NATIONAL ENERGY TECHNOLOGY LABORATORY

Clean Economic Energy in a Carbon Challenged World

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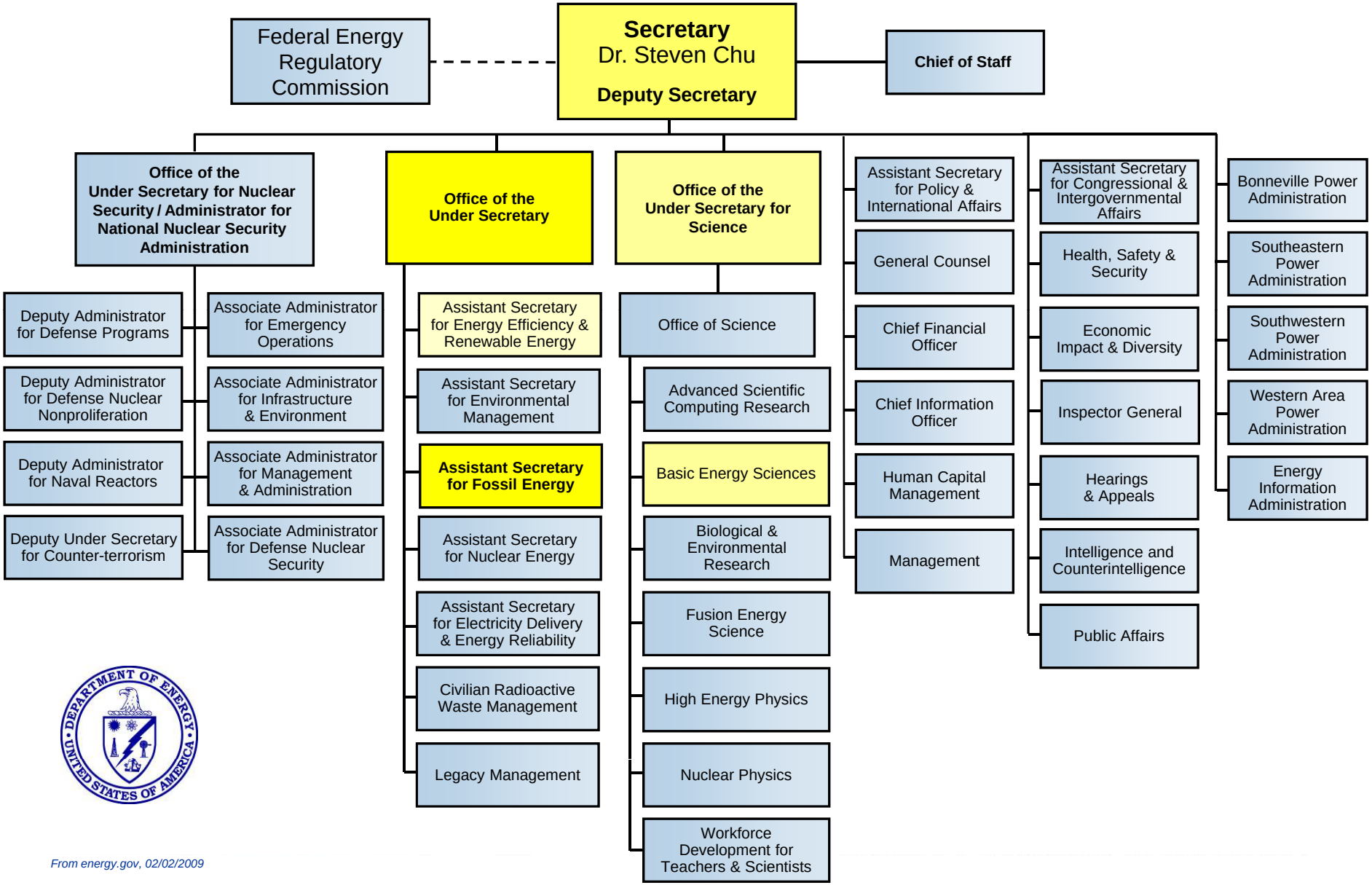
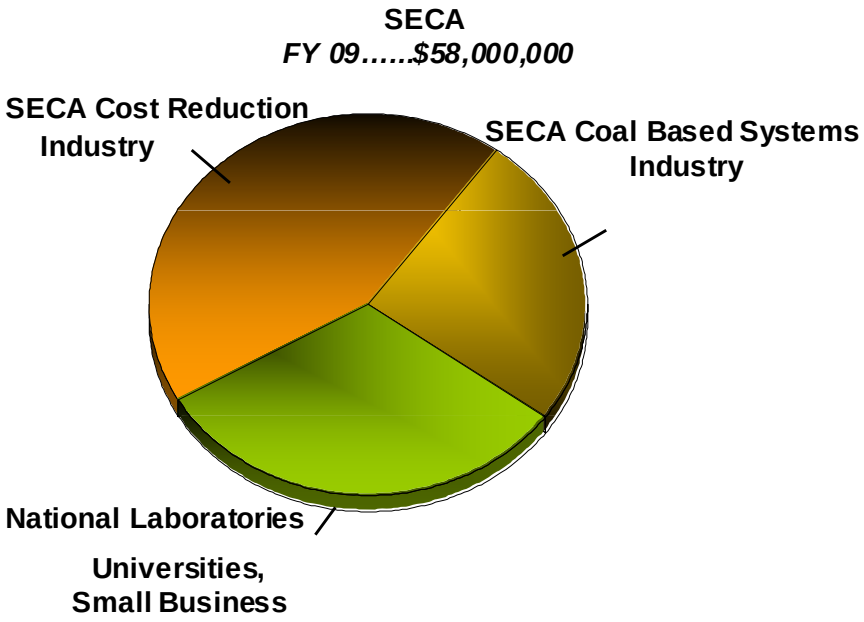
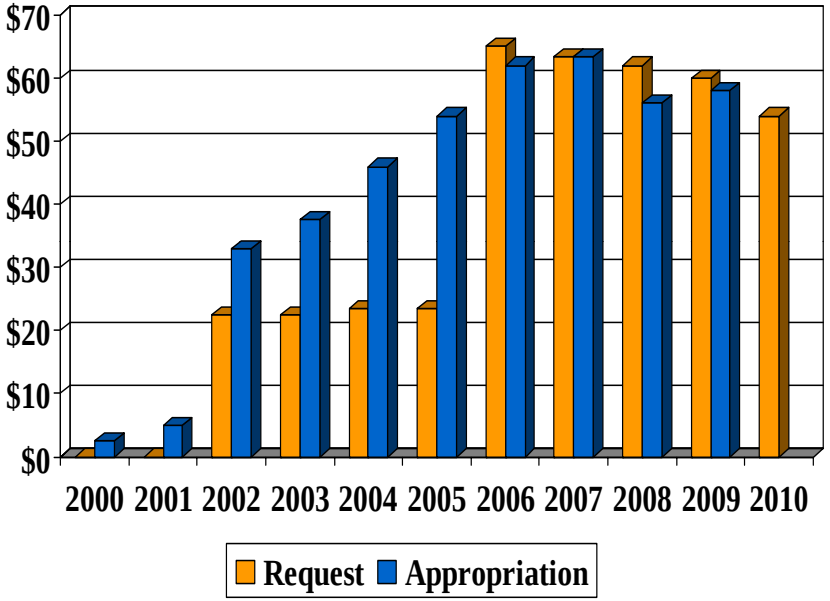
Department of Energy



