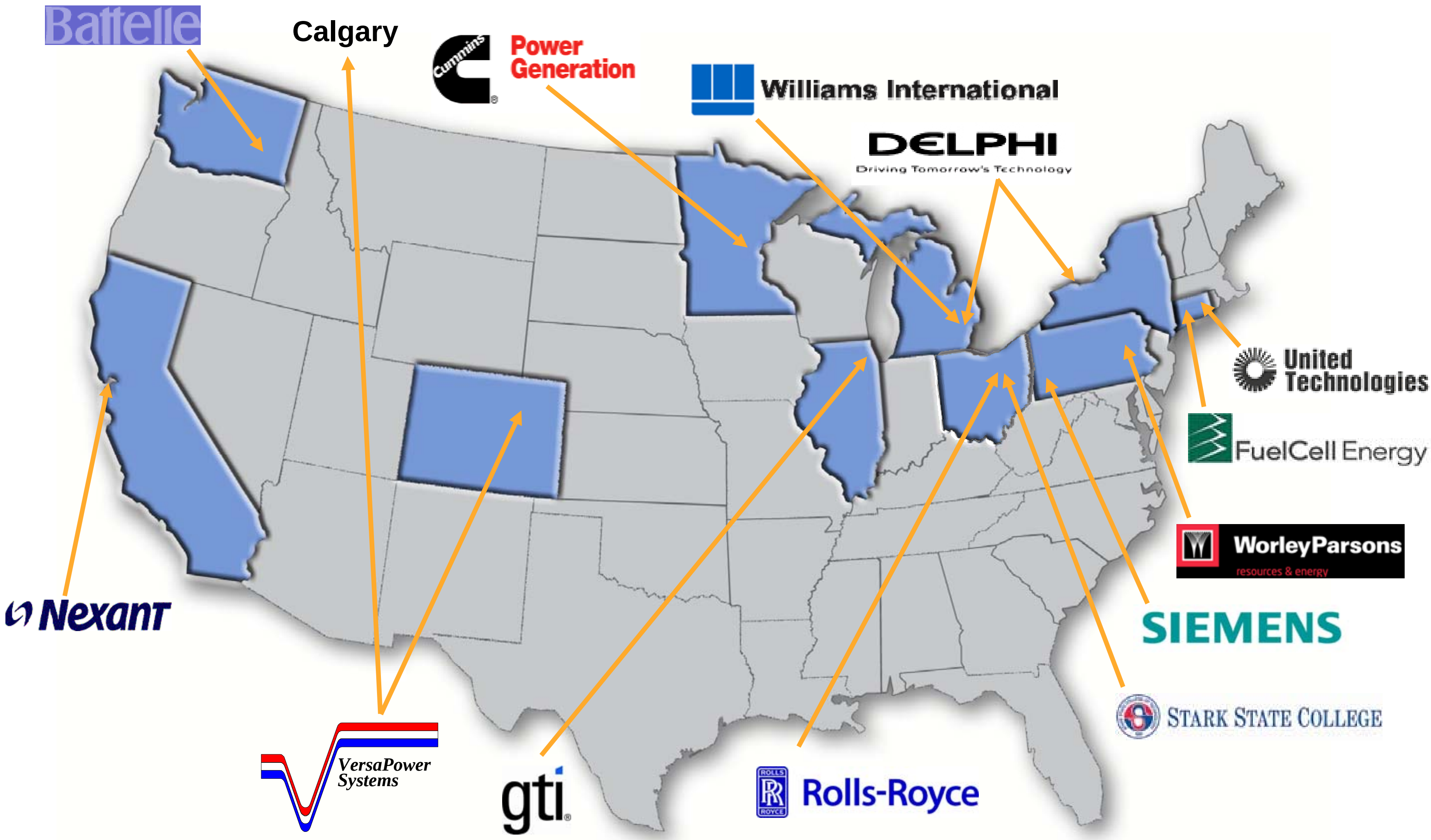
Ce-MC spinel – No spallation observed

SECA Industry Teams FY 2001 – FY 2007 Complete

SECA Industry Team	*Location*	*Prototype*	*NETL Validation*
General Electric	Torrance, CA	Complete	Pass
Delphi	Rochester, NY	Complete	Pass
Fuel Cell Energy	Calgary, BC	Complete	Pass
Acumentrics	Westwood, MA	Complete	Pass
Siemens Power Group	Pittsburgh, PA	Complete	Pass
Cummins Power Gen.	Minneapolis, MN	Complete	Pass

	Size	Efficiency	Degradation	Availability	Cost
Target	3 – 10 kW	35 (LHV)	4%/1,000 hrs	90%	
Aggregate Team Performance	3 – 7 kW	35.4 – 41 %	2%/1,000 hrs	97%	$724 - $775/kW

