NATIONAL ENERGY TECHNOLOGY LABORATORY

Clean Economic Energy in a Carbon Challenged World

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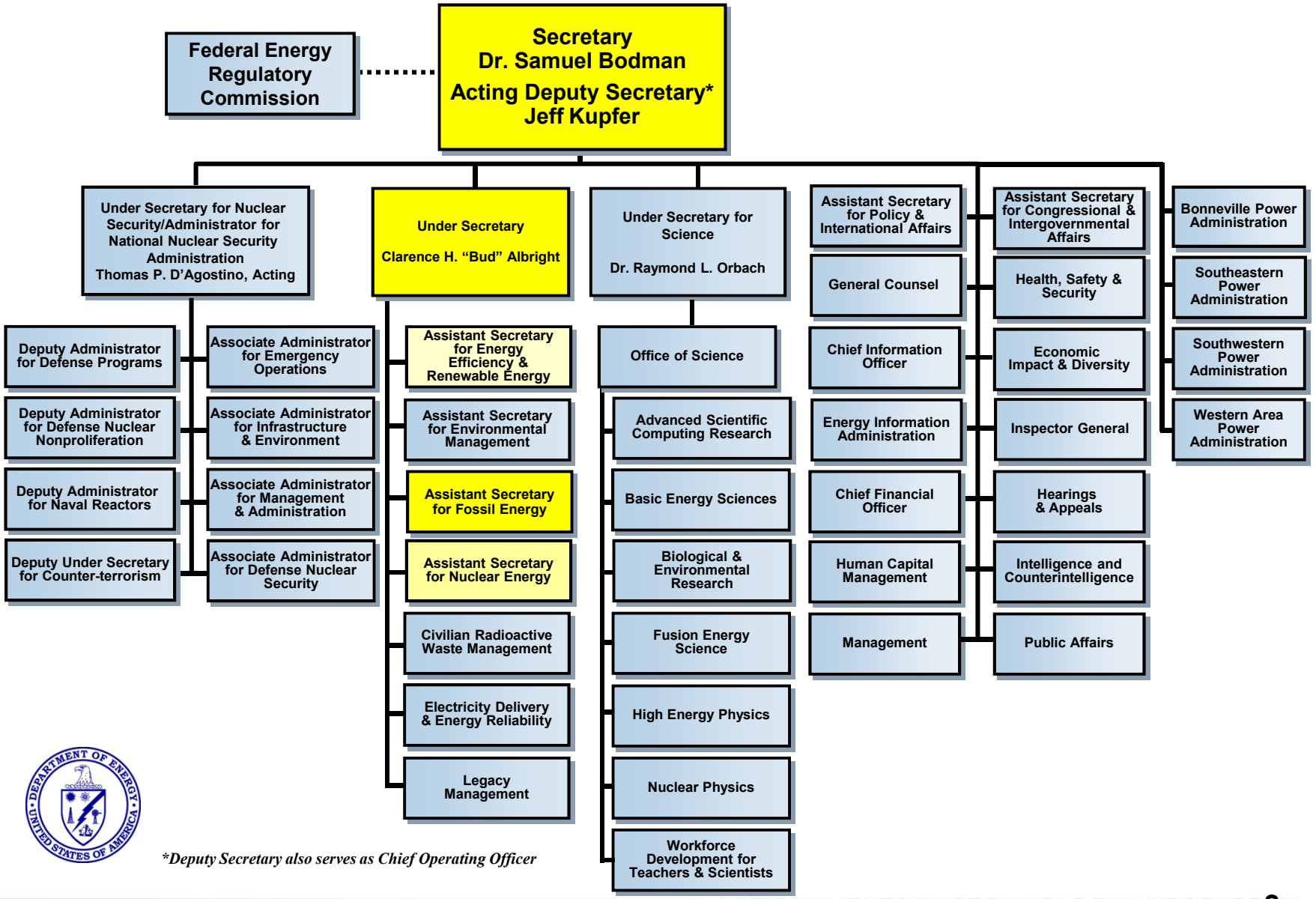
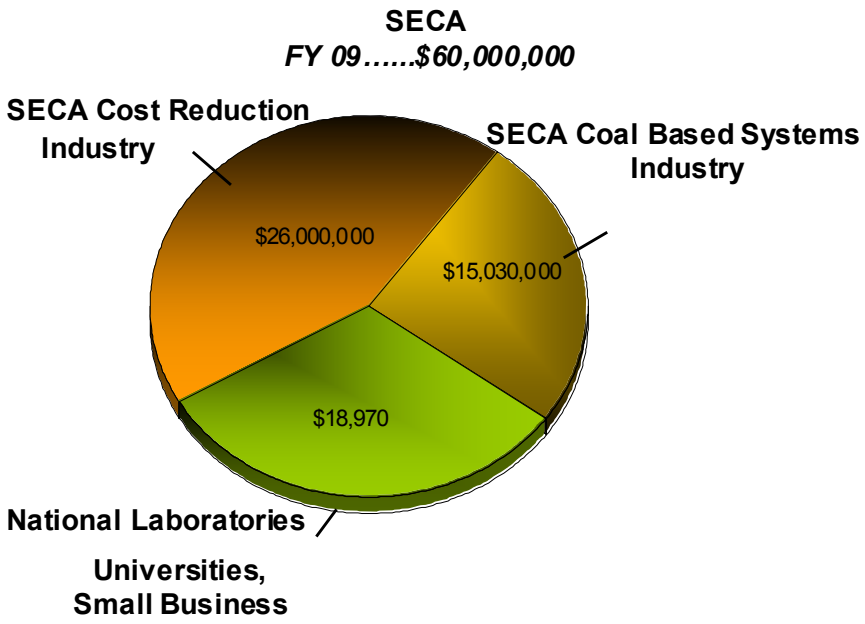
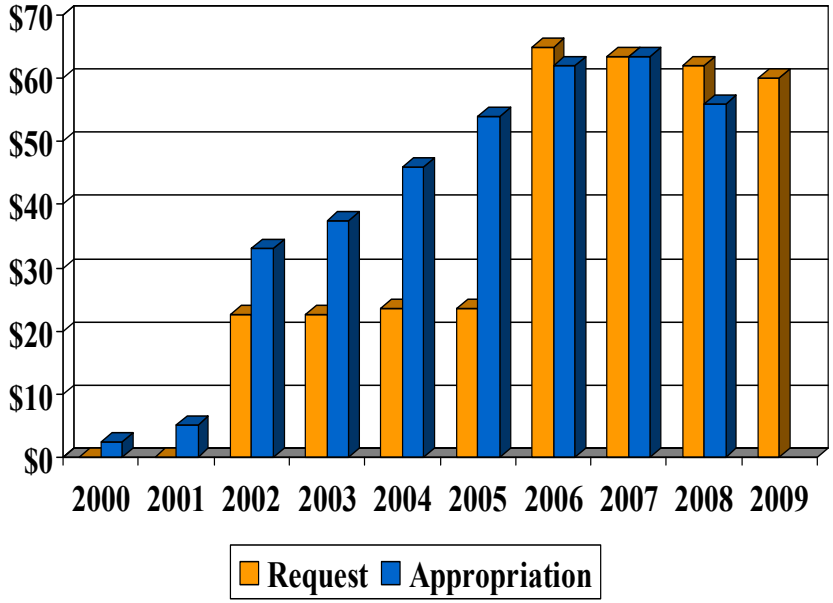
Department of Energy