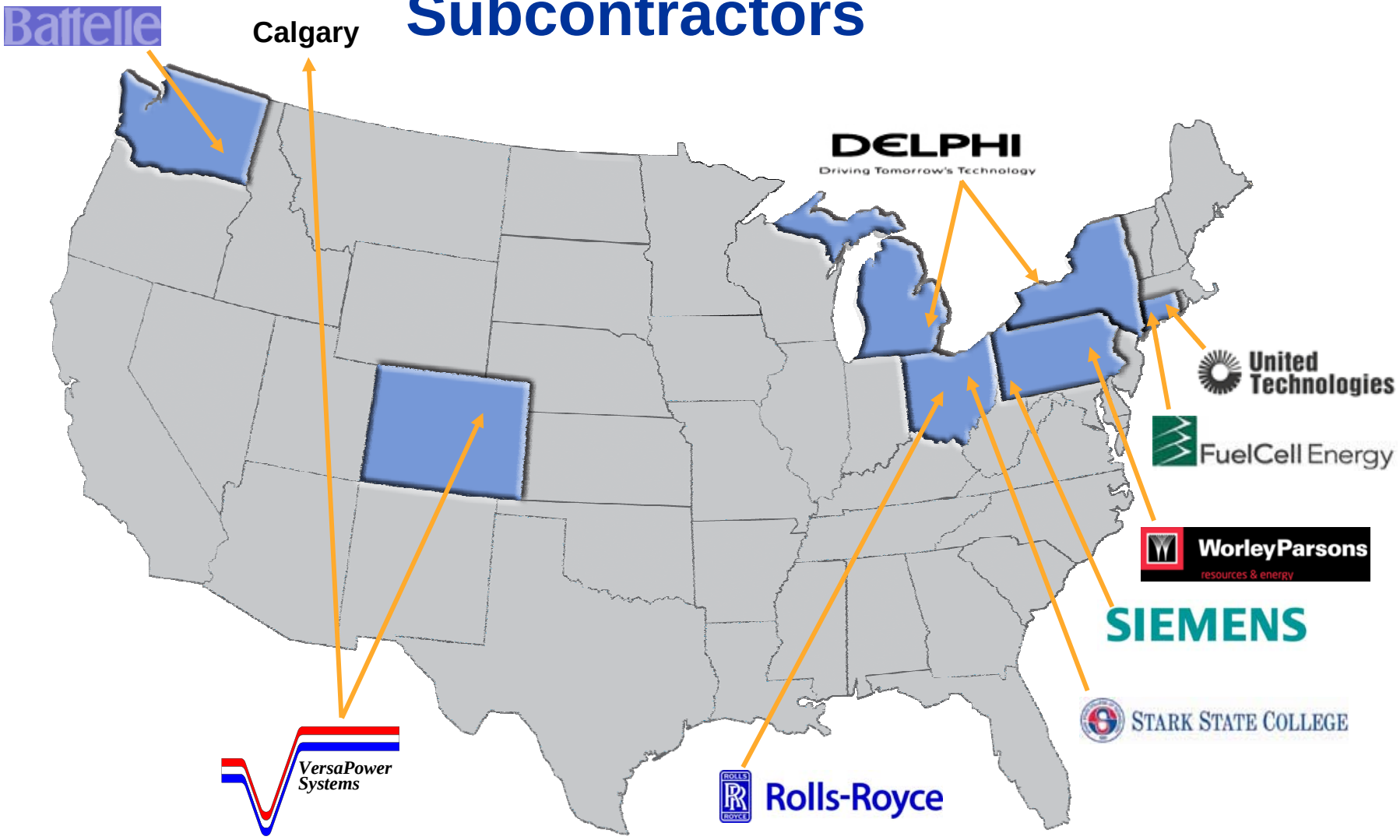
From energy.gov, 02/02/2009

FY 09 Fossil Energy Fuel Cell Program Solid State Energy Conversion Alliance (SECA)

