U.S. Department of Energy's Coal Technology R&D Programs – Responding to Climate Change

Presentation to Irish Government & Environment/Energy Sectors

May 21-24, 2007

Dublin, Ireland

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U.S. Department of Energy

Outline

- **Who is NETL**
- **Coal's critical role**
- **Climate change challenge**
- **DOE's R&D response**
  - Carbon capture
  - Carbon sequestration
- **Economic analyses**
- **FutureGen**

National Energy Technology Laboratory

- **Only DOE national lab dedicated to fossil energy**
  - Fossil fuels provide 85% of U.S. energy supply
- **One lab, five locations, one management structure**
- **1,200 Federal and support-contractor employees**
- **Research spans fundamental science to technology demonstrations**

Alaska

Oklahoma

Oregon

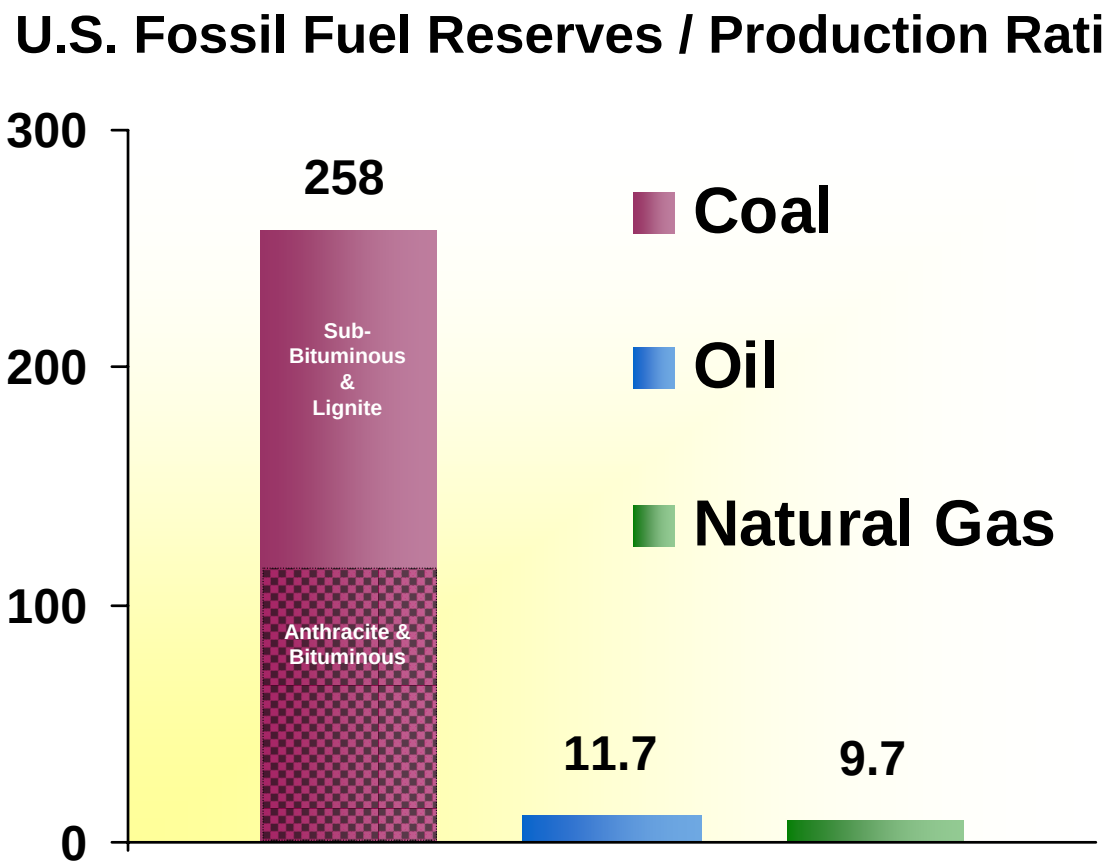
Pennsylvania

West Virginia

Why Coal ?

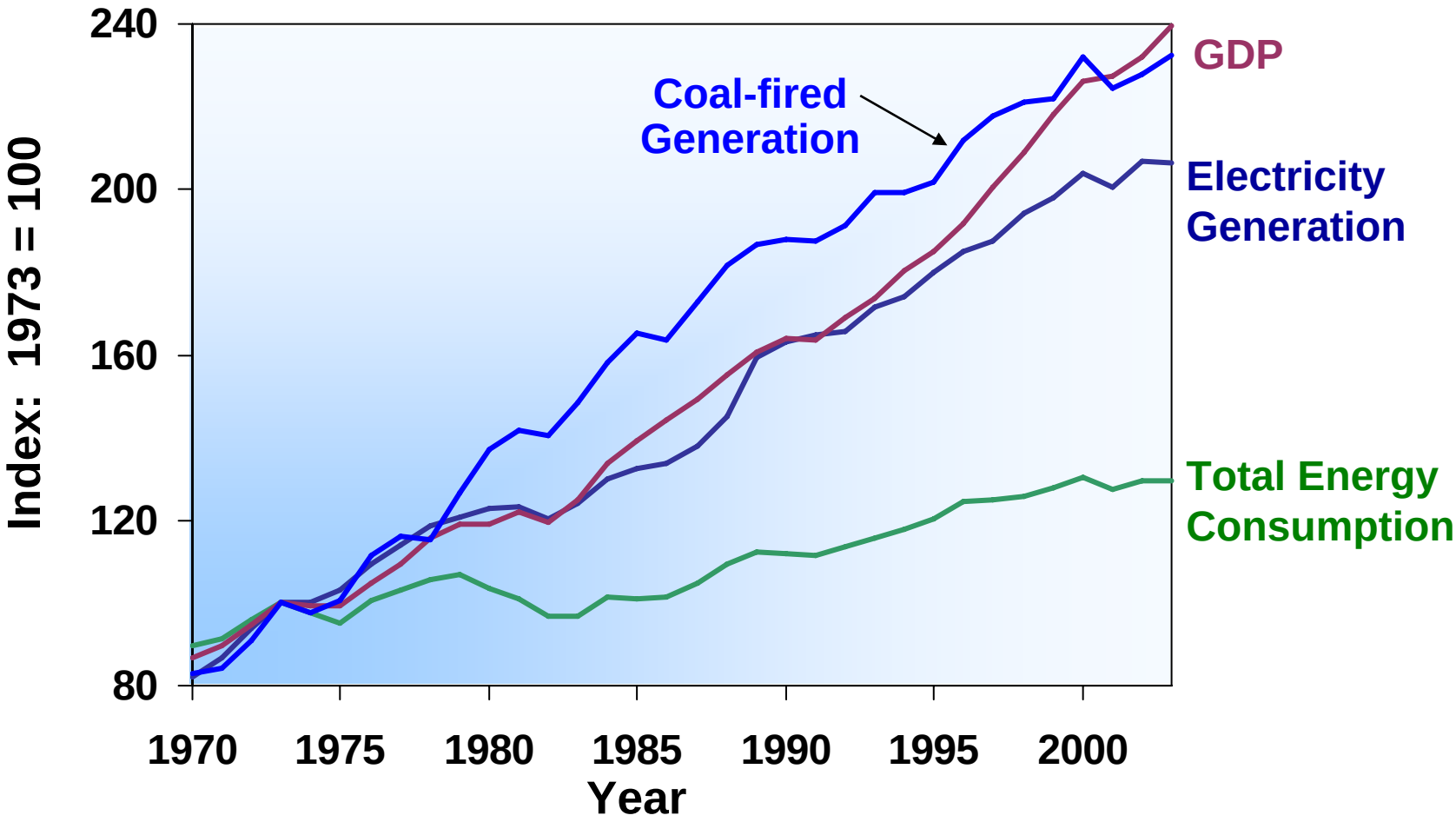
Coal Provides Sustainable, Affordable Energy Security !

250+ Year Supply at Current Demand Levels !



Sources: BP Statistical Review, June 2004, - for coal reserves data - World Energy Council; EIA, Advance Summary U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 2003 Annual Report, September 22, 2004 - for oil and gas reserves data.

Coal Use Linked to Economic Growth in United States!

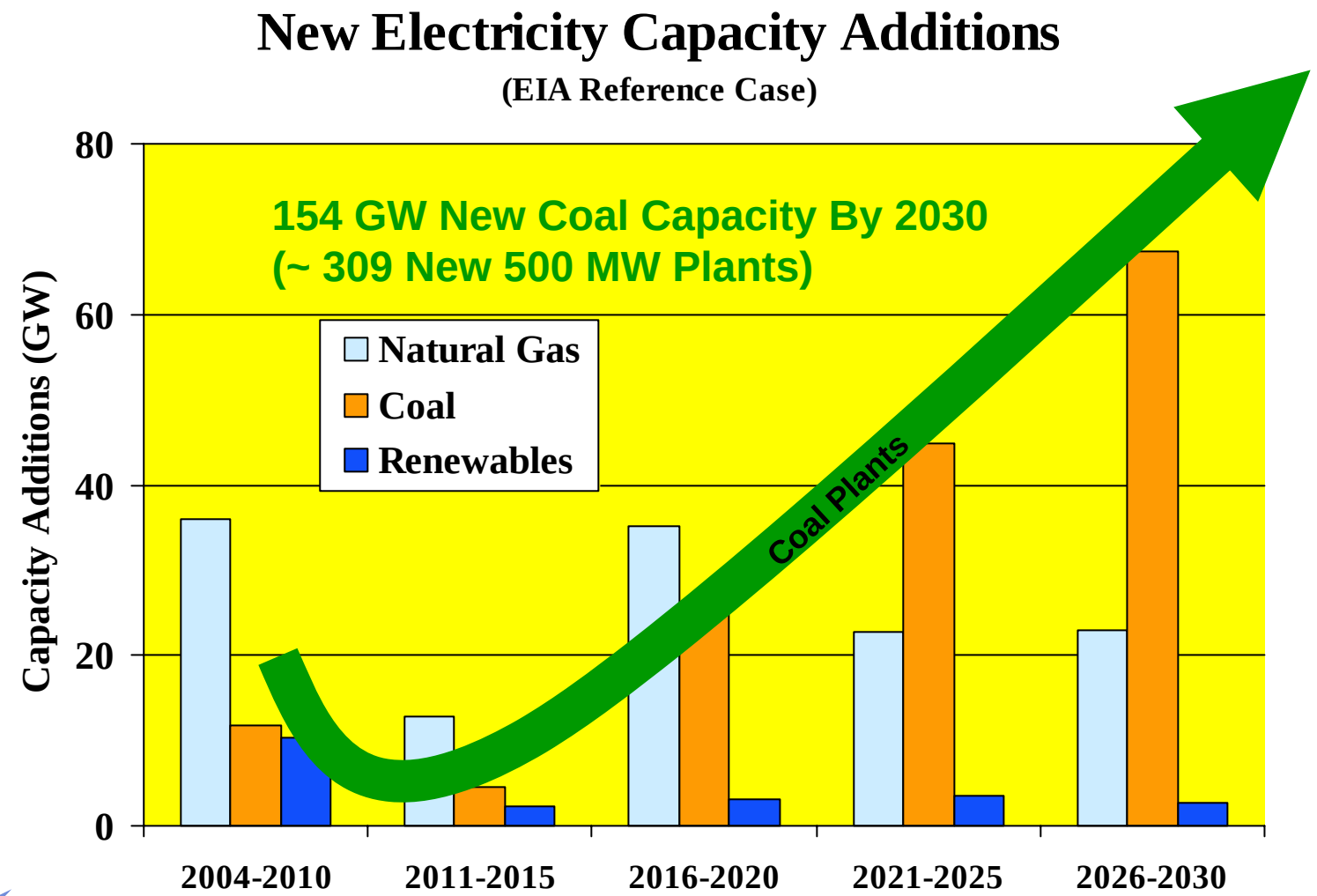


Coal-fired Generation and GDP Have Grown at Nearly the Exact Same Pace Over Last 30 Years

GDP: U.S. DOC, Bureau of Economic Analysis
Energy & Electricity: EIA, Annual Energy Review 2003

Coal Dominates U.S. Power Generation Forecast

(Accounts for 50% of New Capacity Additions)