Deputy Secretary also serves as Chief Operating Officer

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





SECA Program Structure

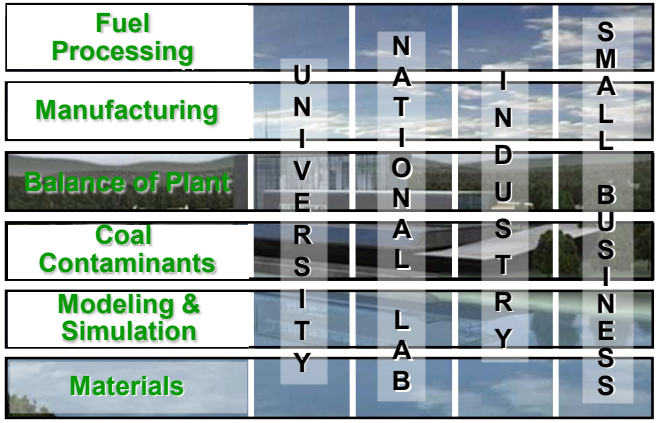
Project Management

Needs

Research Topics

Industry Integration Teams

Technology Transfer



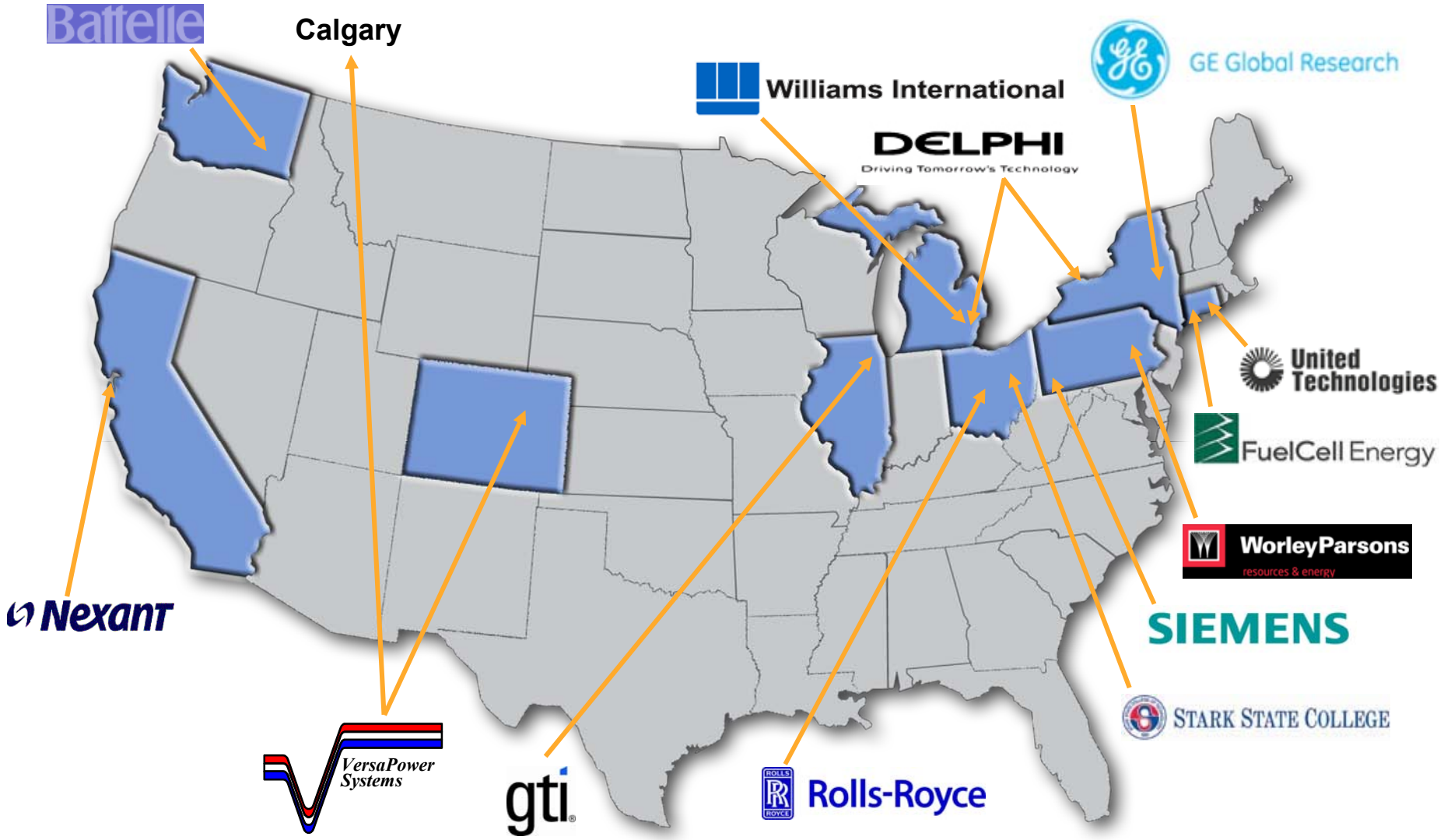
Core Technology Program

Intellectual Property

Cornerstone of the Alliance

- **Non-Exclusive License** **CTP ➡ Industry Teams**
  - **Ready market of potential licensees**
  - **Best designs vs. highest bidder**
- **Promotes Collaboration - Limits Redundancy**