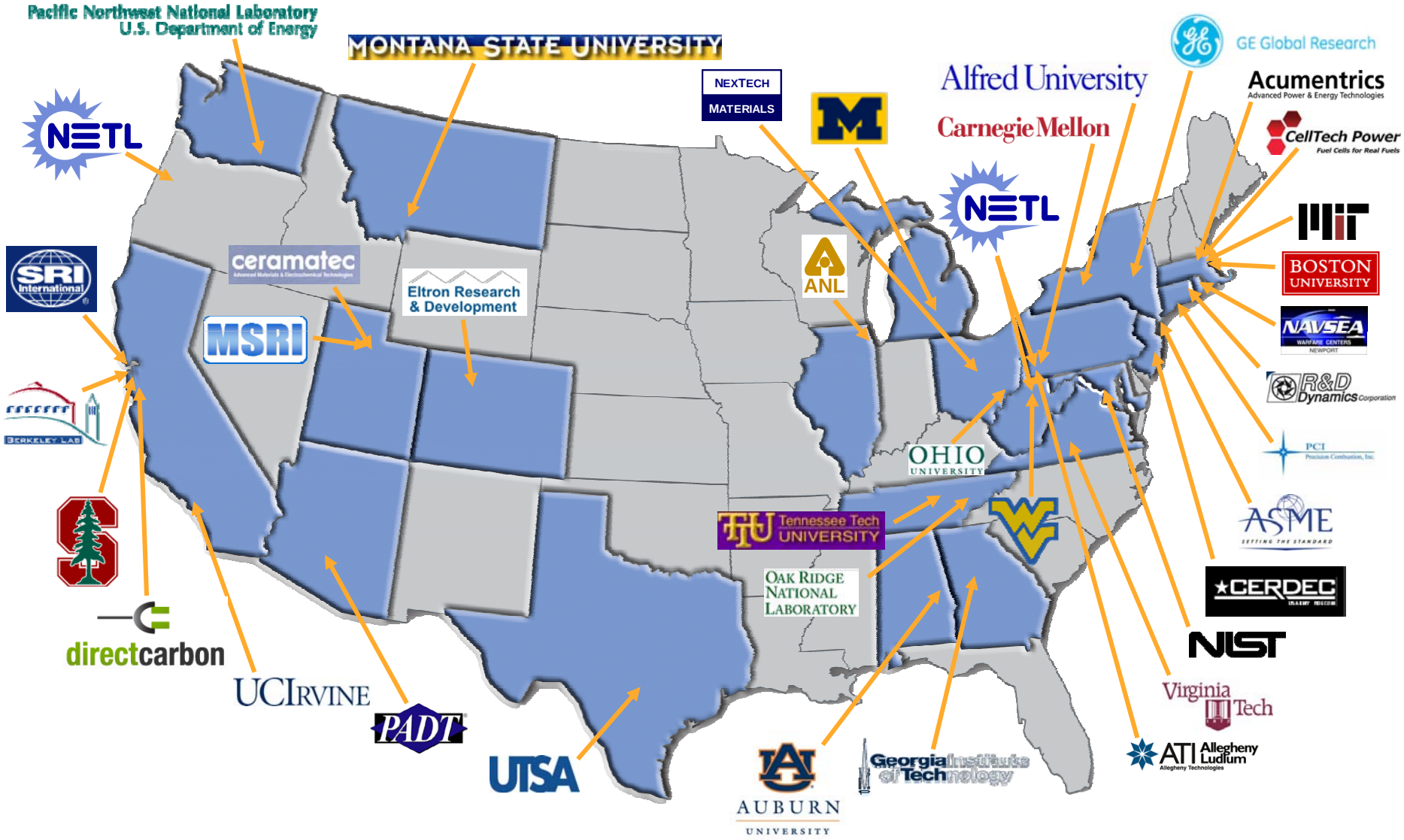




SECA Industry Teams & Major Subcontractors



2009 SECA Core Technology & Other Partners



00076C 6-03-09 WAS

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 Performance Assessment Rating Tool (OMB) 2010