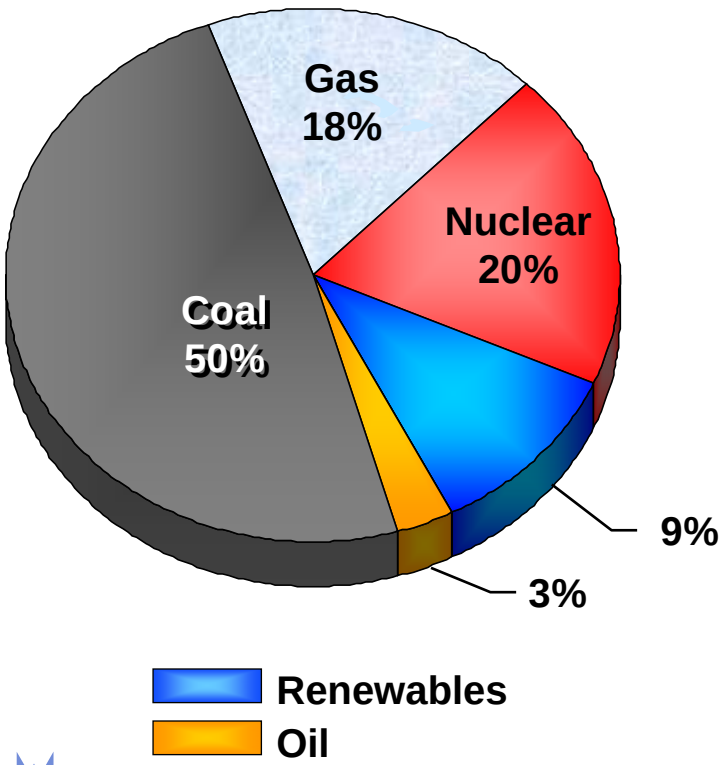
Source: Data Derived From EIA Annual Energy Outlook 2006

Fossil Fuels

World's Dominant Electricity Source

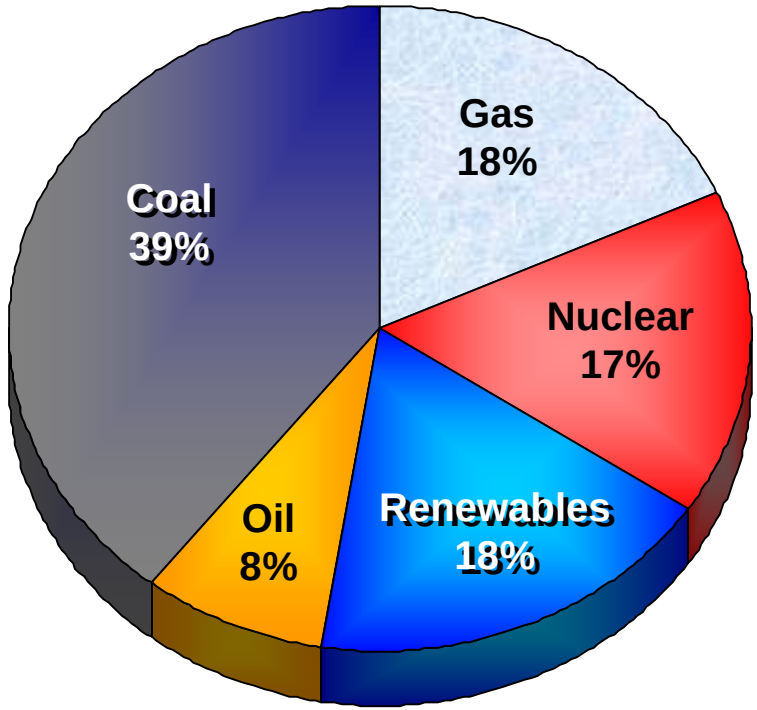
United States - 2004

3.97 Trillion kWh - 71% Fossil Energy



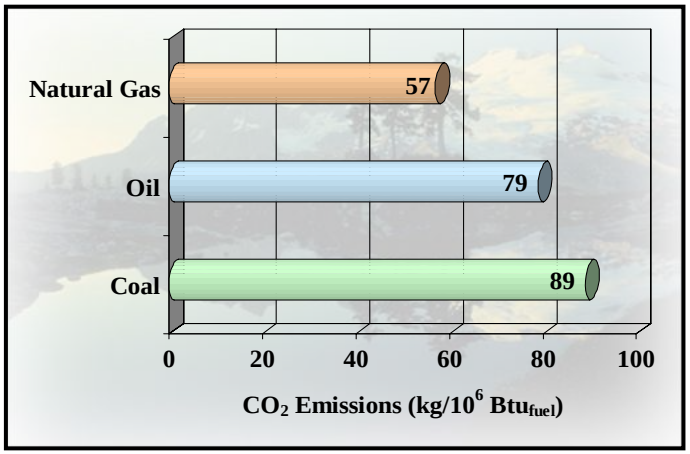
World - 2002

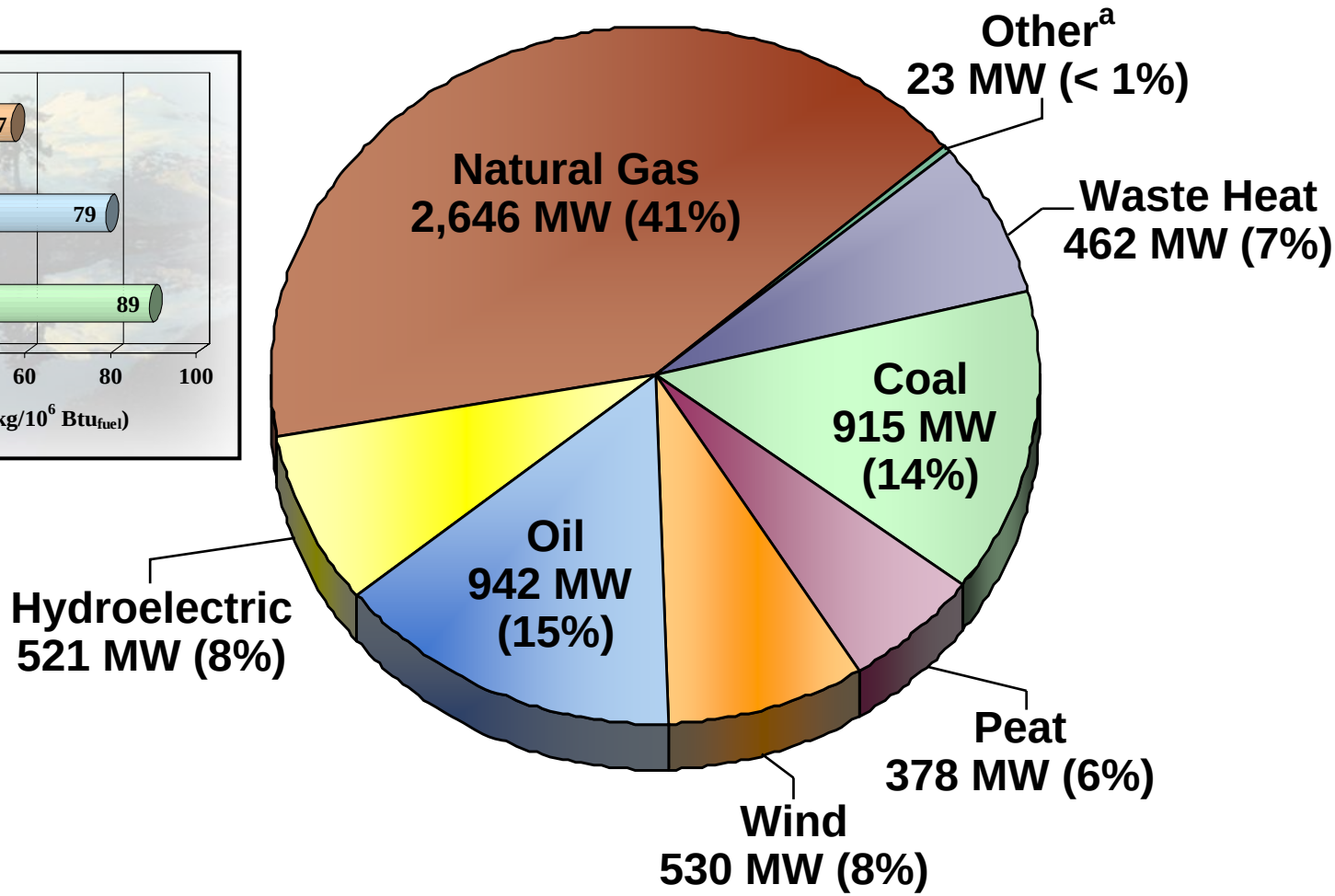
14.3 Trillion kWh - 65% Fossil Energy



Source: EIA International Energy Outlook 2005

Ireland's Electric Generating Capacity

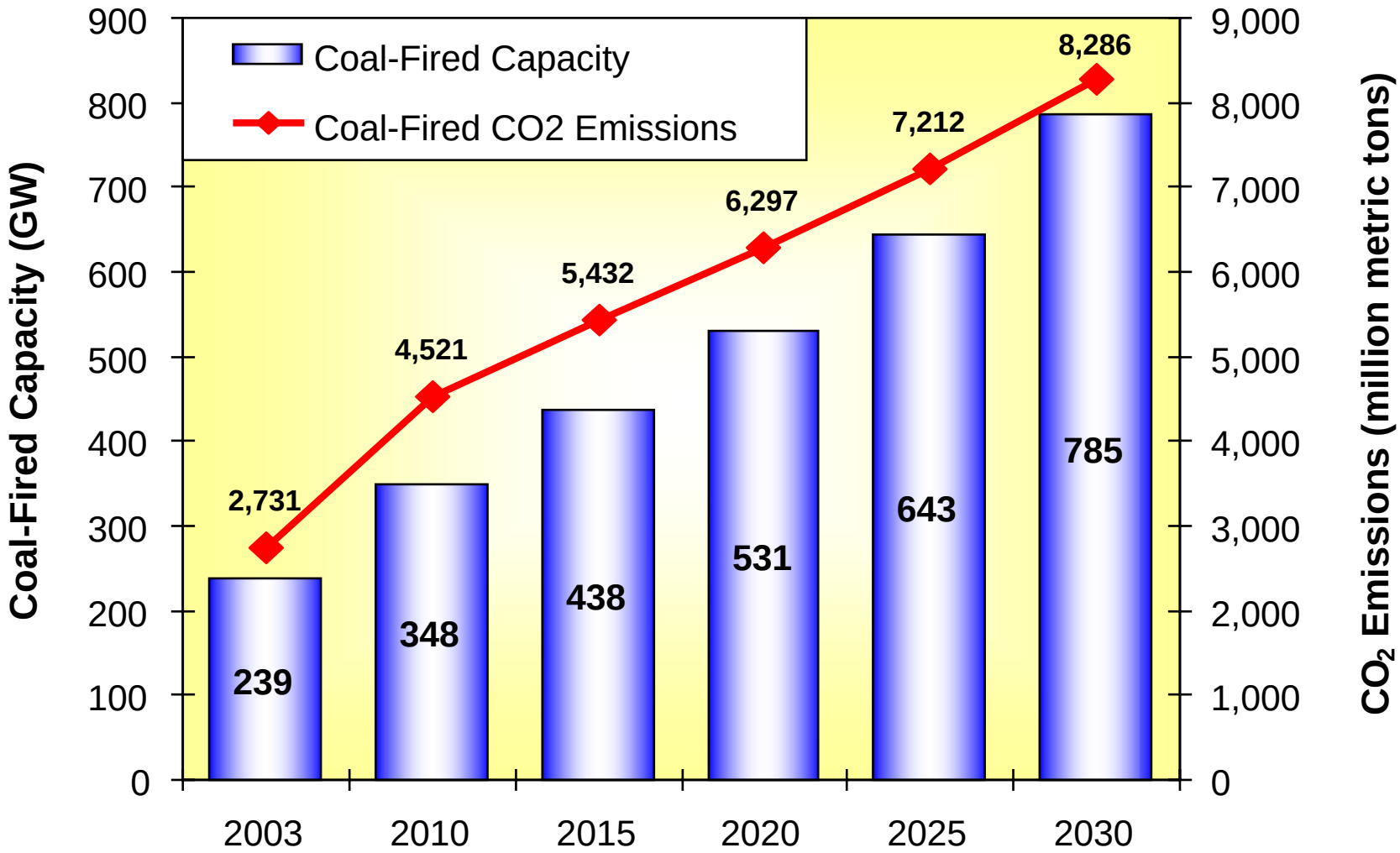




[a] Other category includes biogas (from digestion of sewage sludge, agricultural waste, food waste, and other organic materials), refinery off-gas, landfill gas, and wood.

Source: *The UDI World Electric Power Plants Data Base (WEPP)*

China's Coal Projections

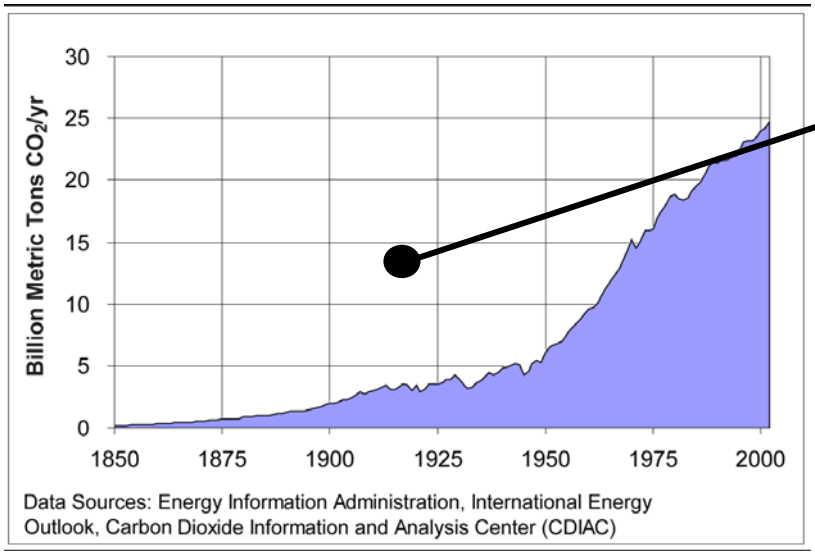


Sources: History: EIA, International Energy Annual 2003 (May-July 2005), website www.eia.doe.gov/iea/. Projections: EIA, Annual Energy Outlook 2006, AEO2006 National Energy Modeling System, run AEO2006.D111905A, web site www.eia.doe.gov/oiaf/aeo/; and System for the Analysis of Global Energy Markets (2006).