SECA Industry Teams & Major Subcontractors



2008 SECA Core Technology & Other Partners

00076 7-25-08 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

Stack Cost ~ $100/kW stack

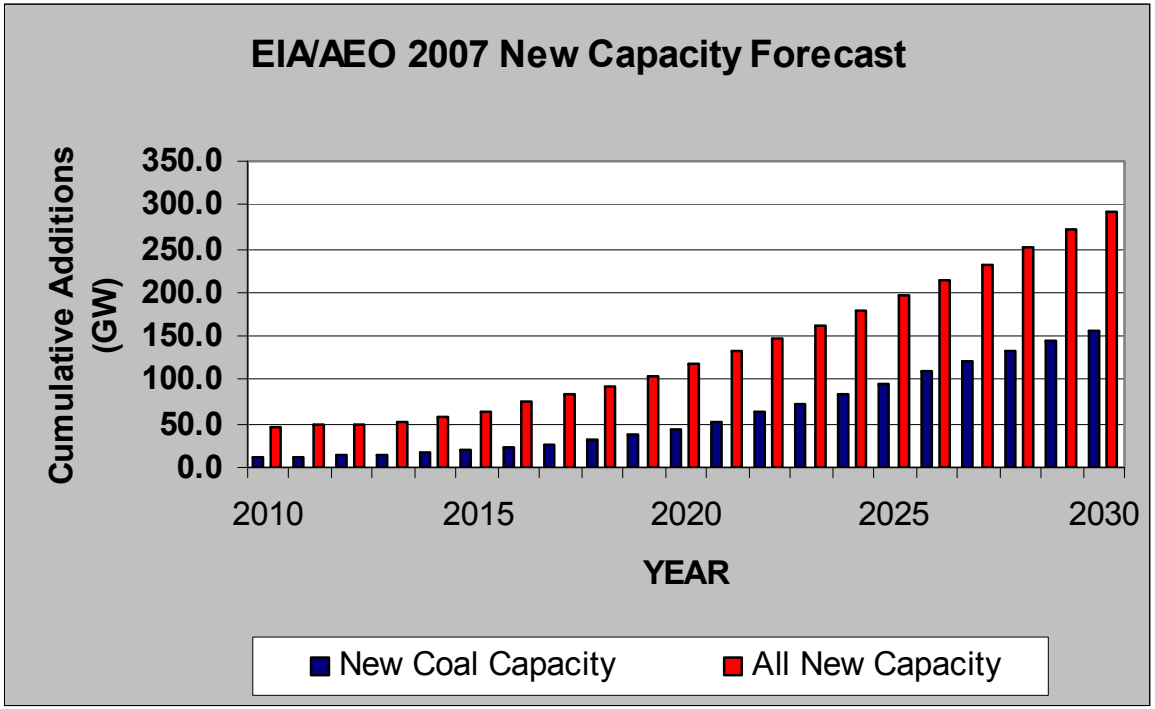
Capital Cost < $400/kW system

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

Ref: 2002
Goal: 2010

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

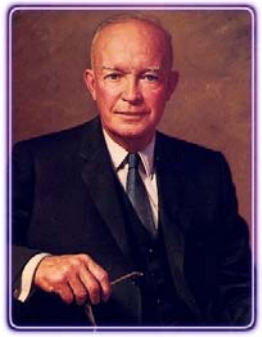
Atoms for Peace
1953

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**.

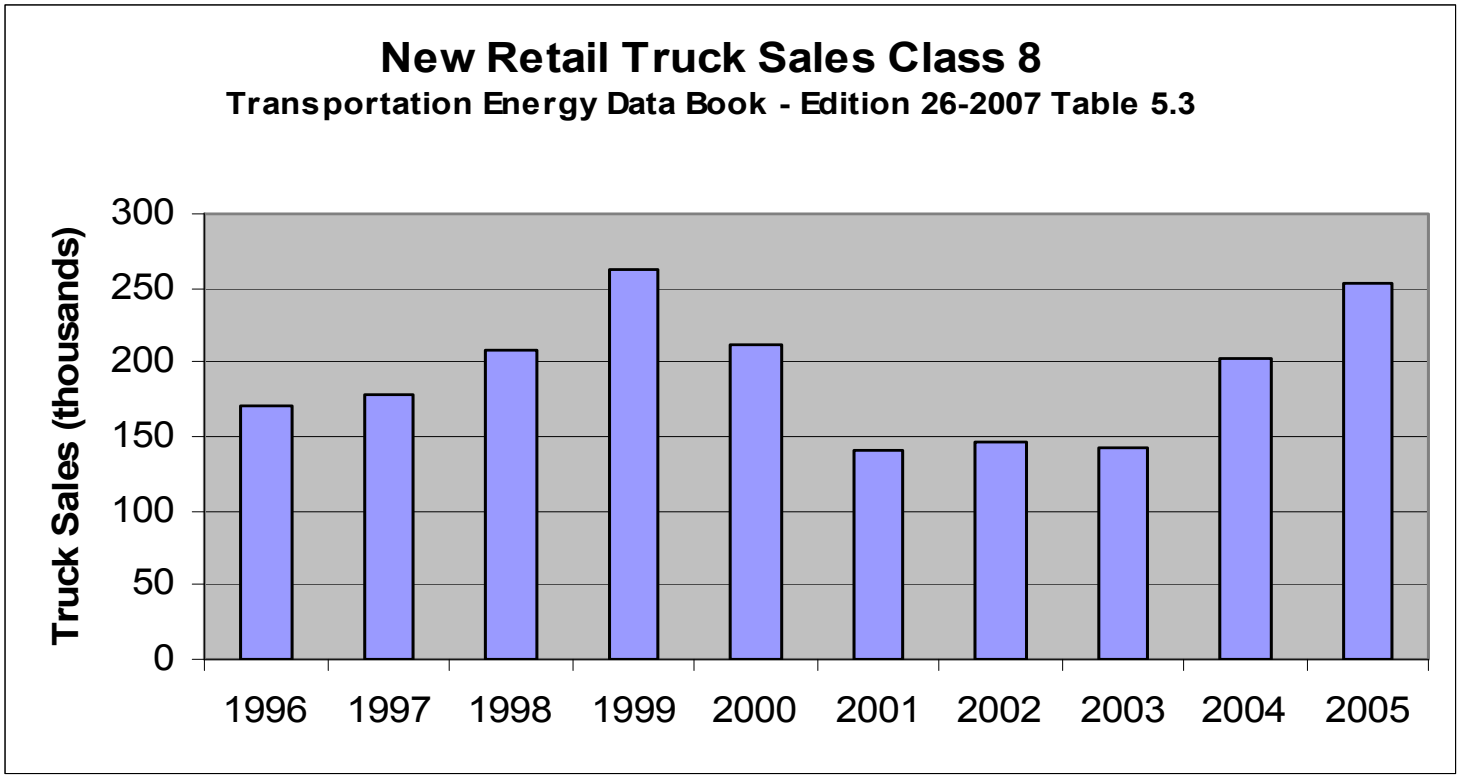
Photograph of the Shippingport Atomic Power Station in Shippingport, Pennsylvania, the first full-scale nuclear power generating station in the United States which began operating in 1957.