SECA Industry Teams & Major Subcontractors



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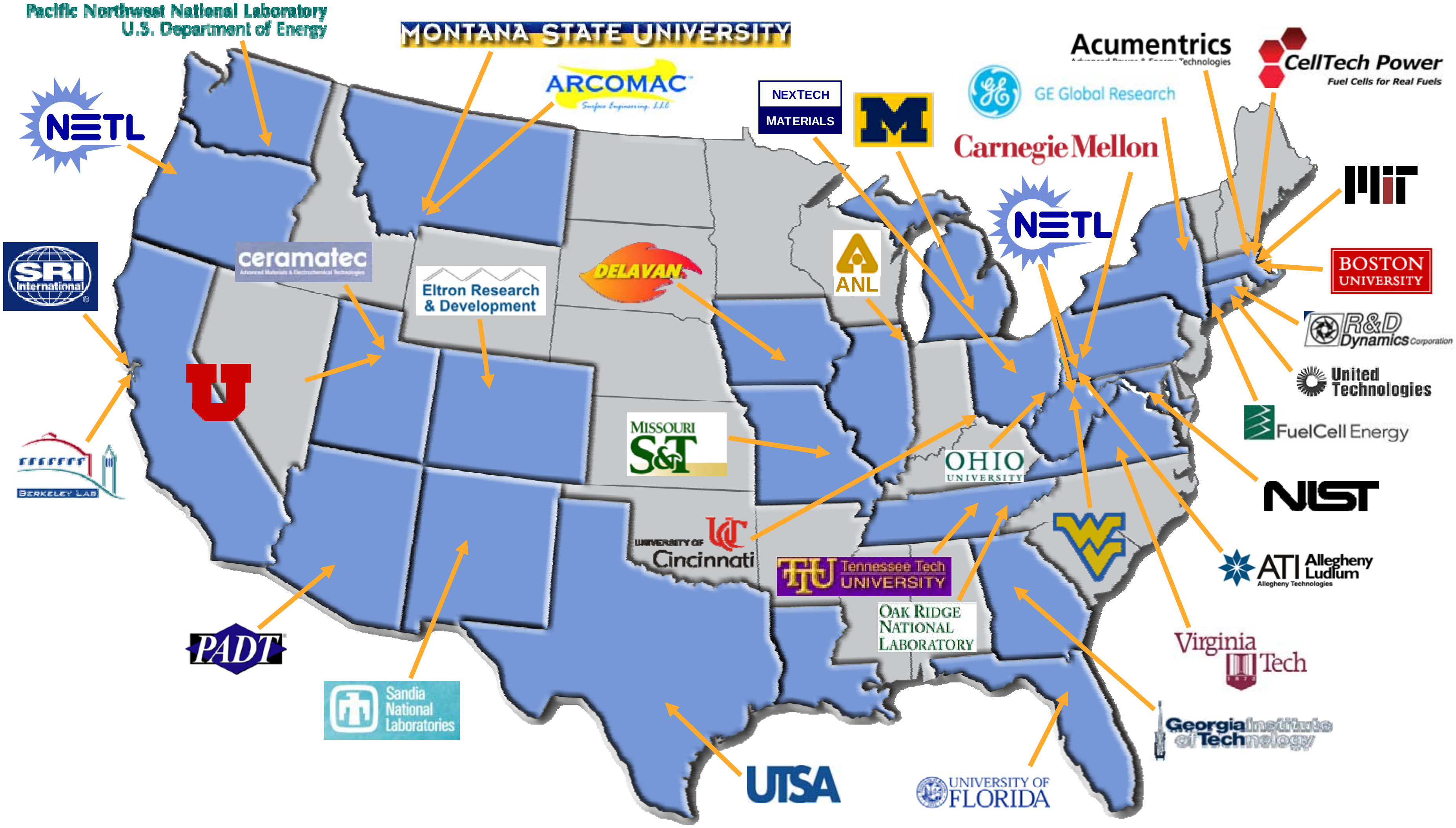
2008 SECA Core Technology & Innovative Concepts



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2008 Peer Review

	Organization	Principal Investigator	Project Type	Score (0 – 5.0)
1	Fuel Cell Energy	Jody D. Doyon	Industry	4.49
2	Delphi Automotive Systems	Steven R. Shaffer	Industry	4.52
3	Santa Clara County	Caroline Judy	Congressional	2.82
4	Siemens Power Generation	Joseph F. Pierre	Industry	4.43
5	Siemens Power Generation	Joseph F. Pierre	Congressional	4.35
6	GE Global Research	Mathew Alinger	Advanced Research	4.19
7	Allegheny Technologies, Inc.	James Rakowski	Interconnects	4.64
8	Oak Ridge National Laboratory	Edgar Laura-Curzio	Material Properties	4.40
9	Pacific Northwest National Laboratory	Matt Chou	Seals	4.59
10	NETL Office of Research and Development	Randall Gemmen	Cathodes	4.52
11	Argonne National Laboratory	Paul Fuoss	Cathodes	4.49
12	Lawrence Berkeley National Laboratory	Steven J. Visco	Contaminants	4.78
13	Georgia Tech Research Corporation	Meilin Liu	Cathodes	4.59
14	University of Michigan	Suljo Linic	Contaminants	4.33
15	Pacific Northwest National Laboratory	Moe A. Khaleel	Modelling	4.53
16	NETL Office of Research and Development	David A. Berry	Fuel Processing	4.62
17	NETL Office of Research and Development	Randall Gemmen	Contaminants	4.60
18	Virginia Tech Polytechnic Institute	Jason Lai	Power Electronics	4.75

For More Information About the DOE Office of Fossil Energy Fuel Cell Program

- **NETL website:**
  - www.netl.doe.gov
- **Office of Fossil Energy website:**
  - [ww.fe.doe.gov](ww.fe.doe.gov)

Reference Shelf

CDs available from the website

- **FE Fuel Cell Program Annual Report _2007**
- **8th Annual SECA Workshop Proceedings** (Coming Soon)
- **Fuel Cell Handbook (7th ed.)**

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