Key Challenges for Coal?

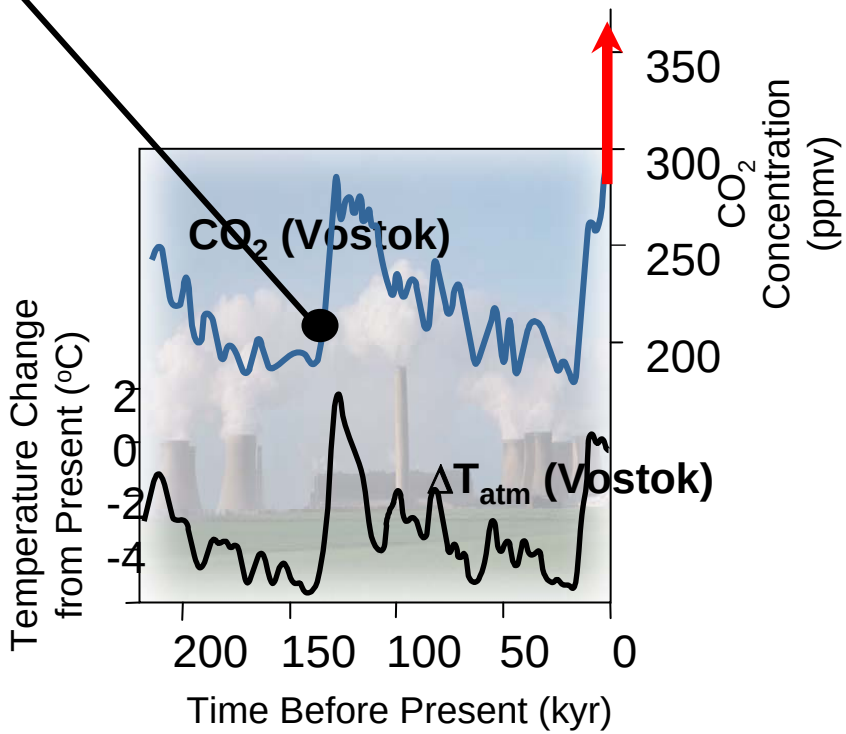
Climate Change!

CO_2 and Climate Change



Worldwide CO_2 Emissions from Fossil Fuel Combustion and Cement Manufacture

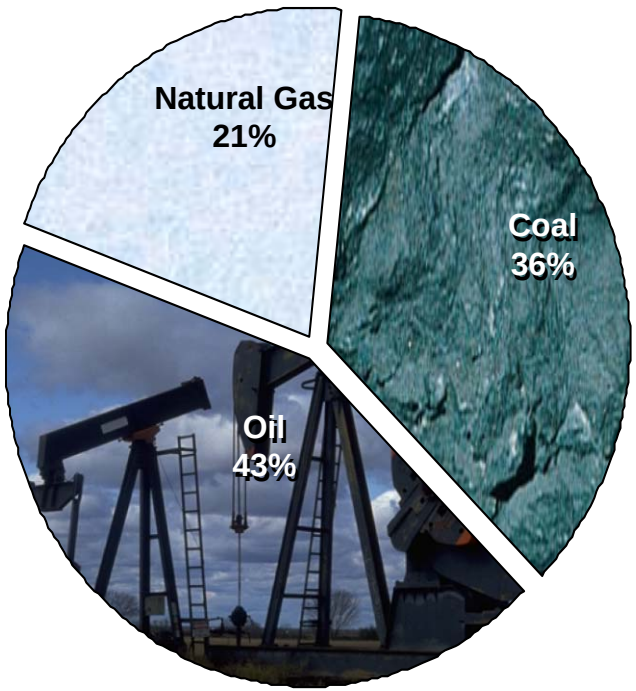
Atmospheric CO_2 concentrations increased from ~280 ppm to 381 ppm over last 100 years



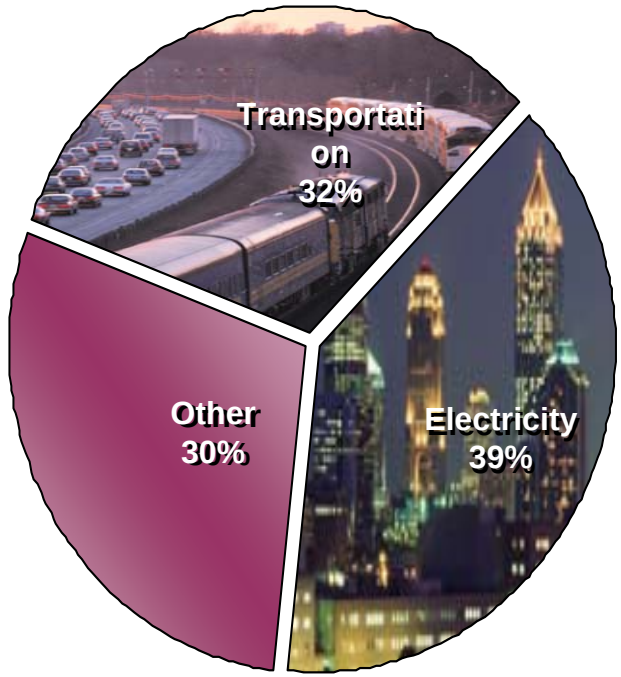
Connecting dots suggest CO_2 is contributing to climate change

All Fossil Fuels & Energy Sectors Contribute U.S. CO_2 Emissions

36% Emissions From Coal



39% Emissions From Electricity



Research & Development

Addressing Climate Change!

Technological Carbon Management Options

Pathways for Reducing GHGs -CO_2

Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

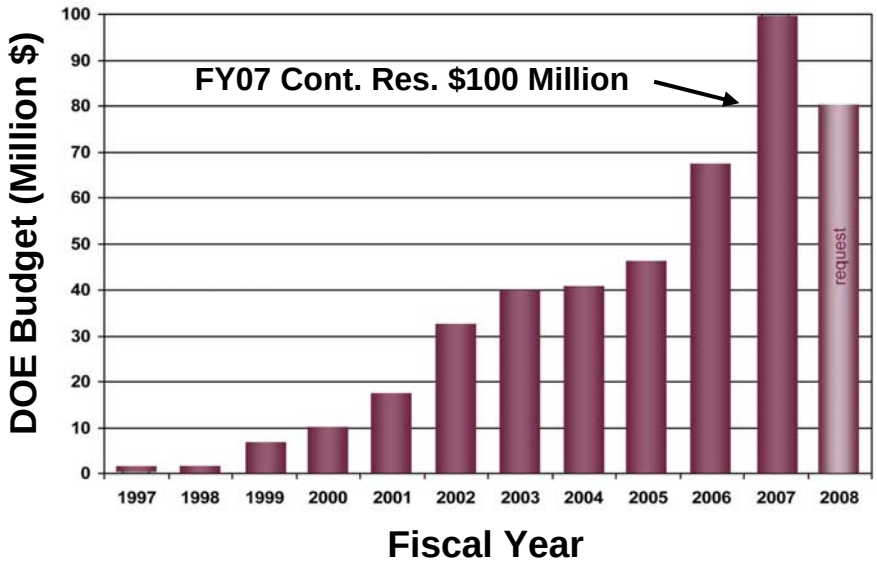
Sequester Carbon

- Enhance Natural Sinks
- Capture & Store

All options needed to:

- Affordably meet energy demand
- Address environmental objectives

U.S. DOE's Carbon Sequestration Program Statistics



Strong industry support

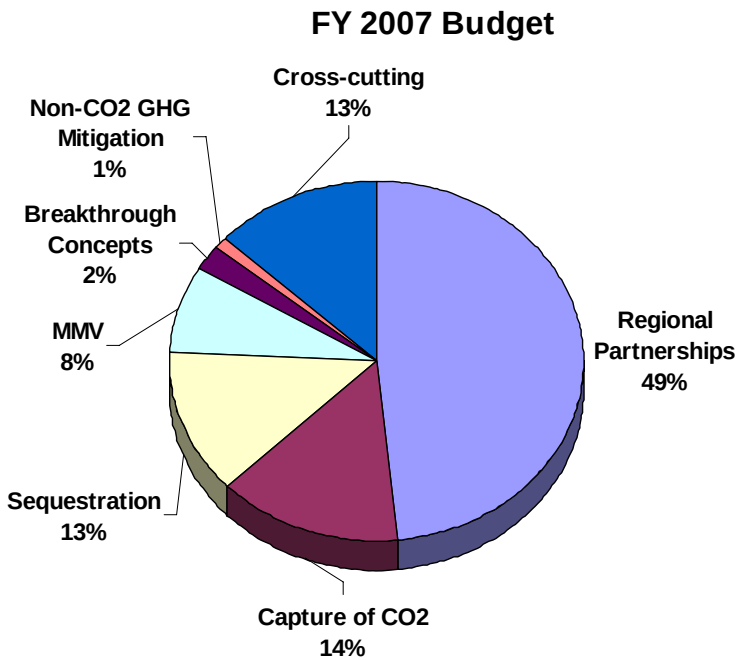
~ 39% cost share on projects

Federal Investment to Date

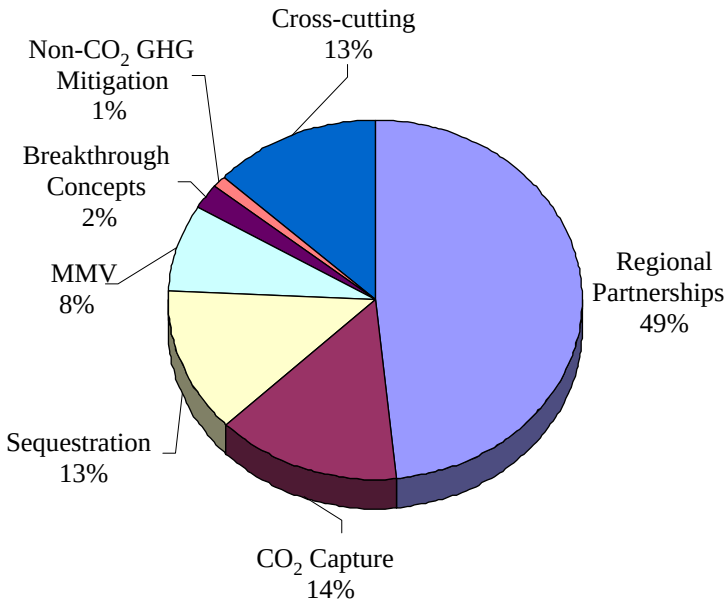
~ $360 Million

Diverse research portfolio

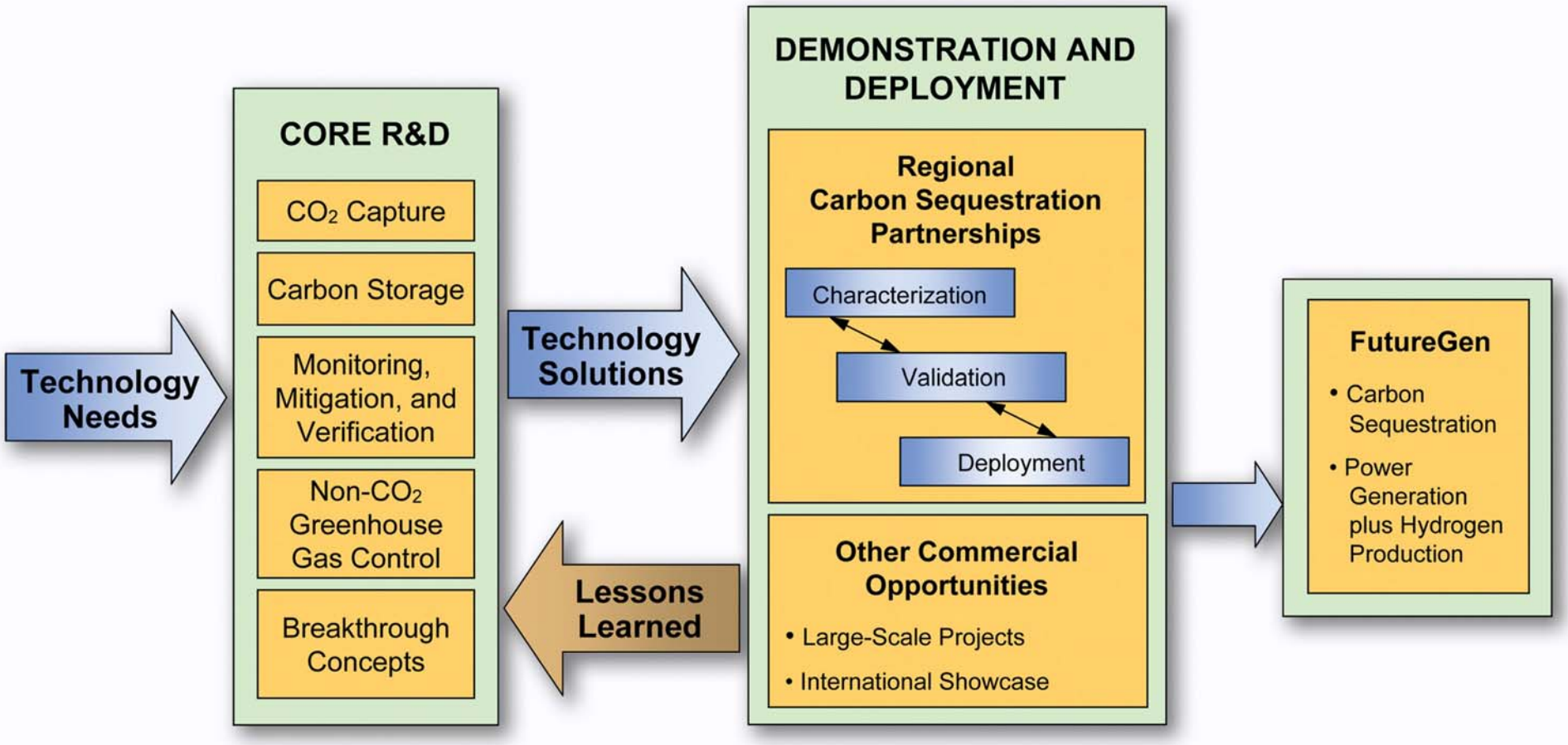
~ 70 Active R&D Projects



U.S. DOE's Carbon Sequestration Program Statistics



Carbon Sequestration Program Structure



Moneypoint Power Plant

- Operated by Ireland's Electric Supply Board
- 3, 305 MW coal-fired units
- Accounts for ~ 14% of Ireland's total electric generating capacity
- Equipped with ESP and low-NOx burners, with SCR and FGD coming on line in 2008, to address PM, NOx, and SO_2 emissions
- What about CO_2?

ESB's Moneypoint Coal-Fired Power Plant, County Clare, Ireland

Before CO_2 Can be Stored….it Must be Captured

Separation and concentration of CO_2 from fuel or flue streams:

Three general classes of capture technology:

- **Pre-combustion (IGCC)**
- **Post-combustion**
- **Oxy-firing combustion**

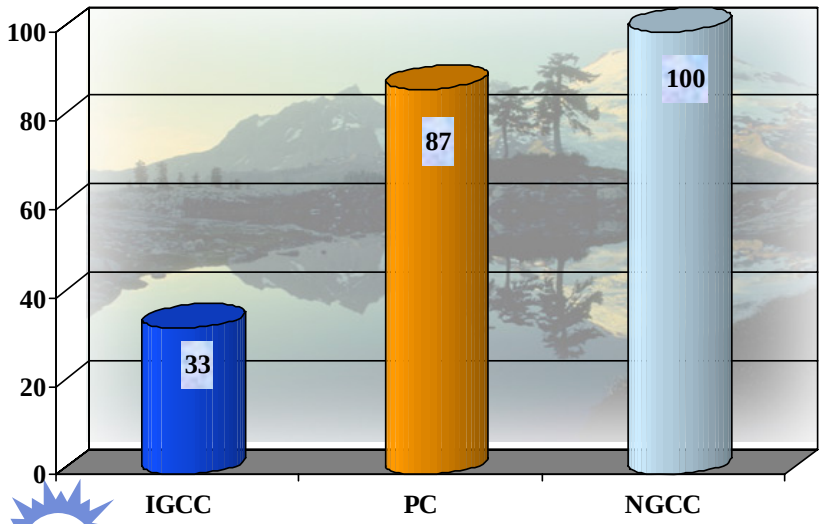
Current "Best Case" Technologies Costly

Using State-of-the-Art Scrubbing Technologies

- 5 to 30% parasitic energy loss
- 30 to 100% increase in capital cost
- 25 to 80% increase in cost of electricity

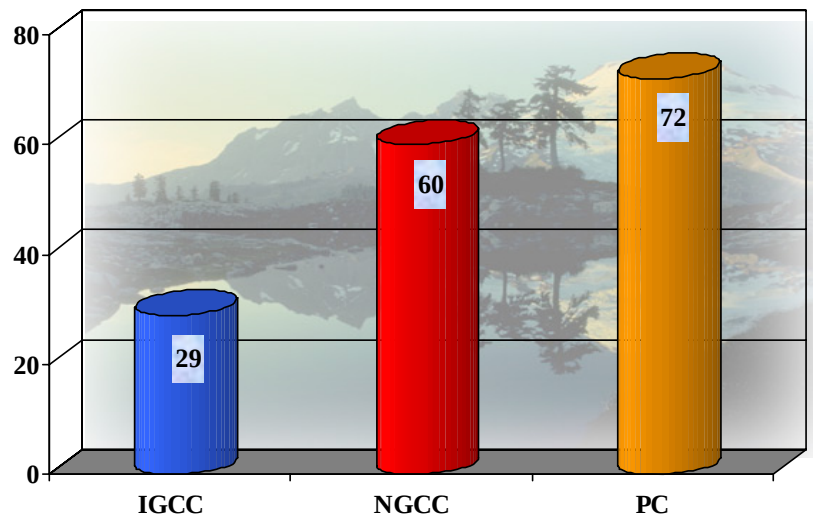
Effect of CO_2 Capture on Capital Cost

(% Increase Resulting From CO_2 Capture)



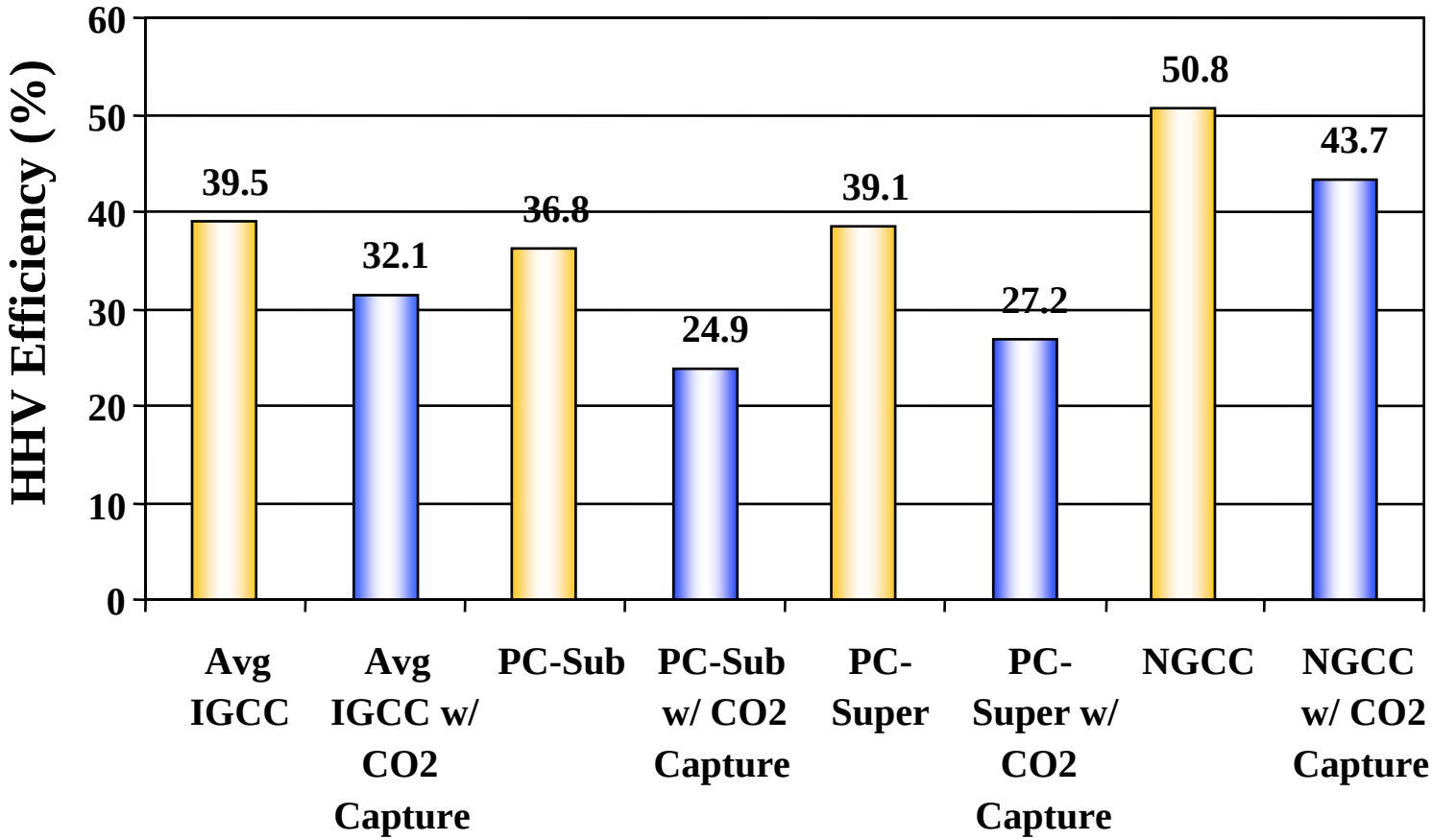
Effect of CO_2 Capture on Cost of Electricity

(% Increase Resulting From CO_2 Capture)



Efficiency Comparison

Significant Energy Penalty with Capture



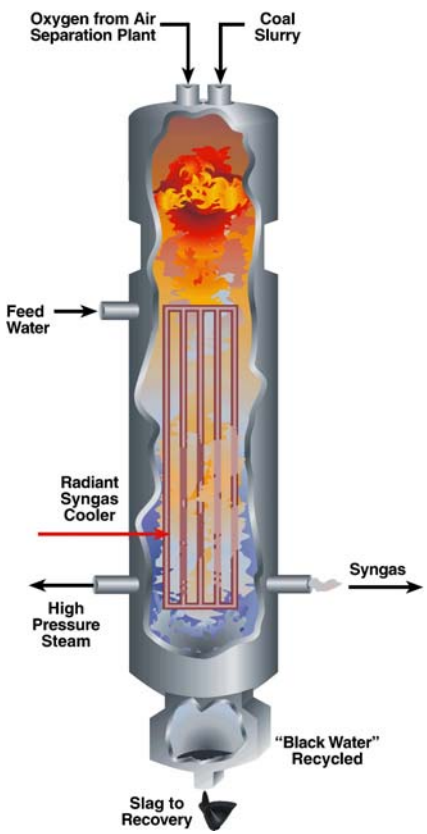
Source: Cost and Performance Baselinefor Fossil Energy Plants, Updated Technical Performance, April 2007, NETL *Available at: http://www.netl.doe.gov/technologies/carbon_seq/Resources/Analysis/*

Research & Development

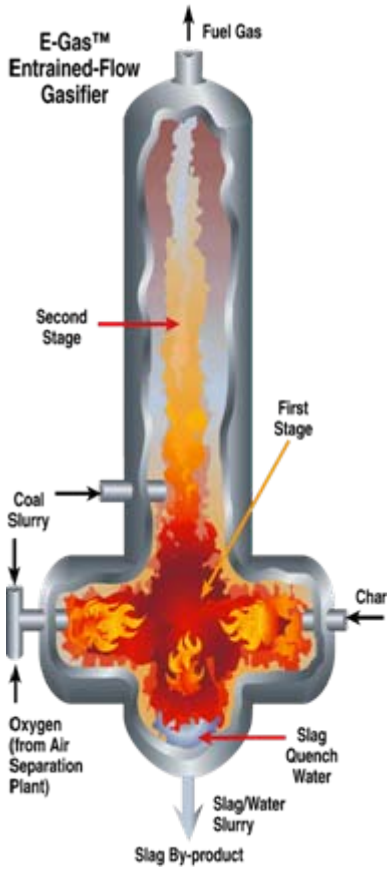
Pre-combustion Capture (IGCC)