SECA

Stack Cost ~ $175/kW stack

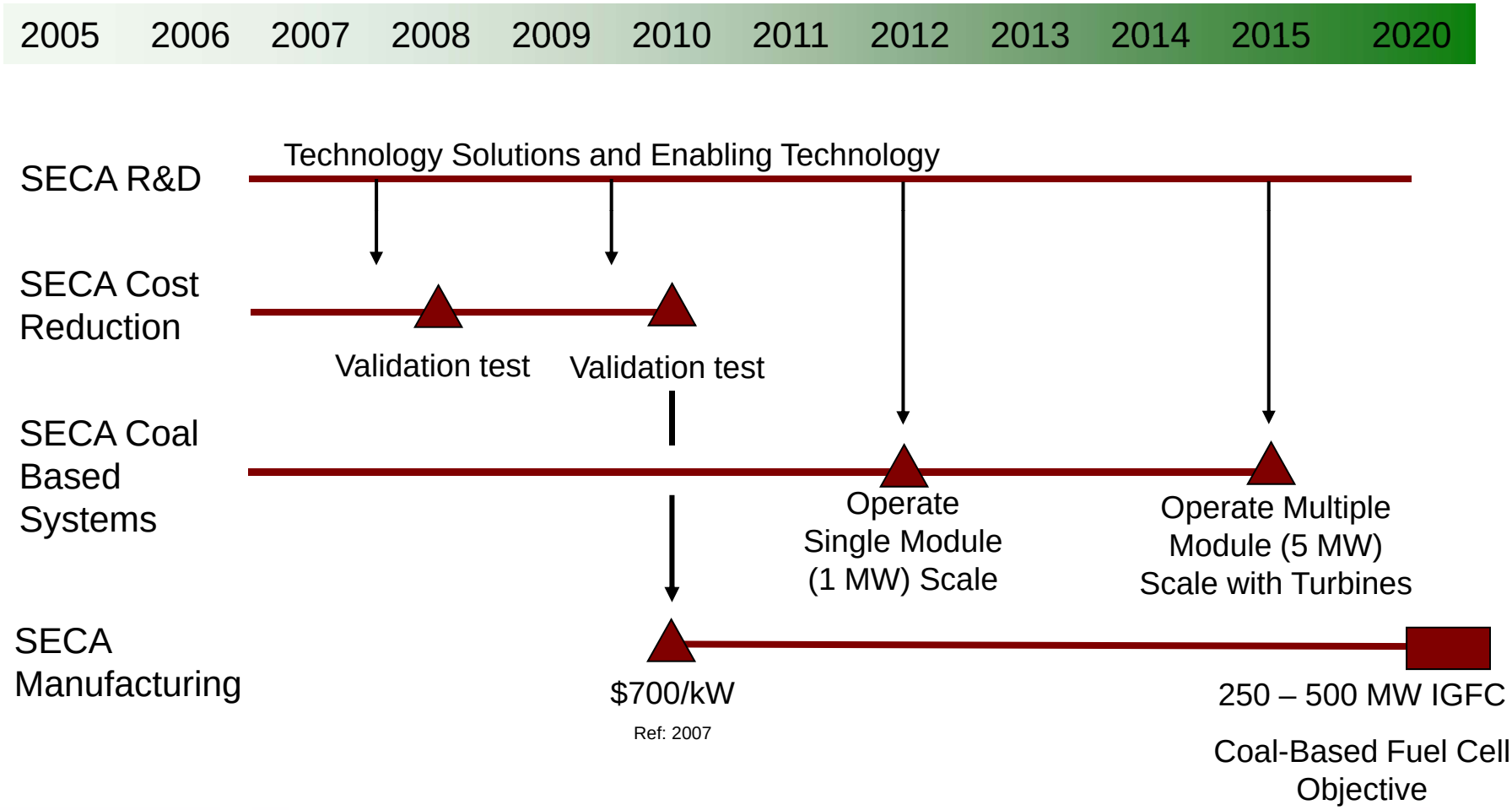
Capital Cost < $700/kW system

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

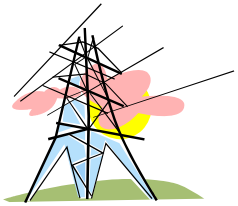
Ref: 2007
Goal: 2010

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

Solid State Energy conversion Alliance
Fuel Cells Technology Timeline

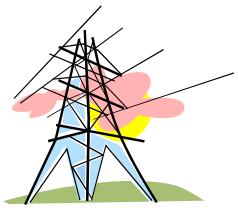


SECA Coal Based Systems reduced water requirement > 90% carbon capture



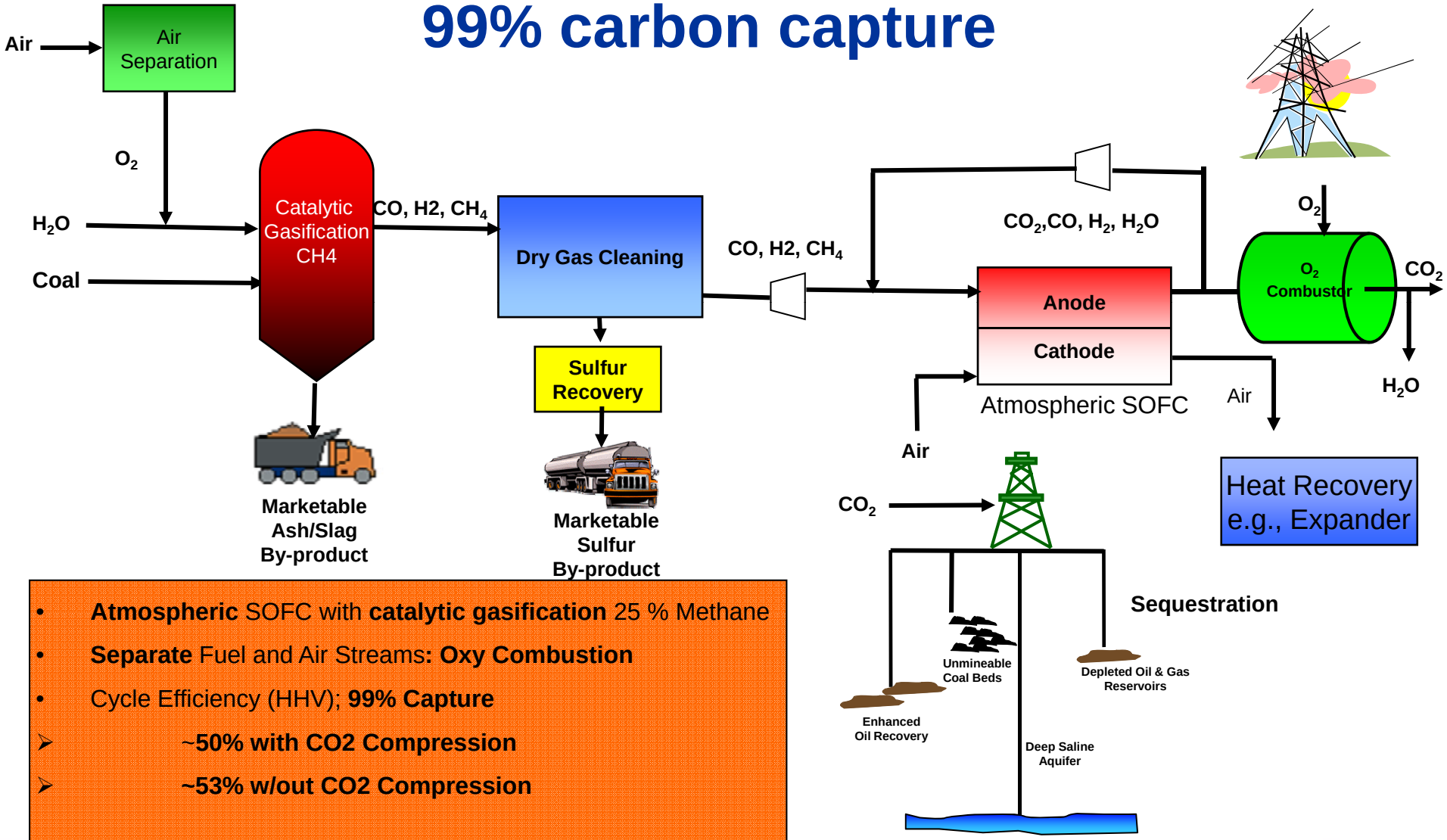
- **Atmospheric SOFC** with **conventional coal gasification**
- **Combined** Fuel and Air Streams
- **Steam cycle** – reduced external water requirement
- Cycle Efficiency (HHV); **90% Capture**
  - **~42% with CO2 Compression**
  - **~45% w/out CO2 Compression**

SECA Coal Based Systems reduced water requirement >90% carbon capture



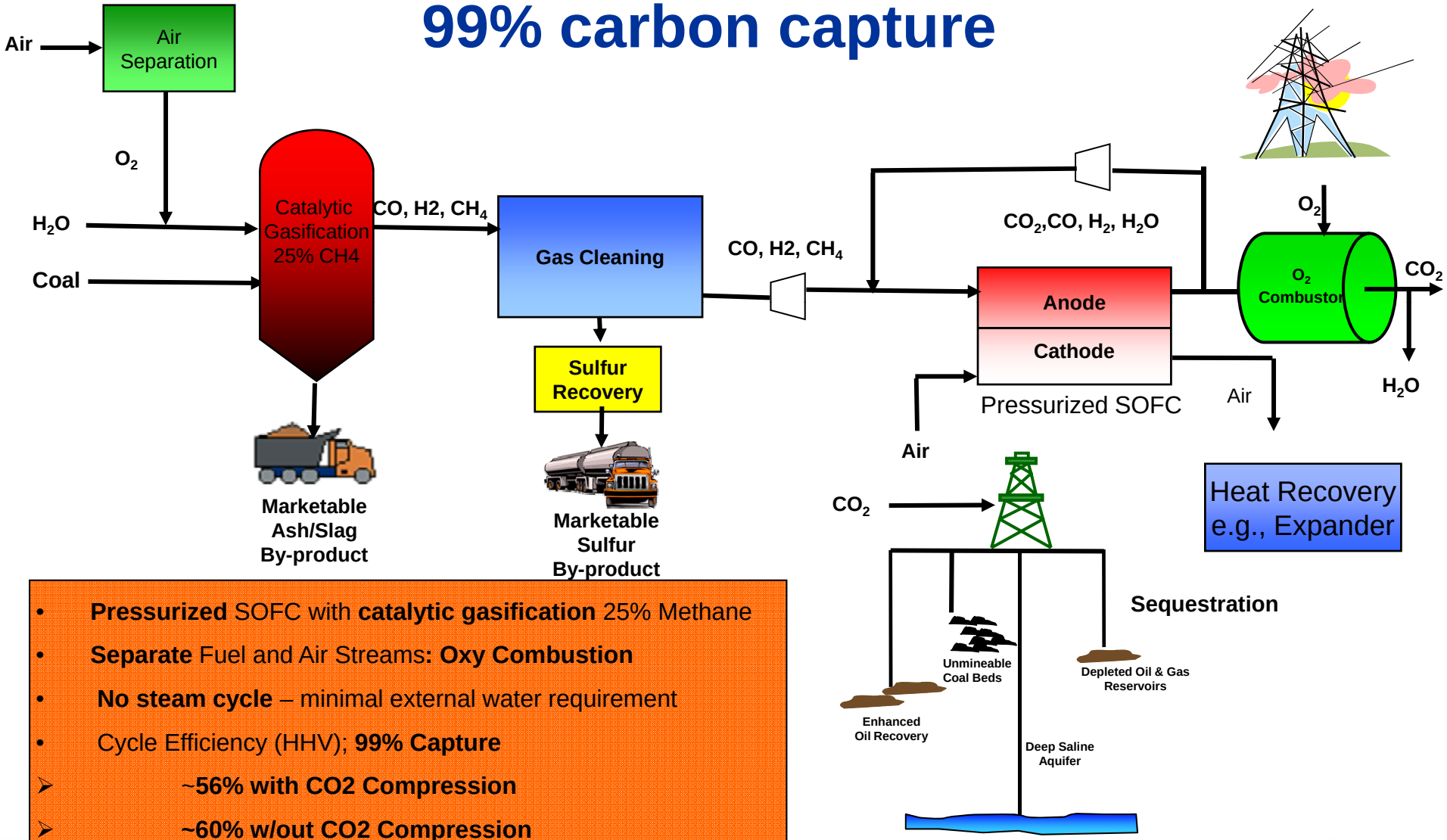
- **Pressurized SOFC** with **conventional coal gasification**
- **Combined** Fuel and Air Streams
- **Steam cycle** – reduced external water requirement
- Cycle Efficiency (HHV); **90% Capture**
  - **~47% with CO2 Compression**
  - **~50% w/out CO2 Compression**