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



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



Average Size of a Truck APU – 5kW

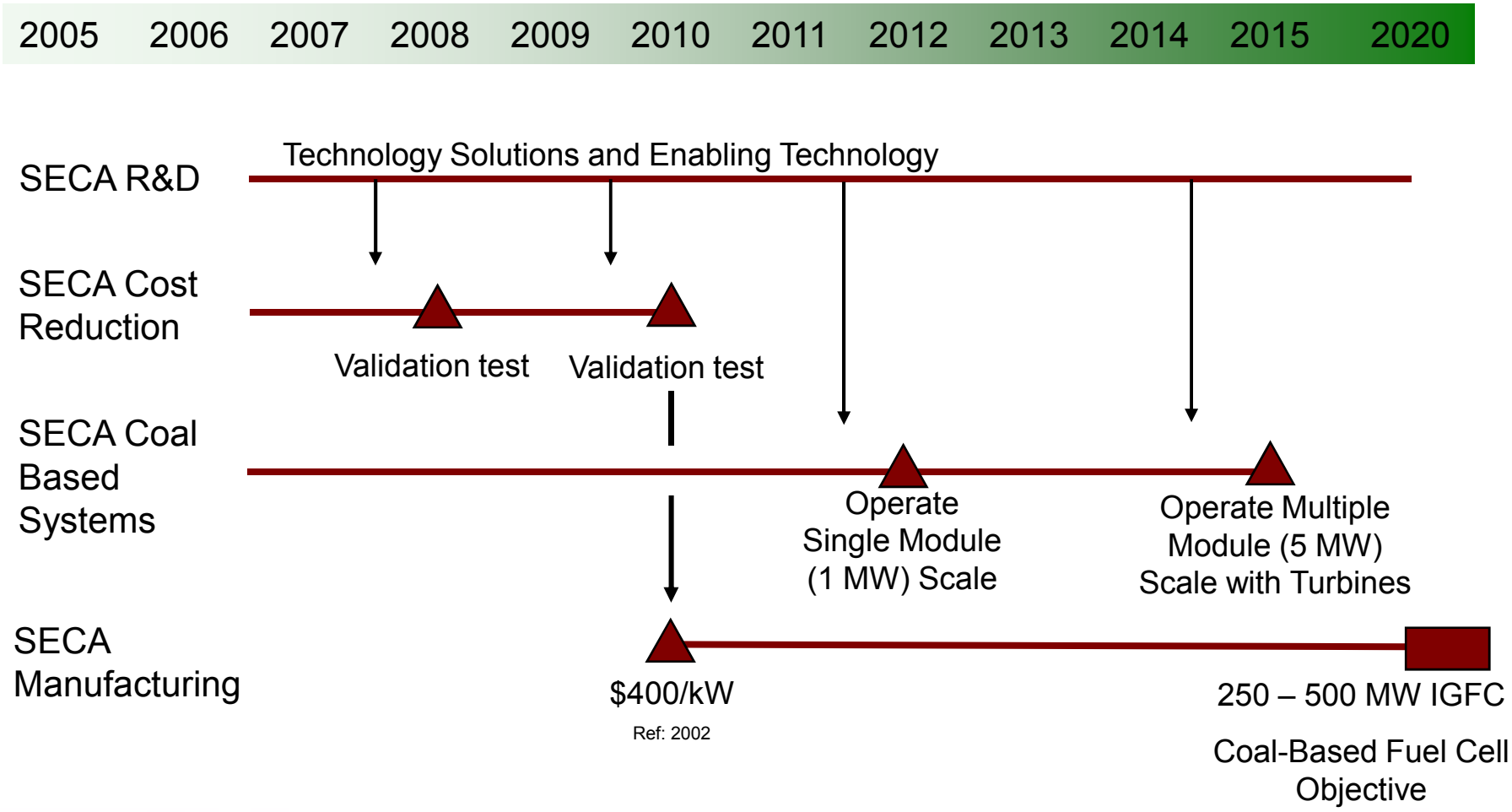
Average Annual Production – 200,000 units

Average SECA Fuel Cell Production…. 1 GW/yr

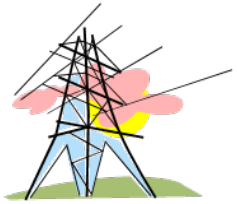
Fuel Cells in a DOD Application's

- **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.**
- **Further size and weight improvements – Focus on the Balance of Plant**