Gasifier Technology

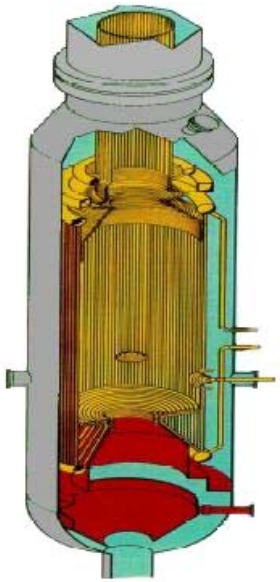
GE Energy
(Chevron-Texaco) *



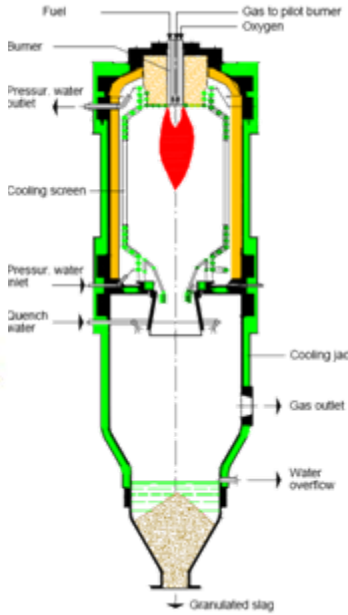
ConocoPhillips E-Gas*



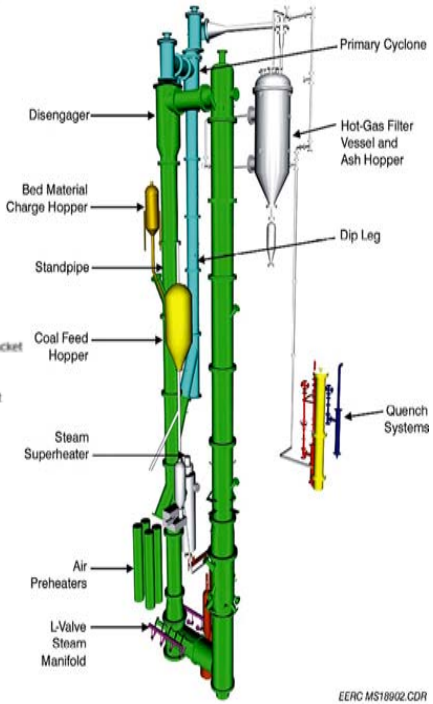
Shell SCGP*



Siemens *(GSP/Noell)**



KBR Transport



*** Commercially available**

Integrated Gasification Combined Cycle (IGCC) Technology

IGCC Advantages

- Fuel and product flexibility
- High efficiency
- Environmentally superior
- Sequestration capable

Current IGCC Issues

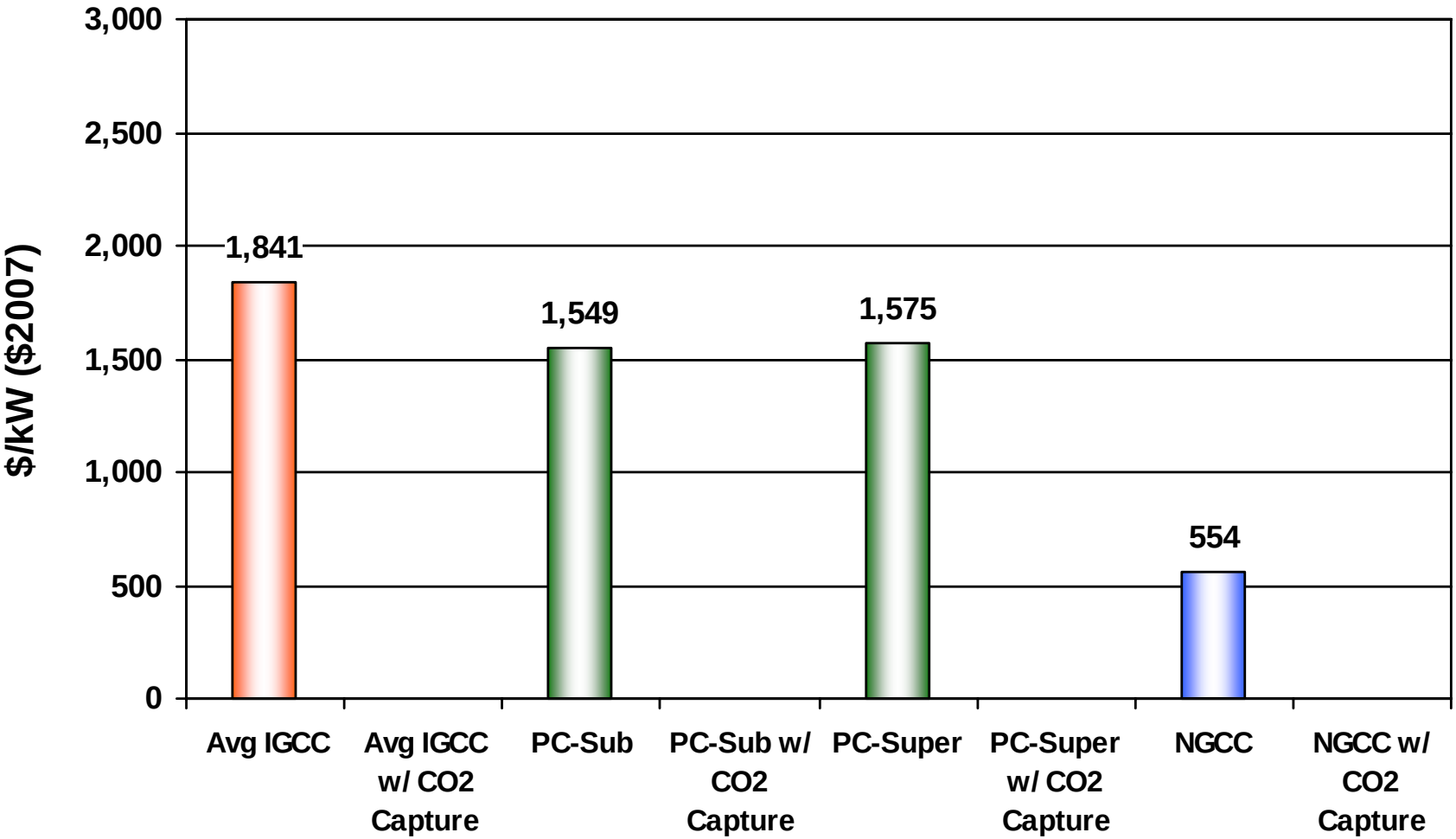
- Capital cost 5–20% higher than conventional coal
- Reliability lower

Tampa Electric's 250 MW_e Polk Station

Cinergy's 262 MW_e Wabash River Plant

Two U.S. IGCC demonstration plants

Total Plant Cost Comparison

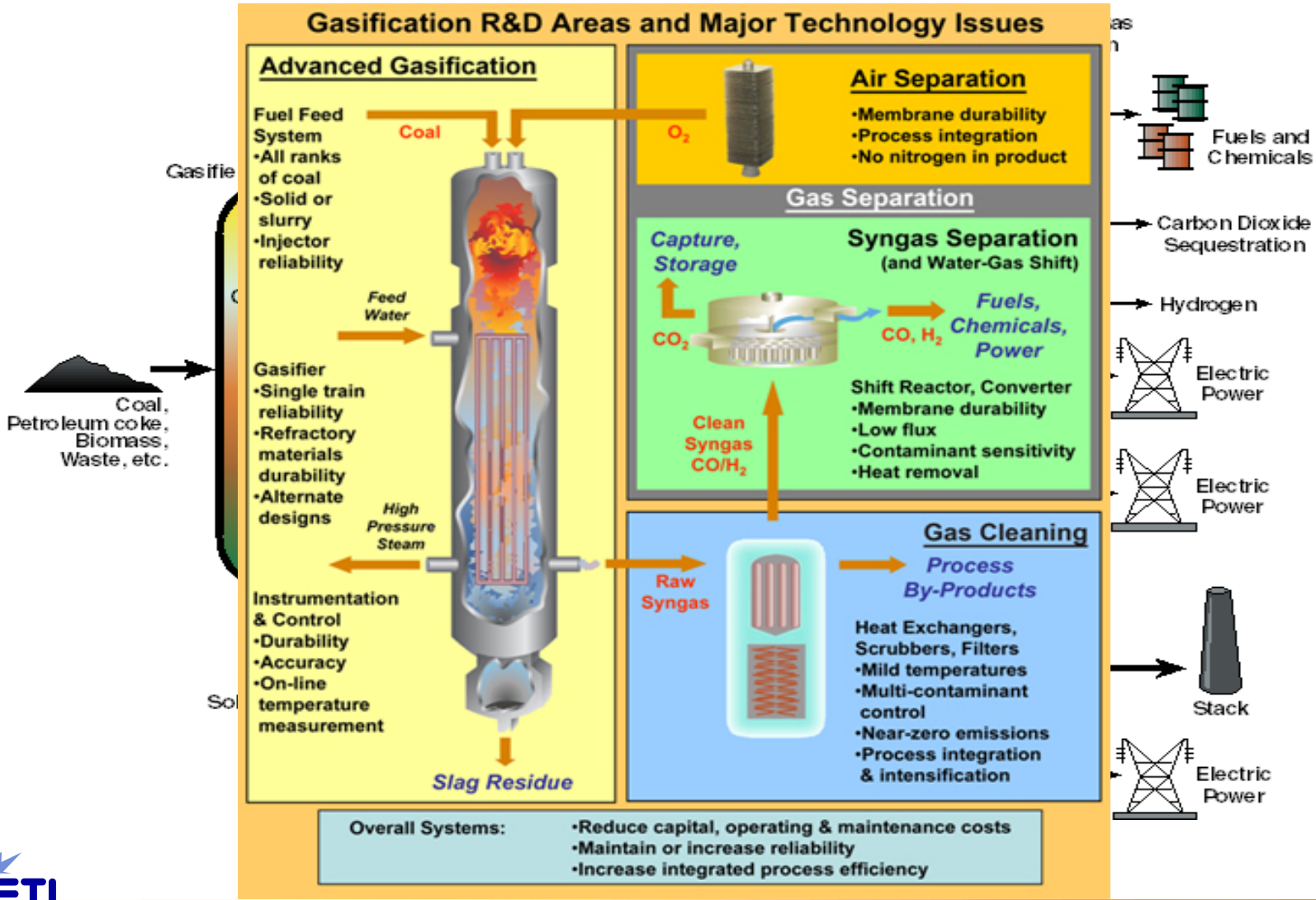


Total Plant Capital Cost includes contingencies and engineering fees

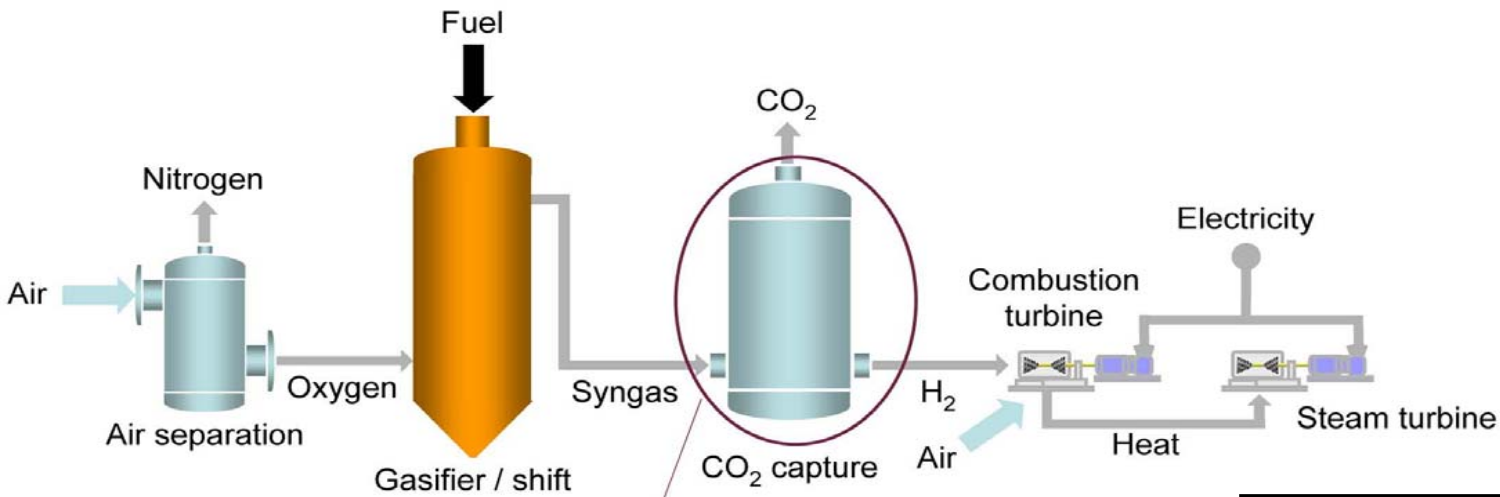
Source: *Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity.*

IGCC – A Multi-product Technology

Major Technology Issues



Pre-Combustion CO_2 Capture



Example: Physical Solvents

The conditions for CO_2 separation in pre-combustion capture processes are quite different from those in post-combustion capture, and may favor physical solvents, which combine less strongly with CO_2. Physical solvents also have a larger CO_2 capacity at pre-combustion conditions, and CO_2 solvent separation can be accomplished at lower stripper pressures, resulting in lower regeneration energy consumption.