SECA Coal Based Systems near-zero water requirement 99% carbon capture



- **Atmospheric** SOFC with **catalytic gasification** 25 % Methane
- **Separate** Fuel and Air Streams**: Oxy Combustion**
- Cycle Efficiency (HHV); **99% Capture**
  - **~50% with CO2 Compression**
  - **~53% w/out CO2 Compression**

SECA Coal Based Systems near-zero water requirement 99% carbon capture



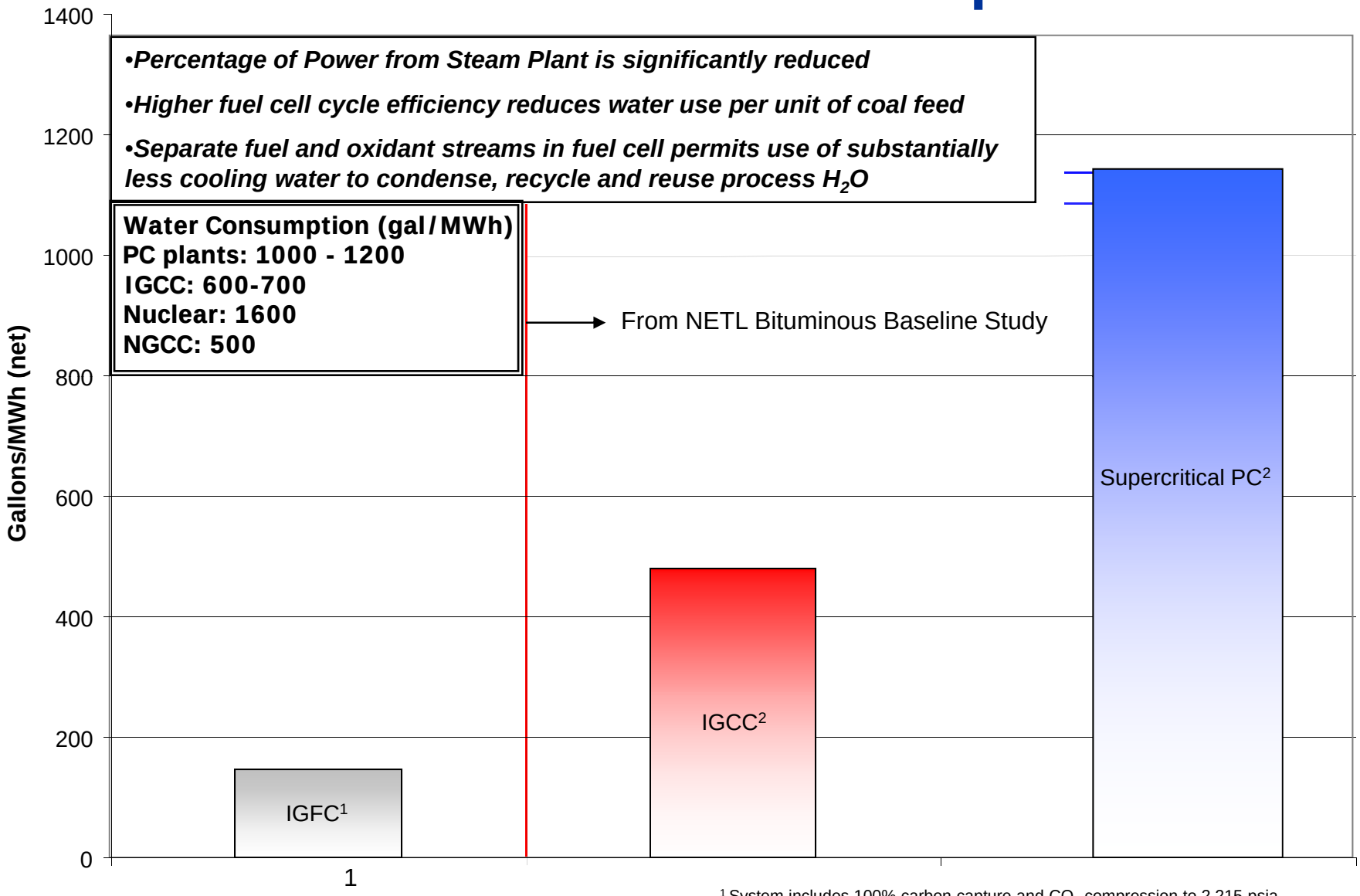
- **Pressurized** SOFC with **catalytic gasification** 25% Methane
- **Separate** Fuel and Air Streams**: Oxy Combustion**
- **No steam cycle** – minimal external water requirement
- Cycle Efficiency (HHV); **99% Capture**
  - **~56% with CO2 Compression**
  - **~60% w/out CO2 Compression**