Solid State Energy conversion Alliance Fuel Cells Technology Timeline

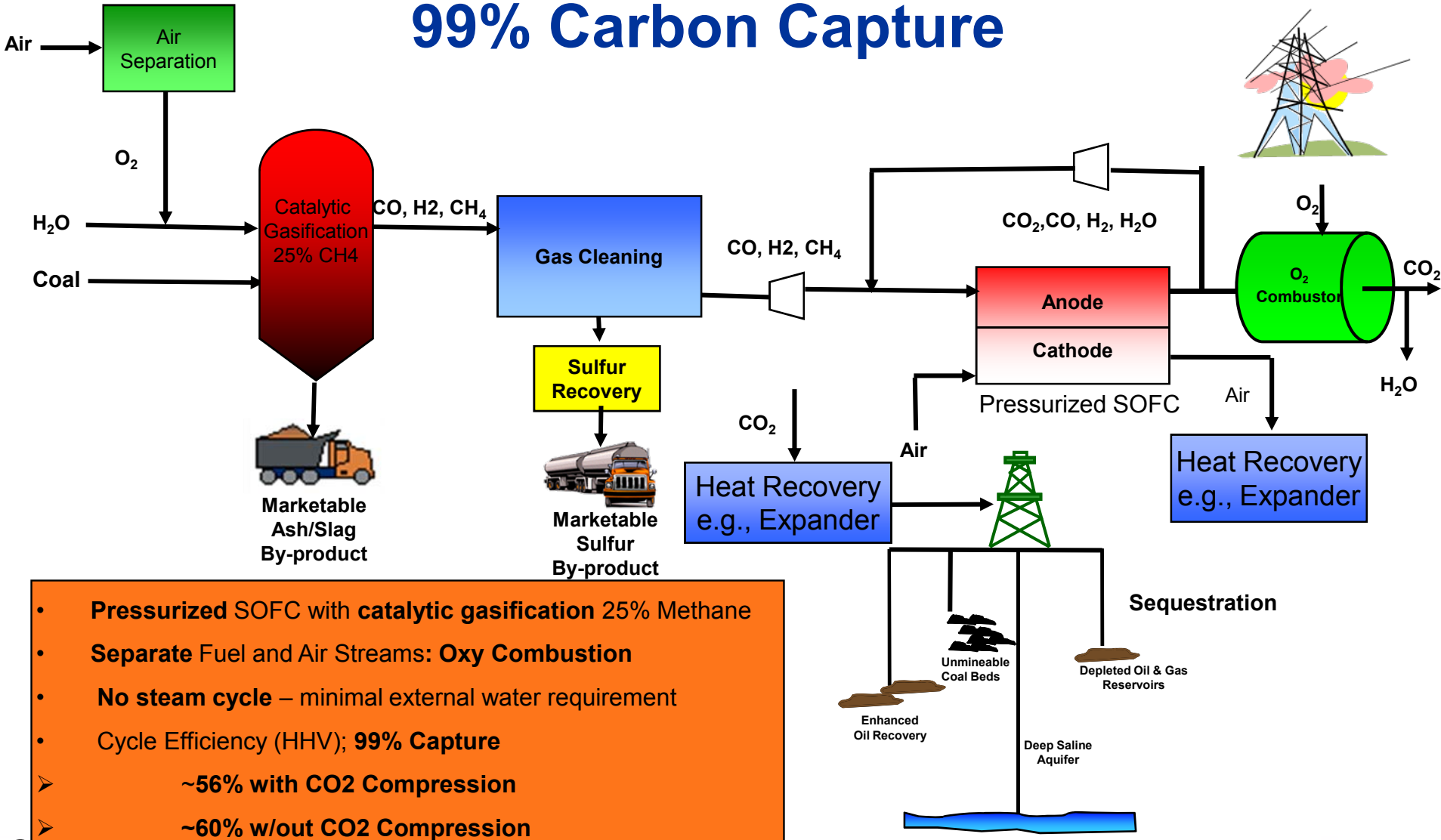


SECA Coal Based Systems
Reduced Water Requirement
> 90% Carbon Capture



- **Atmospheric SOFC** with **conventional coal gasification**
- **Combined** Fuel and Air Streams
- **Steam cycle** – reduced external water requirement
- Cycle Efficiency (HHV); **90% Capture**
  - **~40% with CO2 Compression**
  - **~45% w/out CO2 Compression**

SECA Coal Based Systems
Near Zero Water Requirement
99% Carbon Capture



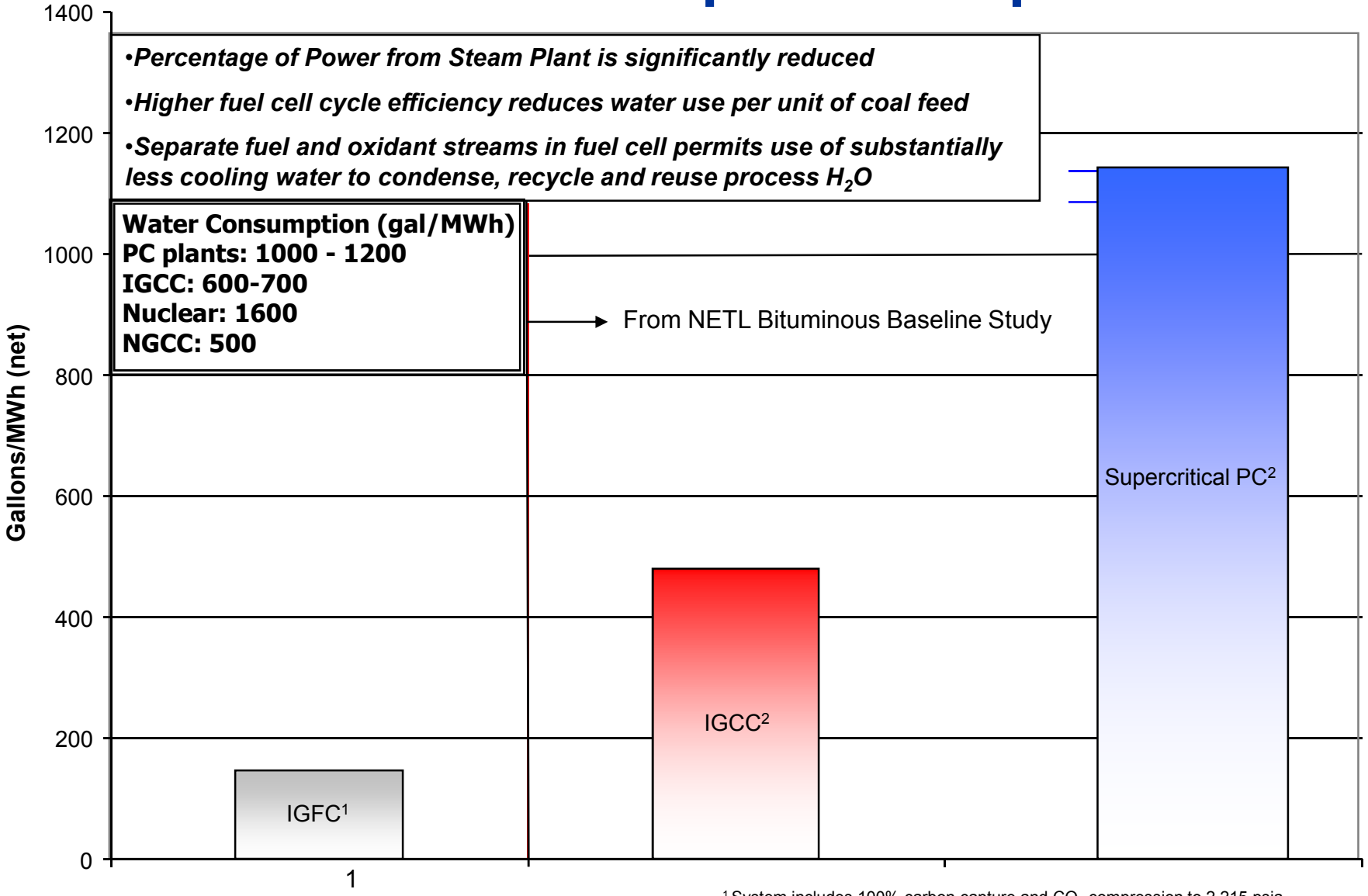
- **Pressurized** SOFC with **catalytic gasification** 25% Methane
- **Separate** Fuel and Air Streams**: Oxy Combustion**
- **No steam cycle** – minimal external water requirement
- Cycle Efficiency (HHV); **99% Capture**
  - **~56% with CO2 Compression**
  - **~60% w/out CO2 Compression**