Pre-Combustion

- **Decarbonization**
- **Advanced Sorbents**
- **Hybrid Sorbent/Membranes**

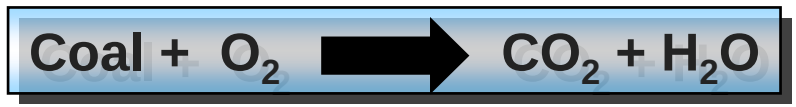
- **NEXANT—**CO_2 Hydrate
- **NETL—**Dry Sorbents, Membranes
- **BP—**CO_2 Capture Project
- **U. Minn—**Hydrogen Silica Membranes
- **Eltron**—Membrane WGS
- **INEEL, LANL**—High Temperature polymer membrane

Research & Development

Oxy-fuel Combustion

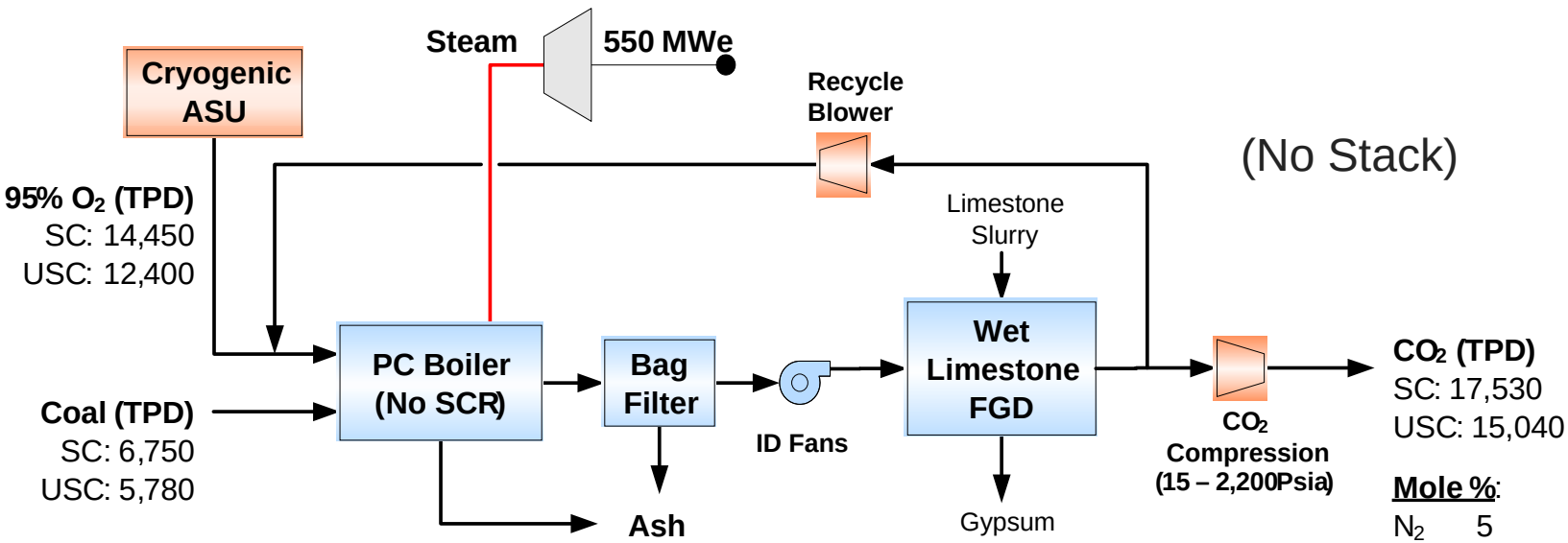
Oxy-combustion in Pulverized Coal Boilers for CO_2 Capture

- **Principle**: O_2 is provided by ASU, N_2 is replaced by re-circulated CO_2



  - O_2 is diluted in re-circulated flue gas **for temperature control**
  - **No nitrogen dilution of the flue gas:** CO_2 rich flue gas **enables easier CO_2 capture**
  - Potential to eliminate NOx control
  - Utilizes existing technologies

Pulverized Coal Oxy-combustion



Challenges:

1. Requires 3 additional units
2. High combustion temperatures requiring large amounts of flue gas recycle, up to 80% of flue gas
3. CO_2 produced at ambient conditions → large compression load
4. High sulfur coal requires FGD unit
5. Cryogenic oxygen production is expensive and energy intensive

Oxy-combustion R&D Projects

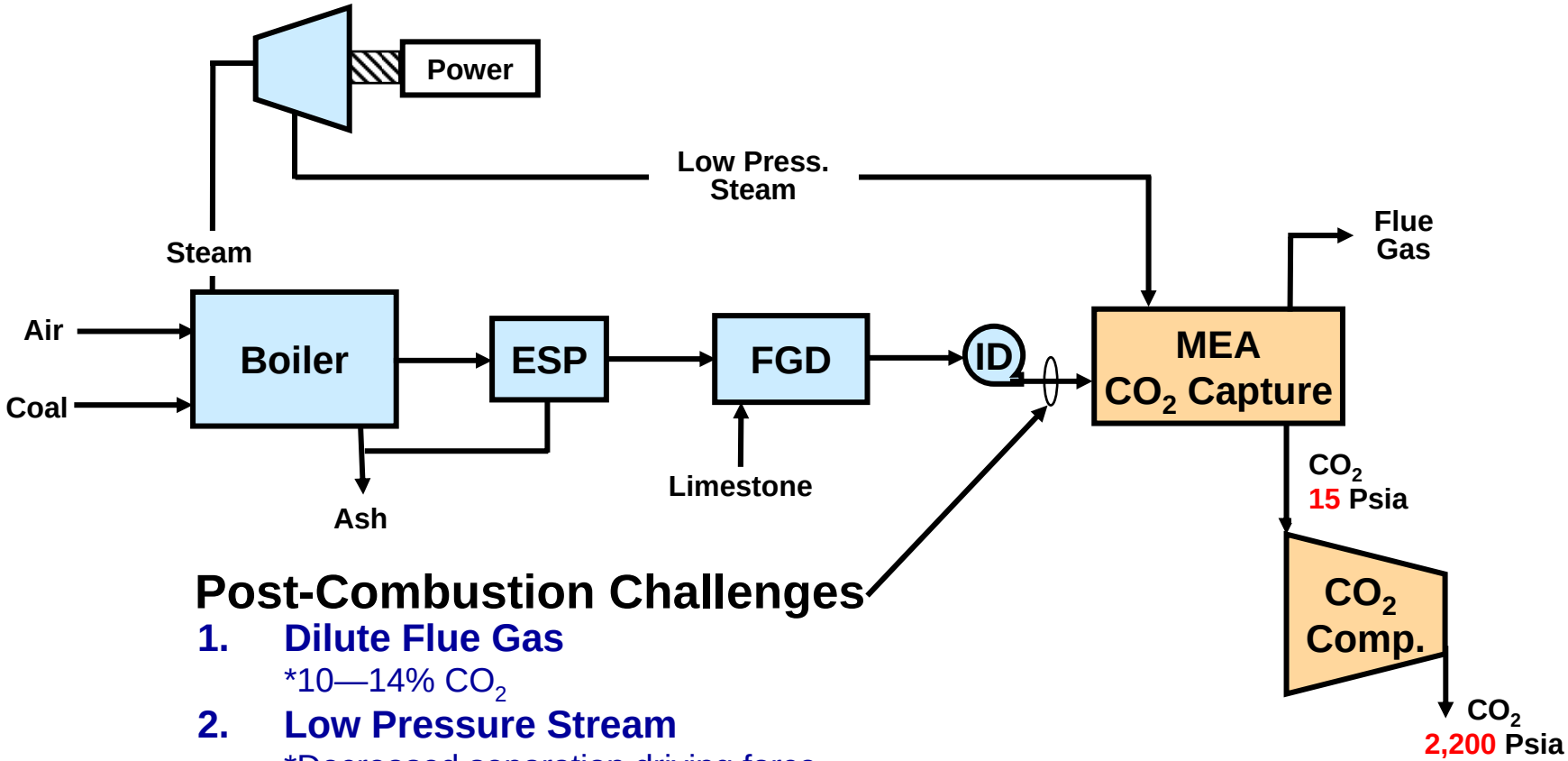
- **Southern Research Institute**
  - Oxygen-Fired CO_2 Recycle for Application to Direct CO_2 Capture from Coal-Fired Power Plants (started October 2005)
- **BOC Group**
  - Pilot-Scale Demonstration of a Novel, Low-Cost Oxygen Supply Process and its Integration with Oxy-Fuel Coal-Fired Boilers (under negotiation)
- **B&W**
  - Development of Cost-effective Oxy-combustion Technology for Retrofitting Coal-fired Boilers (under negotiation)

Research & Development

Post-combustion Capture

Post-Combustion Current Technology

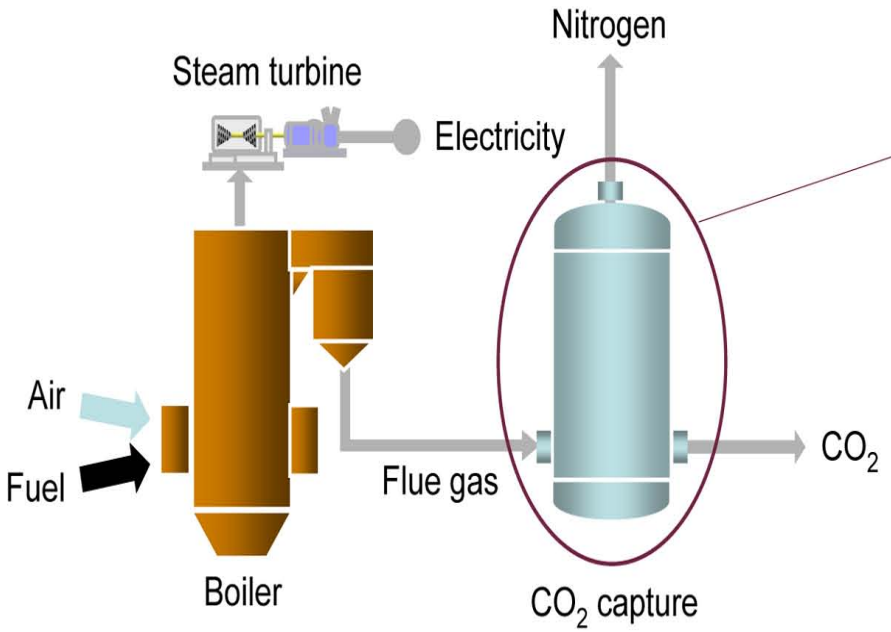
Pulverized Coal Power Plant with CO_2 Scrubbing



Post-Combustion Challenges

1. **Dilute Flue Gas**
   *10—14% CO_2
2. **Low Pressure Stream**
   *Decreased separation driving force
3. **Contaminants**
   *SO_2, Particulates, etc.
4. **Large Parasitic Load (regeneration steam)**

Post-Combustion CO_2 Capture



Example: Chemical Solvents

The most common chemical solvents used for CO_2 capture from low-pressure flue gas are amines. After the CO_2 reacts with the solvent in the absorption vessel, the CO_2-rich solvent passes through the stripping column, where it is heated with steam to reverse the CO_2 absorption reaction. The CO_2 collected in the stripper is compressed for transport and storage, and the CO_2-lean solvent is recycled to the absorption stage.

Post Combustion Challenges

- **Chemical and Physical Sorbents**
- **Hybrid Sorbent/Membranes**
- **Gas/Liquid Contactors**

- **NETL**—Aqueous Ammonia
- **NETL**—Amine Enriched Sorbents
- **UT Austin**—K_2CO_2/Piperazine adsorption
- **U New Mexico**—Membranes
- **Notre Dame**—Ionic Liquids
- **RTI**—Dry Regenerable Sorbent

Post-combustion CO_2 Capture

Critical Technology Pathways

1) **Amine-based Systems** ***(Fluor, MHI, Cansolv Technologies)***
2) **Carbonate-based Systems** ***(University of Texas @ Austin)***
3) **Ammonia-based Systems** ***(Alstom, NETL/ORD, Powerspan)***
4) **Membranes** ***(University of New Mexico, New Mexico Institute of Mining & Technology)***
5) **CO_2 Capture Sorbents (solids) –** ***(NETL/ORD, Research Triangle Institute)***
6) **Metal Organic Frameworks (MOFs) –** ***(UOP, Univ. of Michigan, Northwestern University)***
7) **Enzyme-based Systems** ***(Carbozyme)***
8) **Ionic Liquids (ILs) –** ***(University of Notre Dame)***
9) **Novel Techniques** ***(University of Akron, Membrane Technology & Research)***

Significant Parasitic Power Requirements for MEA

Energy Penalty due to CO_2 Capture	10%	20%	30%	40%
Target Market, GW	184	184	184	184
Fleet CO_2 Reduction, %	50.2	49.2	47.9	46.3
New Capacity Req'd, GW	25.5	57.5	98.5	153.3
Additional Coal Req'd., tons x 10^3	79,940	179,864	308,338	479,637
Cost of New Capacity, MM$	45,975	103,444	177,332	275,850
Cost of CO_2 Retrofits, MM$	91,950	91,950	91,950	91,950
Total New Cost, MM$	137,925	195,394	269,282	367,800