Impact of Efficiency on COE

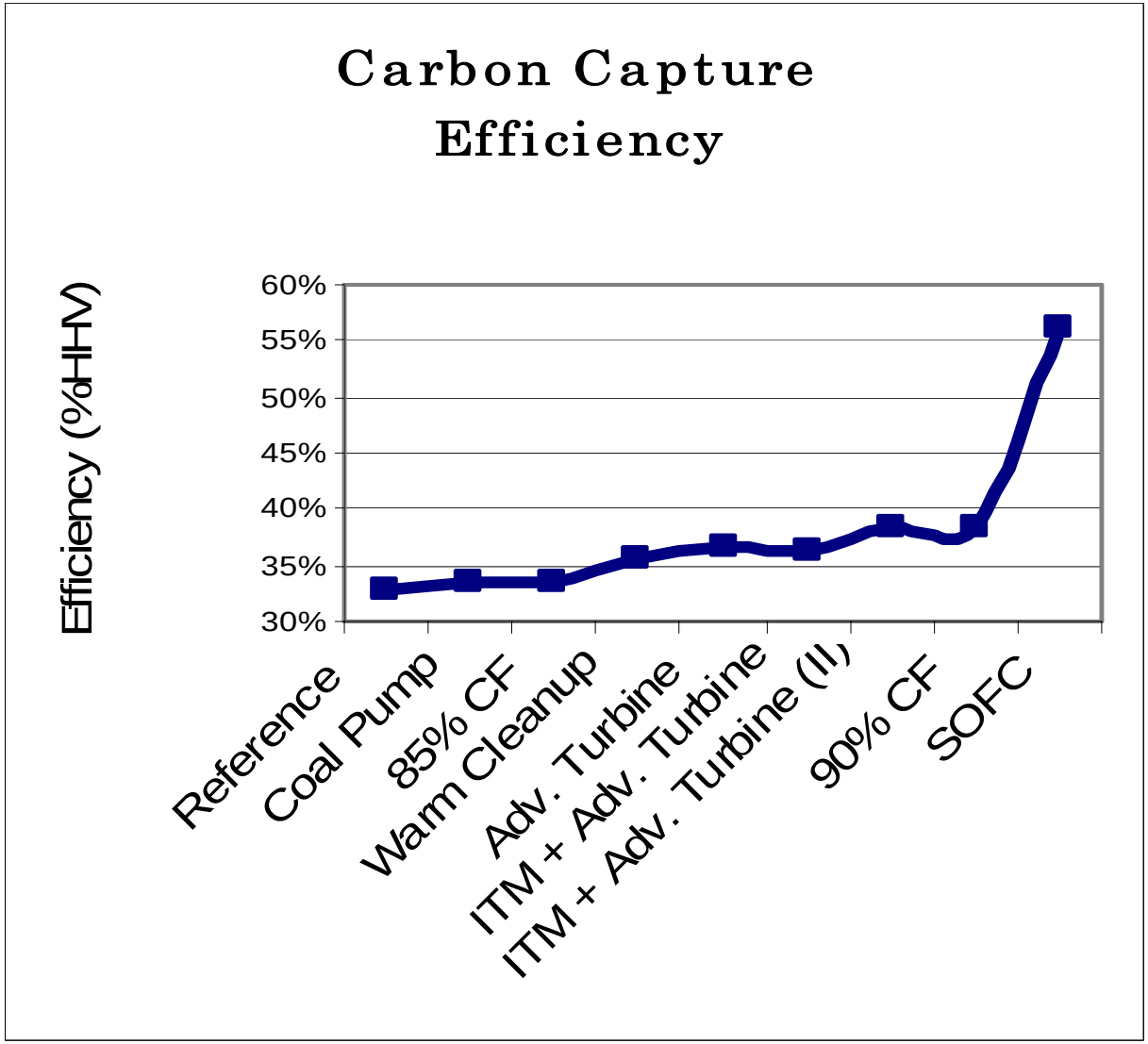
Advanced Power Systems With CO2 Capture, Compression and Storage					
	PC Baseline	IGCC Baseline		IGFC Atmos.	IGFC Press.
Efficiency HHV (%)	27.2	32.5		42.8	57.3
Capital Cost $/kW	2,870	2,390		1,991	1,667
Steam Cycle % Power	100	37		26	2
Cost-of-Electricity ¢/kW-hr	11.6	10.6		8.5	7.3

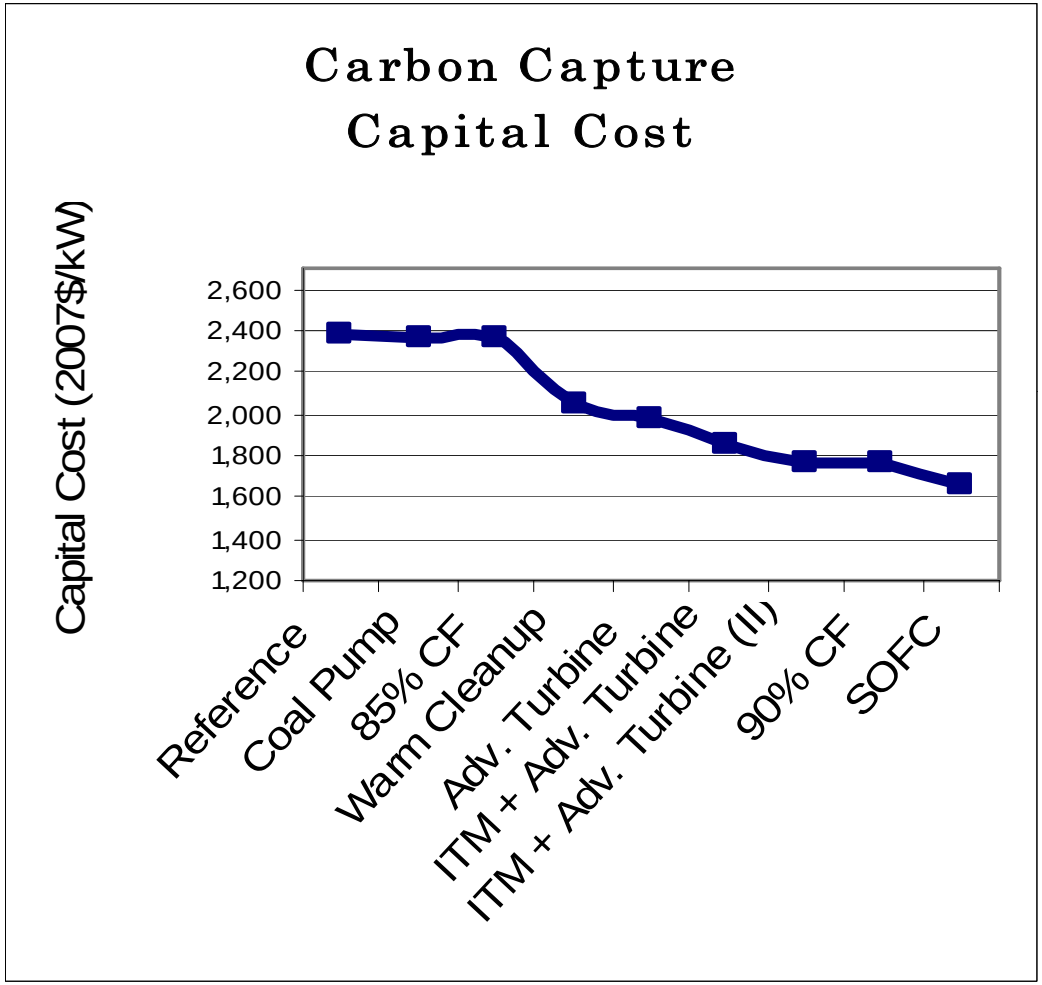
The Benefit of SOFC for Coal Based power Generation, Report Prepared for U. S. Office of Management and Budget, 30OCT07