Impact of Efficiency on COE

Advanced Power Systems With CO_2 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 Consumption Comparison



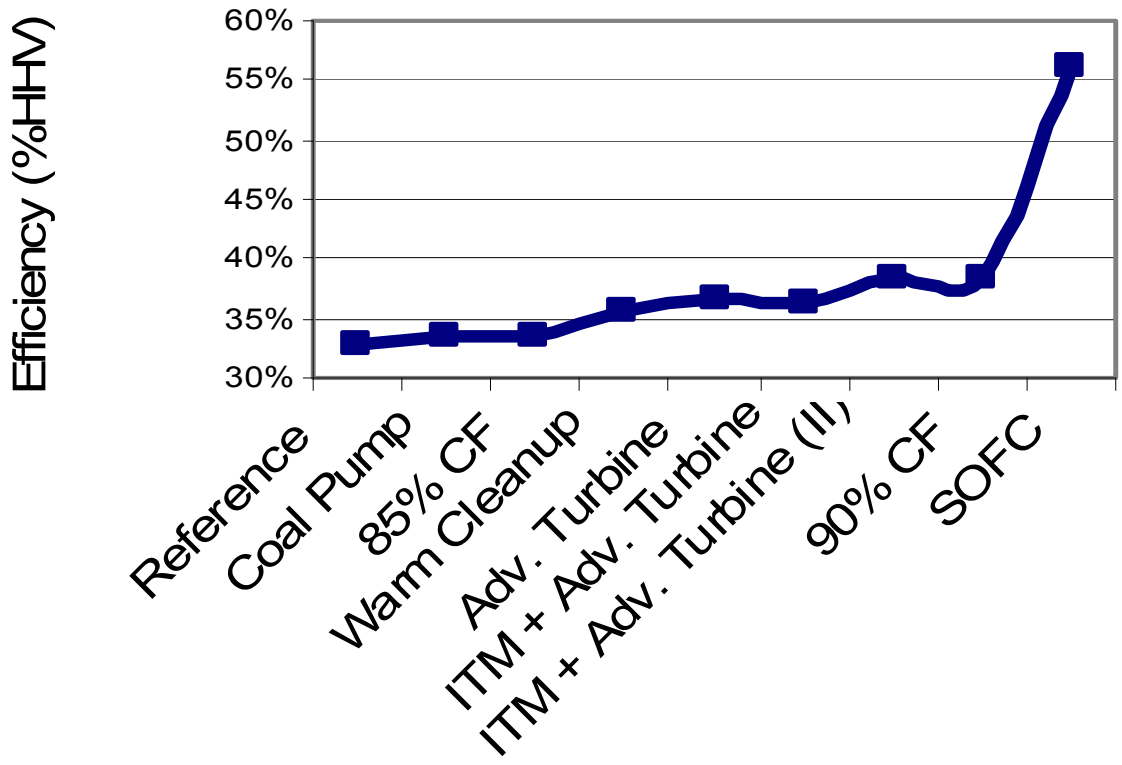
[1] System includes 100% carbon capture and CO_2 compression to 2,215 psia
[2] System includes 90% carbon capture and CO_2 compression to 2,215 psia

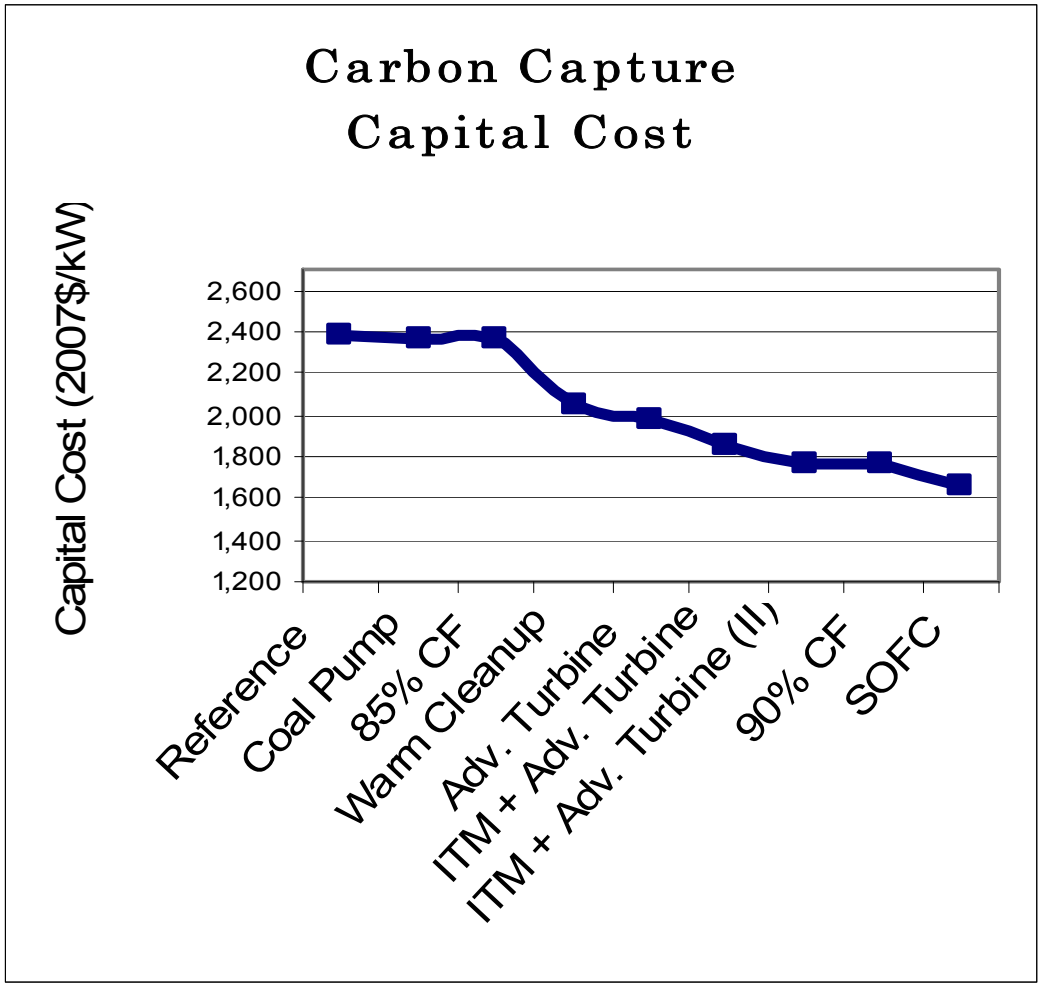
Current & Future IGCC Technologies with Carbon Capture