Current energy penalty of CO_2 BACT MEA absorption system

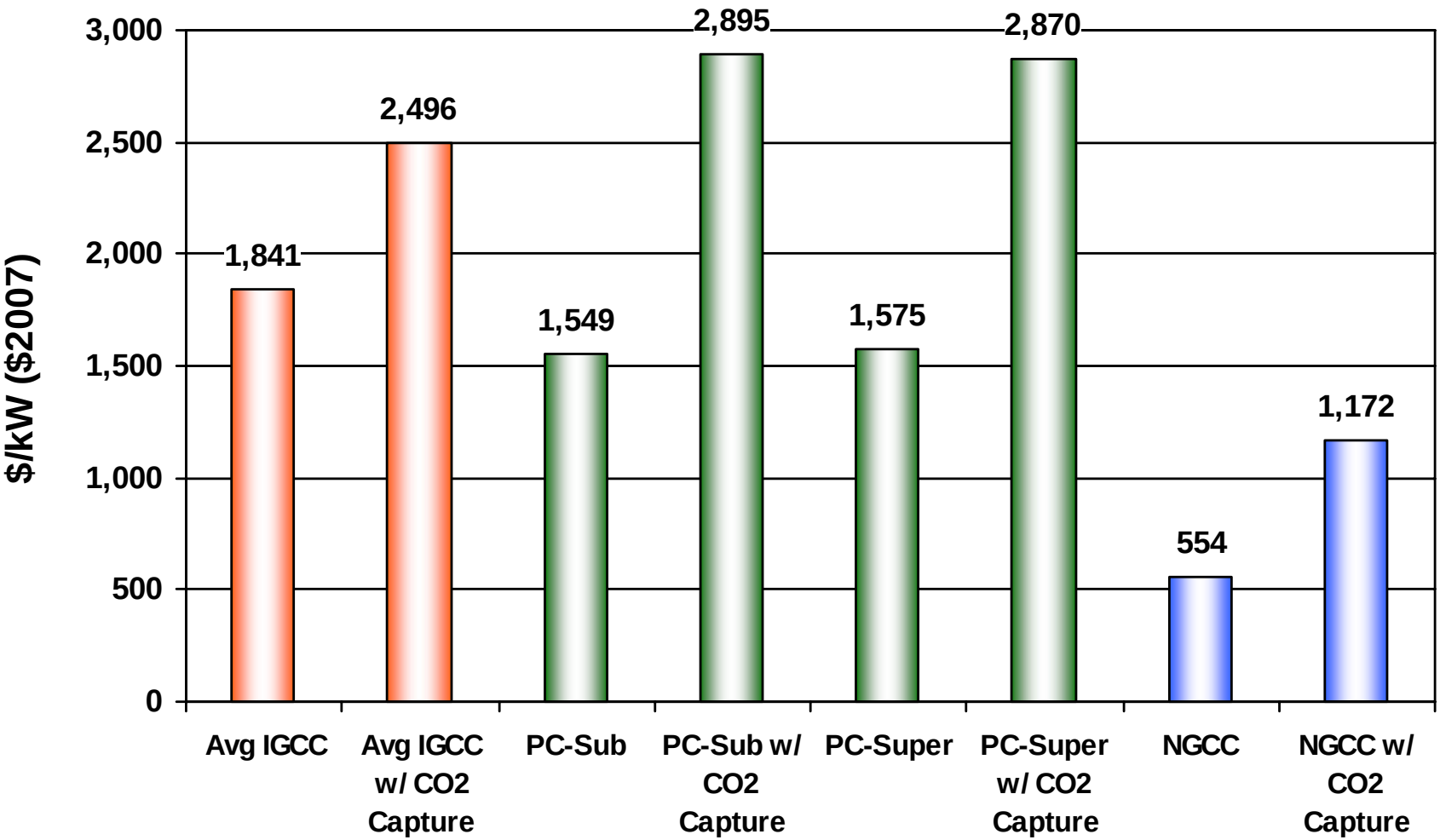
Source: U.S. DOE Carbon Capture and Separation Program: A Program Synopsis

CO_2 Capture Technology Demonstrations at Existing Plants

- **Alstom's Chilled Ammonia Process (CAP)**
  - 5 MW slipstream test at WeEnergies' Pleasant Prairie (summer 2007)
  - 30 MW pilot-scale test at AEP's Mountaineer Plant (mid-2008)
  - Full-scale installation at AEP's 450 MW Northeastern Station (late 2011)
    - Capture ~1.5MM tonnes CO2/yr for Enhanced Oil Recovery (EOR)

- **B&W's Oxy-coal Combustion Technology**
  - 10 MW pilot-scale test B&W's Clean Environment Development Facility (summer 2007)
  - Feasibility study to select an existing AEP unit for full-scale installation (early 2008)
  - Complete full-scale installation at an existing AEP site (2012 – 2015)

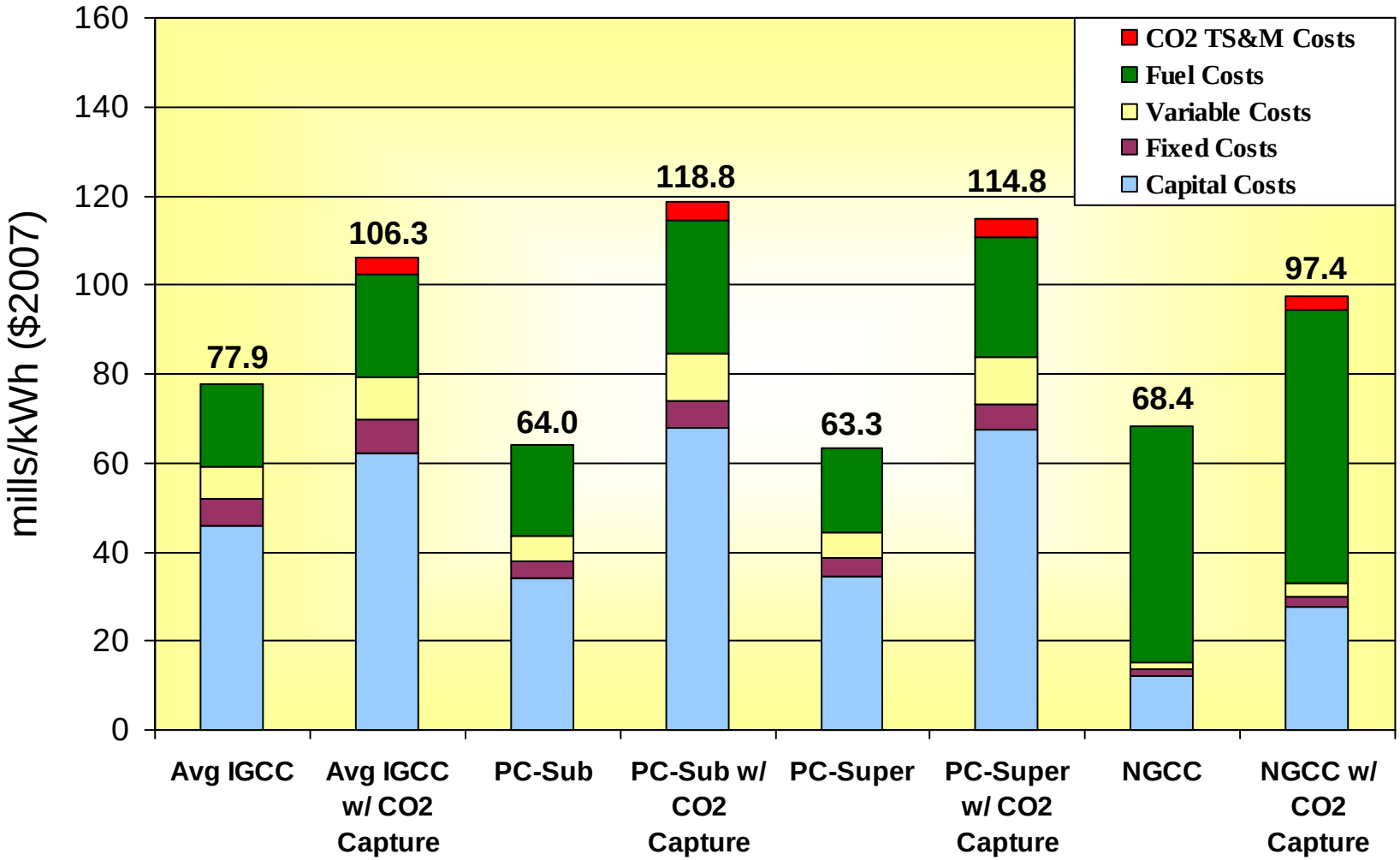
Total Plant Cost Comparison



Total Plant Capital Cost includes contingencies and engineering fees

Source: *Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity.*

Cost of Electricity Comparison



January 2007 Dollars, Coal cost $1.80/$10^6$Btu. Gas cost $6.75/$10^6$Btu

CO2 Transport, Storage and Monitoring (TS&M) costs include 50 miles of pipeline transport, storage in saline formation at a depth of 4,000 ft, and continuous monitoring for 80 years.

Source: *Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity.*

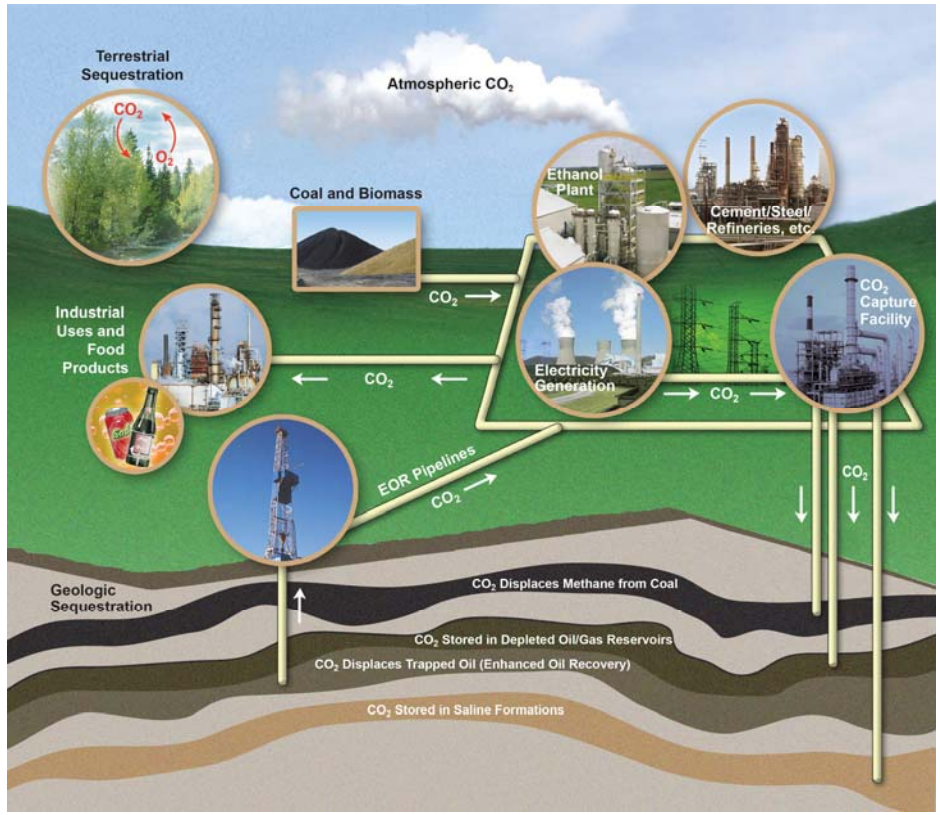
Research & Development

CO_2 Sequestration/Storage

Once Captured, CO_2 Needs to be Stored

Storage locations include:

- Underground reservoirs (geological)
  - **Enhanced oil recovery**
  - **Depleted oil and gas fields**
  - **Saline aquifers**
  - **Unmineable coal beds**
- Trees, grasses, soils, or algae (terrestrial)
- Dissolved in deep oceans



Regional Carbon Sequestration Partnerships

"Developing the Infrastructure for Wide Scale Deployment"

400 Organizations
40 States (NY soon to join)
4 Canadian Provinces
3 Indian Nations
Total of 34% cost share

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

MGSC

MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

The Plains CO_2 Reduction Partnership PCOR Partnership

Southwest Regional Partnership on Carbon Sequestration

Southeast Regional Carbon Sequestration Partnership SECarbon.org

West Coast Regional Carbon Sequestration Partnership westcarb.org

Characterization Phase

- 24 months (2003-2005)
- 7 Partnerships (40 states)
- $16M DOE funds

Validation Phase

- 4 years (2005 - 2009)
- Field validation tests
  - 25 Geologic
  - 11 Terrestrial
- $100M DOE funds
- $43M cost share