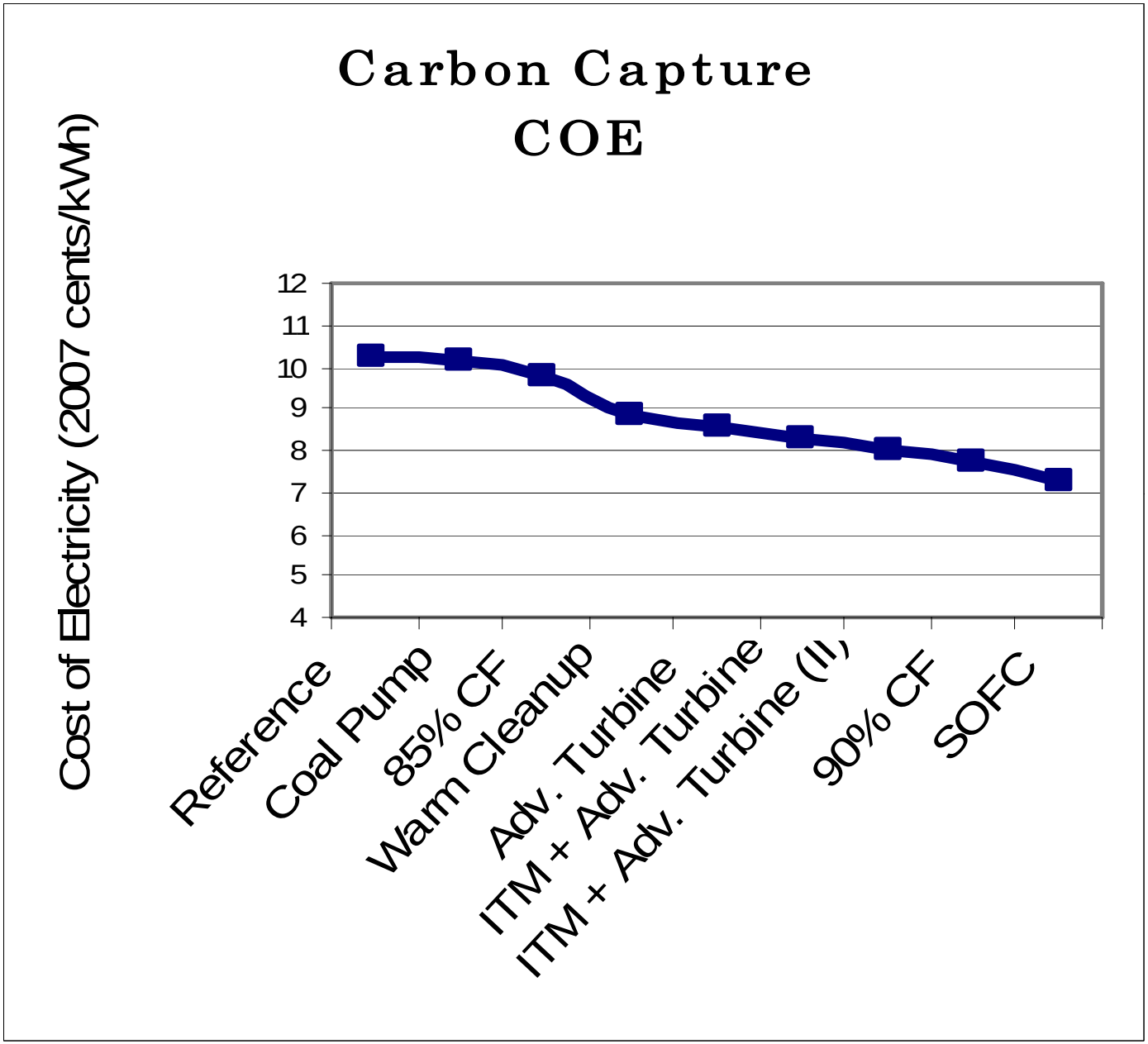
Raw Water Withdrawal Comparison



[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


Carbon Capture
Efficiency
Efficiency (%HHV)
60%
55%
50%
45%
40%
35%
30%
Reference
Coal Pump
85% CF
Warm Cleanup
Adv. Turbine
ITM + Adv. Turbine
ITM + Adv. Turbine (II)
90% CF
SOFC


Carbon Capture
Capital Cost
Capital Cost (2007$/kW)
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
Reference
Coal Pump
85% CF
Warm Cleanup
Adv. Turbine
ITM + Adv. Turbine
ITM + Adv. Turbine (II)
90% CF
SOFC


Carbon Capture
COE
Cost of Electricity (2007 cents/kWh)
12
11
10
9
8
7
6
5
4
Reference
Coal Pump
85% CF
Warm Cleanup
Adv. Turbine
ITM + Adv. Turbine
ITM + Adv. Turbine (II)
90% CF
SOFC

Key Points

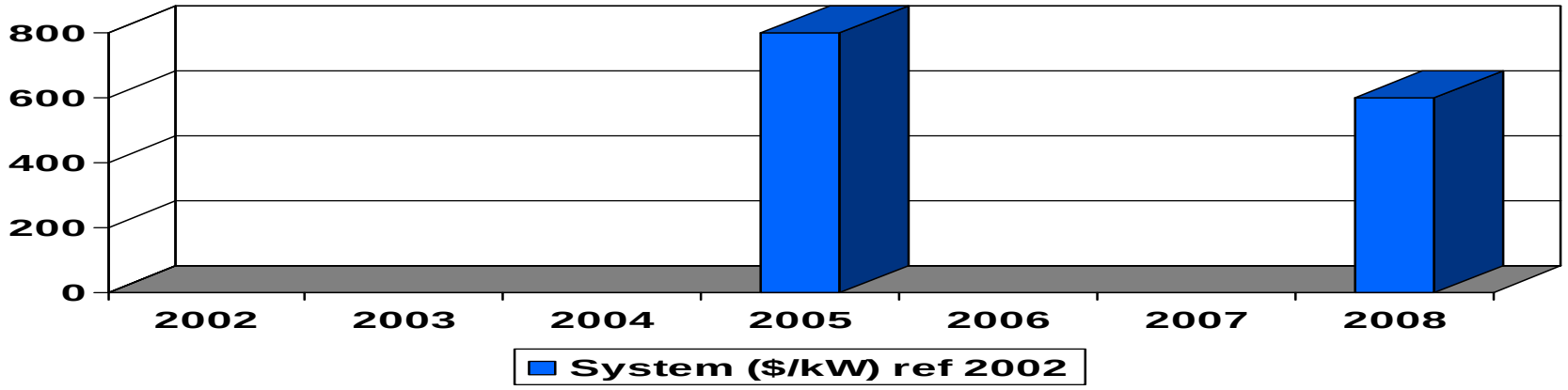
- **25% Methane**
  +
- **Pressure**

→ *60% Efficiency HHV*

- **Balance of Plant** → **Cost Scales with Size**
- **Fuel Cell Stack** → **Cost Scales with Power**
- **Separate Air & Fuel Streams / w/o Steam Plant**
  - ➢ **99 % Carbon Capture**
  - ➢ **Near Zero Water Use**