Case	Description
14	**Reference: Slurry Feed Gasifier / Cryogenic ASU / Cold Gas Cleanup wcc / 7FB Syngas Turbine** / 80 % Capacity Factor
15	**Coal Feed Pump** / Cryogenic ASU / Cold Gas Cleanup wcc / 7FB Syngas Turbine / 80 % Capacity Factor
16	**Coal Feed Pump / Cryogenic ASU / Cold Gas Cleanup wcc / 7FB Syngas Turbine / 85 % Capacity Factor**
17	**Coal Feed Pump / Cryogenic ASU / Warm Gas Cleanup wcc / 7FB Syngas Turbine / 85 % Capacity Factor**
18	**Coal Feed Pump / Cryogenic ASU / Warm Gas Cleanup wcc / 2010-AST Syngas Turbine** / 85 % Capacity Factor
19	**Coal Feed Pump / Ion Transport Membrane (ITM)** / Warm Gas Cleanup wcc / 2010-AST Syngas Turbine / 85 % Capacity Factor
20	**Coal Feed Pump / Ion Transport Membrane (ITM) / Warm Gas Cleanup wcc / 2015-AST Syngas Turbine** / 85 % Capacity Factor
21	**Coal Feed Pump / Ion Transport Membrane (ITM) / Warm Gas Cleanup wcc / 2015-AST Syngas Turbine / 90 % Capacity Factor**
24	**Catalytic Gasifier / Cryogenic ASU / Warm Gas Cleanup / Pressurized SOFC** / 90 % Capacity Factor

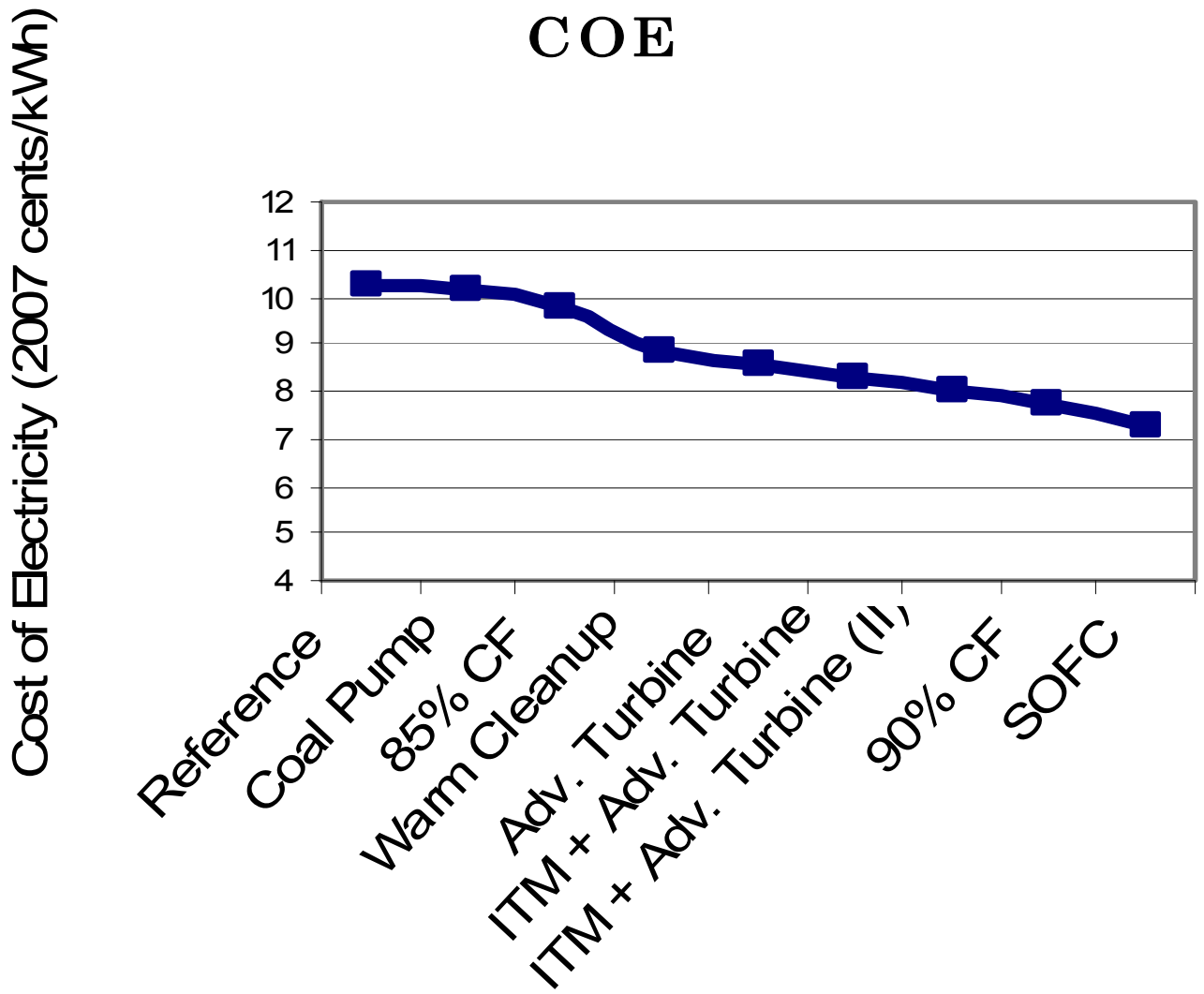
Current & Future IGCC Technologies, DOE/NETL – 2008/1337, 16OCT2008