Deployment Phase

- 10 years (2008-2017)
- Several large volume injection tests

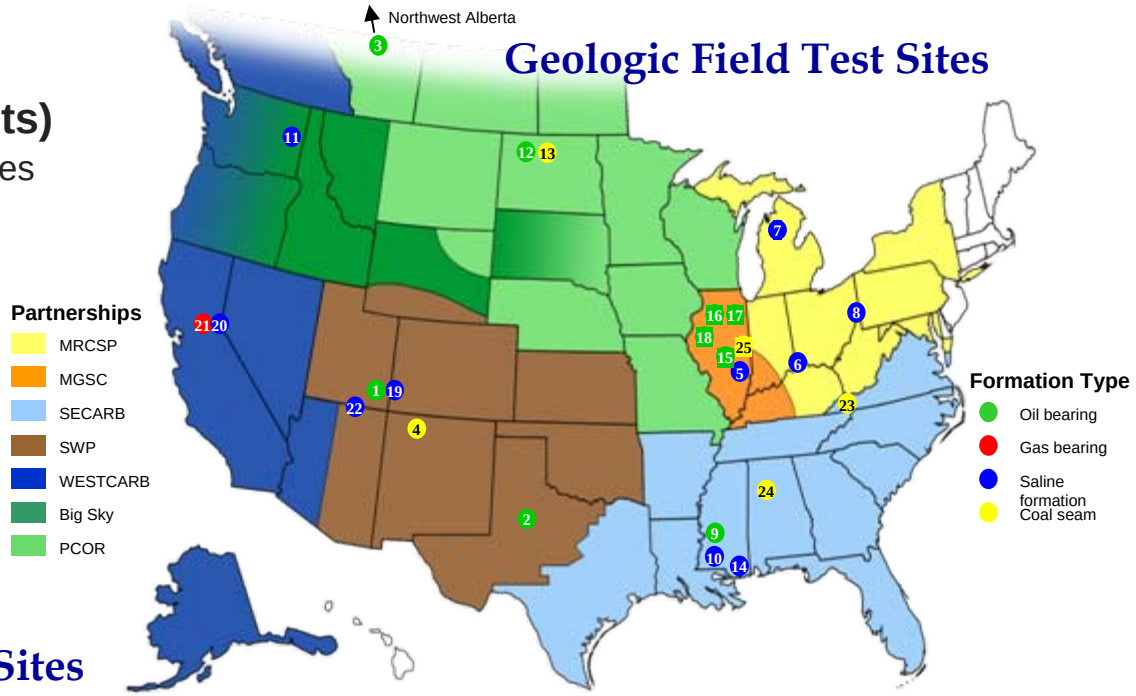
NETL

Validation Phase Field Tests

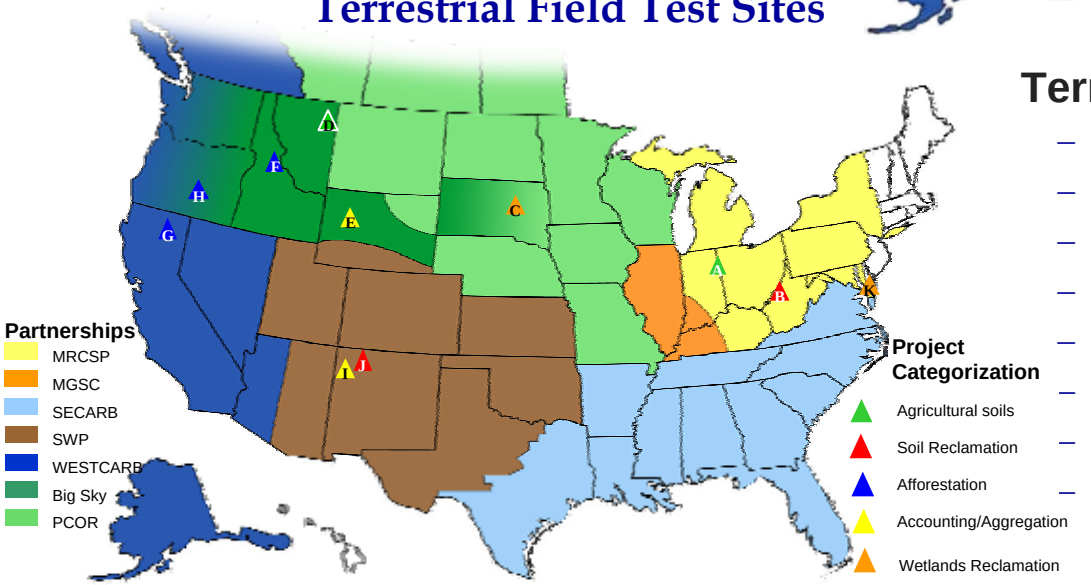
Geologic Tests (25 injection tests)

- Validating geologic formation capacities
- Validating injectivity
- Monitoring mitigation and verification technologies (reservoir modeling)
- Permitting requirements
- Public outreach and perception
- Testing formation seals
- Investigating well bore construction methods

Geologic Field Test Sites



Terrestrial Field Test Sites



Terrestrial Tests (11 field tests)

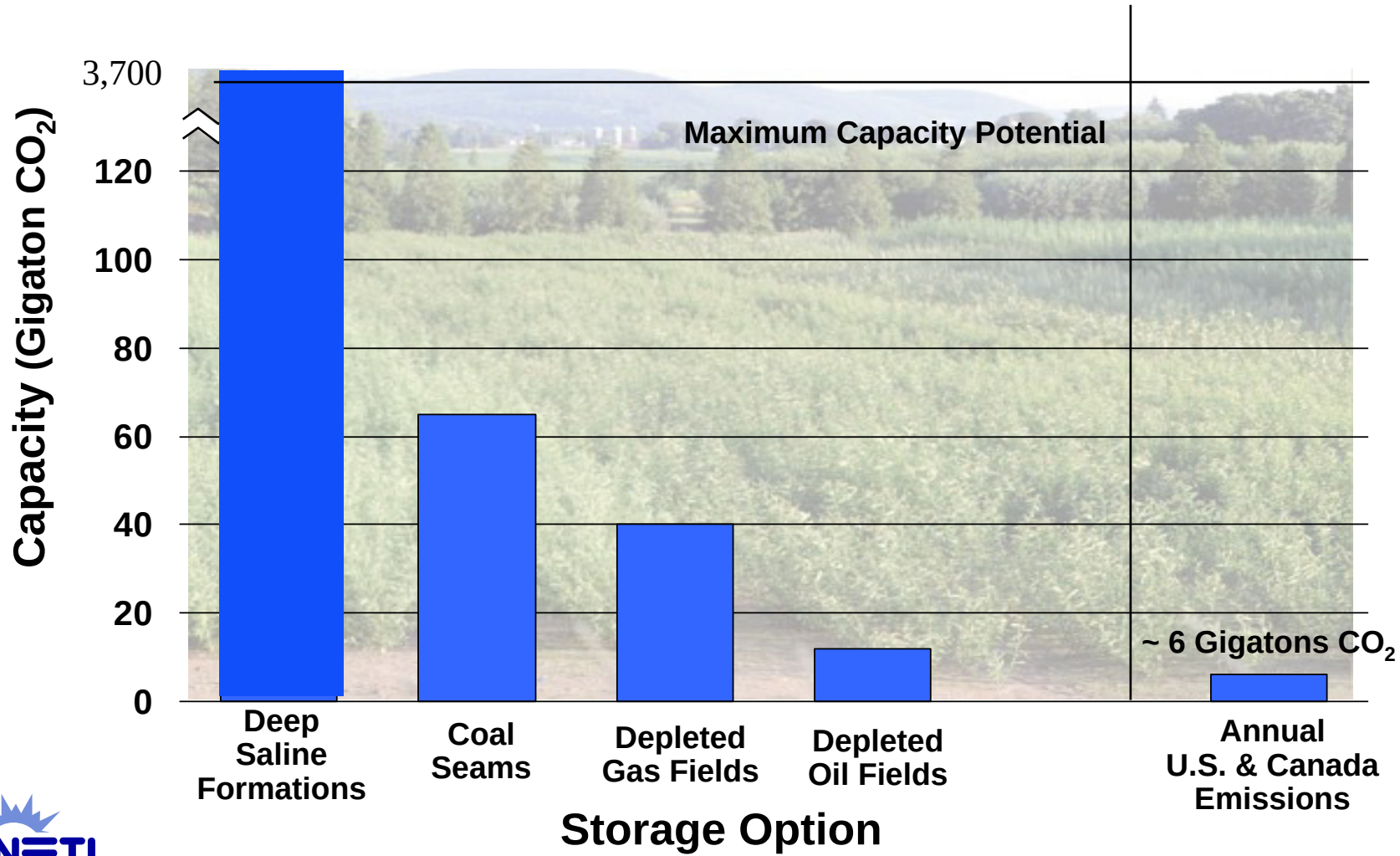
- Tree-plantings
- No-till farming
- Wetlands restoration
- Land management: grasslands, grazing lands
- Fire management
- Forest preservation
- Monitoring, mitigation, and verification technologies
- Accounting protocols for trading markets (CCX)

Deployment Phase

- **Several large volume injection tests**
- **Large volume – 100K to 1M tons CO_2 injected**
- **Requirement of 20% cost share**
- **Currently negotiating cooperative agreements**
- **Divided into 3 stages**

Years 1-3	Site selection and characterization Permitting and NEPA compliance Well completion and testing Infrastructure development
Years 4-7	CO_2 procurement and transportation Injection operations Monitoring activities
Years 8-10	Site closure Post injection monitoring Project assessment

North America Geologic Storage Capacity
(> 600 Year Storage Capacity for U.S. & Canada)



Source: Battelle, "A CO2 Storage Supply Curve for North America", September 2004, PNWD-3471

Ireland Presentation, May 2007

National Atlas Highlights

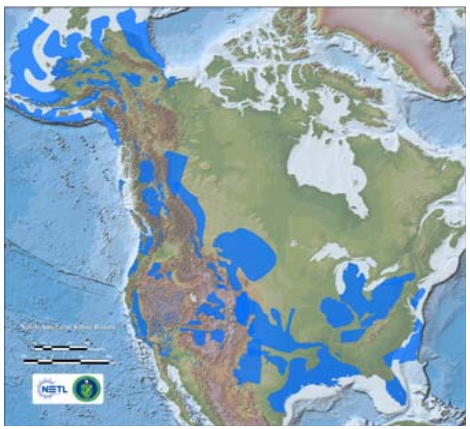
CO_2 Sources Documented in NatCarb

	CO_2 Emission (Million Tons)	Number of Facilities
CO_2 Sources	3,809	4365

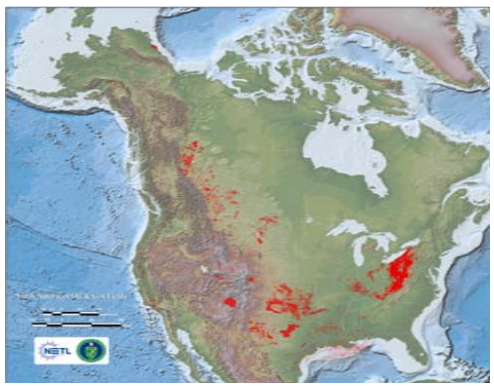
***U.S. ~ 6 GT CO_2/yr all sources**

North American CO_2 Storage Potential (Giga Tonnes)

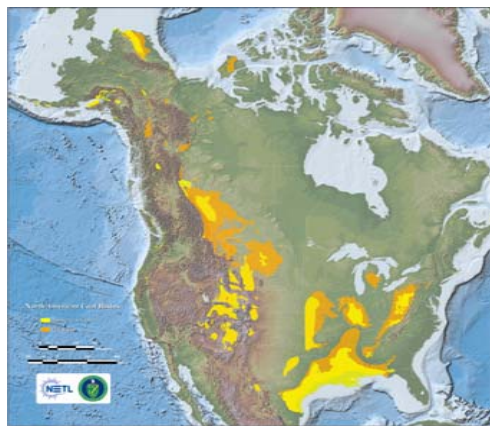
Sink Type	Low	High
Saline	969	3,223
Unmineable Coal Seams	70	97
Oil and Gas Fields	82	83



Saline Aquifers



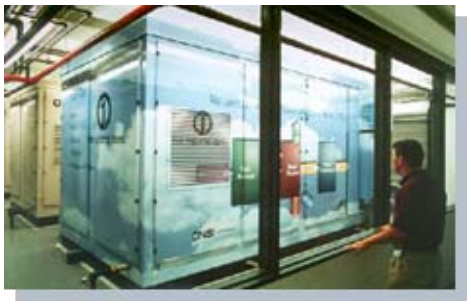
Unmineable Coal Seams



Oil and Gas Fields

Available for download at http://www.netl.doe.gov/publications/carbon_seq/refshelf.html

FutureGen: Integrating Function for R&D Program



Fuel Cells

FutureGen

Carbon Sequestration

Gasification with Cleanup Separation

H_2 Production

Optimized Turbines

System Integration

Key Take Home Points

- **Economic growth tied to energy availability, particularly lower-cost fossil fuels**
- **Release of CO_2 from fossil fuels widely believed to contribute to climate change**
- **Retaining fossil fuels as a viable world energy source will require carbon capture and storage (CCS) technologies**
- **U.S. DOE taking a leadership role in development of cost-effective CCS technologies**

Visit Office of Fossil Energy & NETL Websites

http://fossil.energy.gov/

http://www.netl.doe.gov