Single Cell Module Performance
Planar Cell - Atmospheric

						(x10)
250mw/cm²@ 0.6 V 144 cm²	275mw/cm²@ 0.7V 144cm²	400mw/cm²@ 0.7V 144cm²	450mw/cm²@ 0.7V 144cm²	600mw/cm²@ 0.7V 144cm²	500mw/cm²@ 0.8V 144 cm²	450mw/cm²@ 0.85V 550 cm²



Research Priorities:
SECA Cost Reduction and Coal Systems

Risk Level

Low

Medium

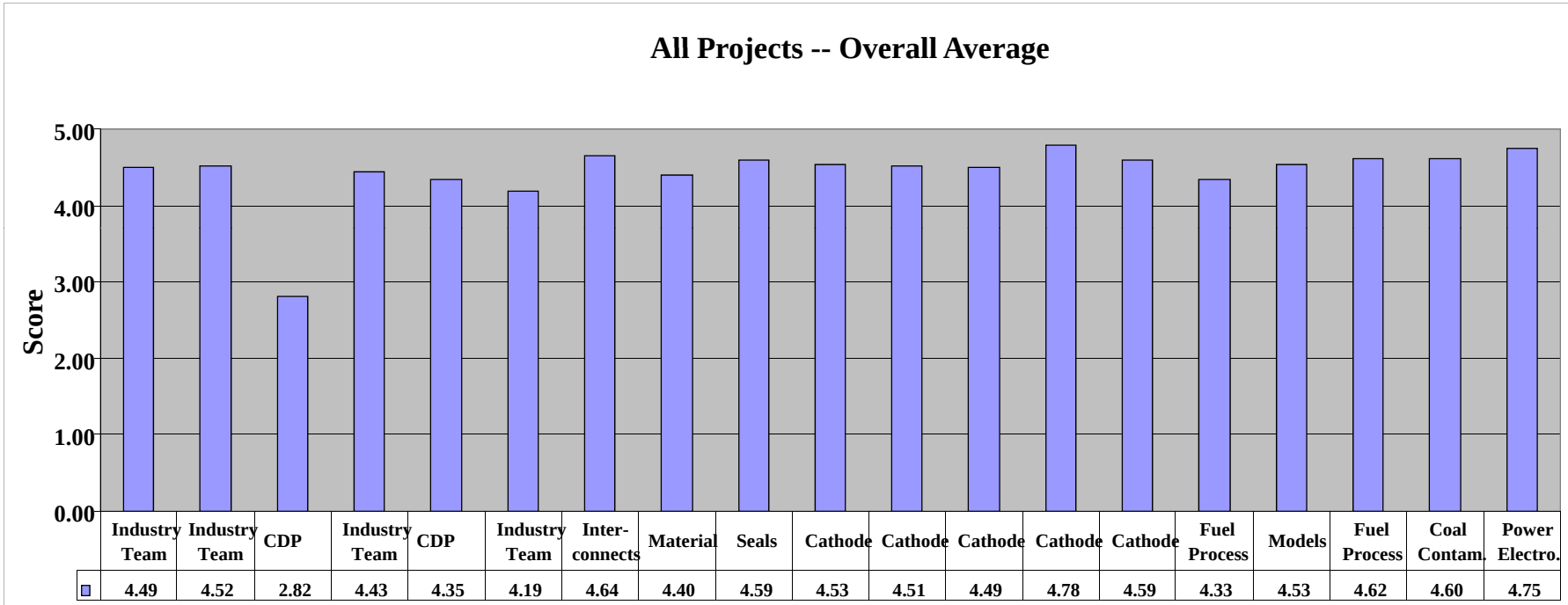
High

	Gas Seals	▪ Glass and Compressive Seals ▪ Compliant Seals ▪ Self-healing Materials ▪ High Temperature Refractive Seal
	Failure Analysis	▪ Models with Electrochemistry & EMF ▪ Define Operating Window (Not possible experimentally) ▪ Structural Failure Analysis & Design Criteria (ASME)

	Cathode performance	▪ Understand Mechanism
		  ▪ Ad-atom Modification of Surfaces
		  ▪ Modification through Infiltration } *Electronic Effect versus Defect Chemistry*

	Interconnect	▪ Coatings ▪ Electrode to Interconnect Interface - Contact Material
	Anode / fuel processing	▪ Establish Fuel Specification ▪ Characterize Thermodynamics/Kinetics/ Contaminants
	Heat Exchangers/ High Temperature Blowers	▪ Cost and Reliability ▪ Design Guidelines

SECA Peer Review 2008
Project Average Score Results



OMB cited SECA as Leading the Way in Government-Industry Partnerships

The Office of Management and Budget cited the SECA program as leading the way in Government-industry partnerships. "*The SECA program leverages private-sector ingenuity by providing Government funding to Industry Teams developing fuel cells, as long as the Teams continue to exceed a series of stringent technical performance hurdles. This novel incentive structure has generated a high level of competition between the Teams and an impressive array of technical approaches. The SECA program also develops certain core technologies that can be used by all the Industry Teams to avoid duplication of effort. The program exceeded its 2005 performance targets, and it is on track to meet its goal for an economically competitive technology by 2010*."

SECA Industry Teams
FY 2001 – FY 2007
5kW Systems - 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

Peterbilt - Delphi Auxiliary Power Unit

- **Delphi's SECA APU powered the Peterbilt Model 386's electrical hotel loads, including air-conditioner, radio, CB, lights, battery, & start-up.**
- **The Delphi SECA APU provided an average of 800 watts of electricity on diesel.**
- **The Delphi SECA APU addresses anti-idling regulations.**

SOFCs in Unmanned Undersea Vehicles (UUVs)

21UUV (2-5 kW)
- **Fisher-Tropsch**
- **SECA Stacks and Blower**

- **Naval Undersea Warfare Center, Division Newport, (NUWCDIVNPT) successfully tested SECA SOFCs in extreme conditions. Used SECA Stacks (2 Developers) and SECA developed High Temperature Blower**
- **SOFC technology has the potential to greatly increase UUV mission time compared with current battery technology.**
- **Although SECA has a coal-based, central generation focus, spin-off applications are encouraged. Military applications like UUVs provide operating experience and independent validation for SECA.**
- **Cost and operational lifetime are not necessarily major concerns for military applications, as long as new mission capability can be delivered.**

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

Websites:

www.netl.doe.gov

www.fe.doe.gov

www.grants.gov

CDs available from the website

- **FE Fuel Cell Program Annual Report _2008**
- **9th Annual SECA Workshop Proceedings**
- **Fuel Cell Handbook (7th ed.)**

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2009 SECA Workshop

July 14th – 16th

Pittsburgh, PA