Carbon Capture Efficiency




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



Key Points

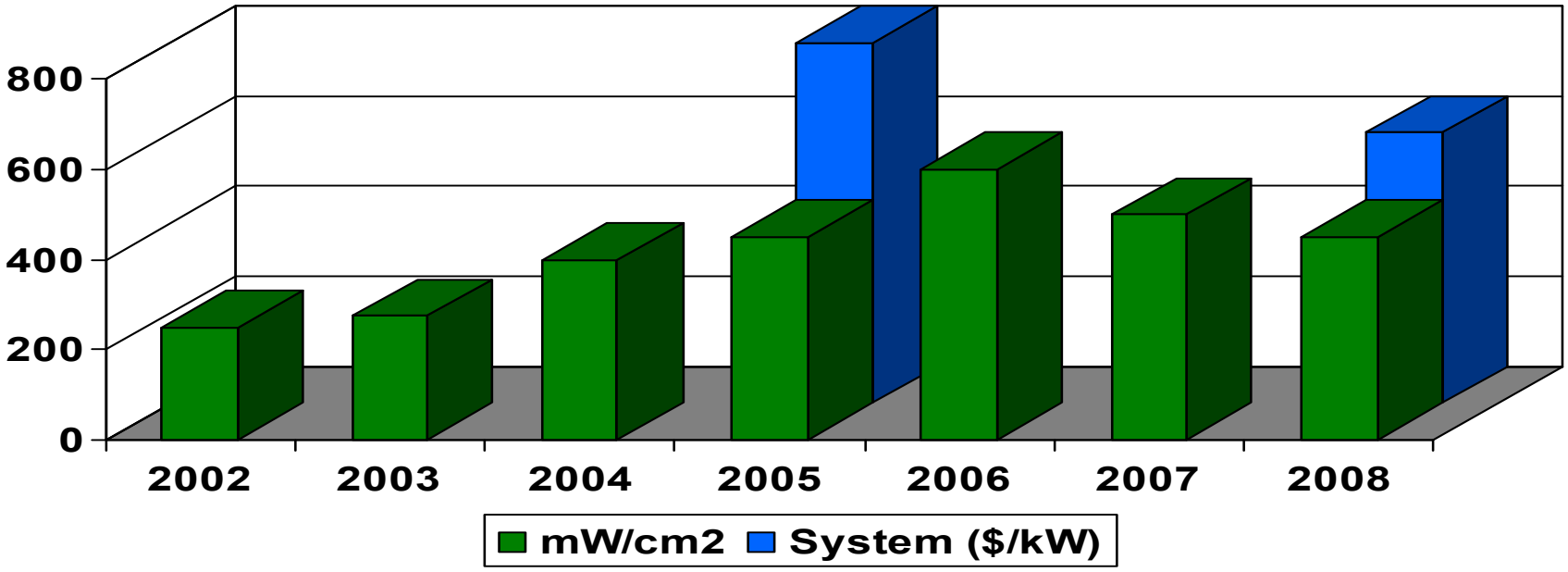
- 25% Methane
  +
- Pressure

→ *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

250@ 0.6 V 144 cm^2	275@ 0.7V 144cm^2	400@0.7V 144cm^2	450@0.7V 144cm^2	600@0.7V 144cm^2	500 @ 0.8V 144 cm^2	450@ 0.8V 550 cm^2



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

SECA Industry Team Prototypes

FuelCell Energy

DELPHI Battelle

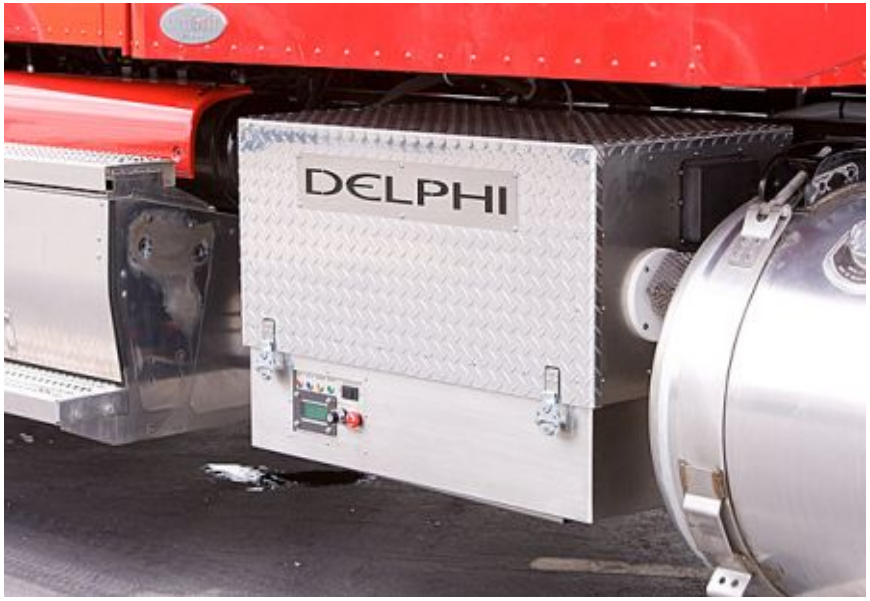
General Electric Company

SIEMENS Westinghouse

Acumentrics
Advanced Power & Energy Technologies

Cummins Power Generation

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)

- **> 100 In-Water Runs**
- **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

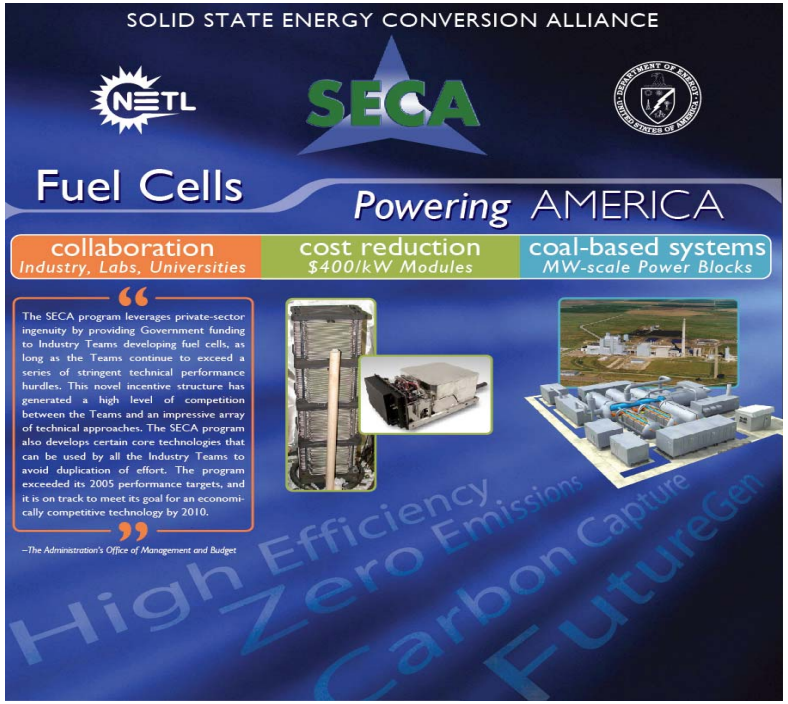
- **NETL website:**
  - www.netl.doe.gov

Reference Shelf

CDs available from the website

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

- **Office of Fossil Energy website:**
  - ww.fe.doe.gov



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