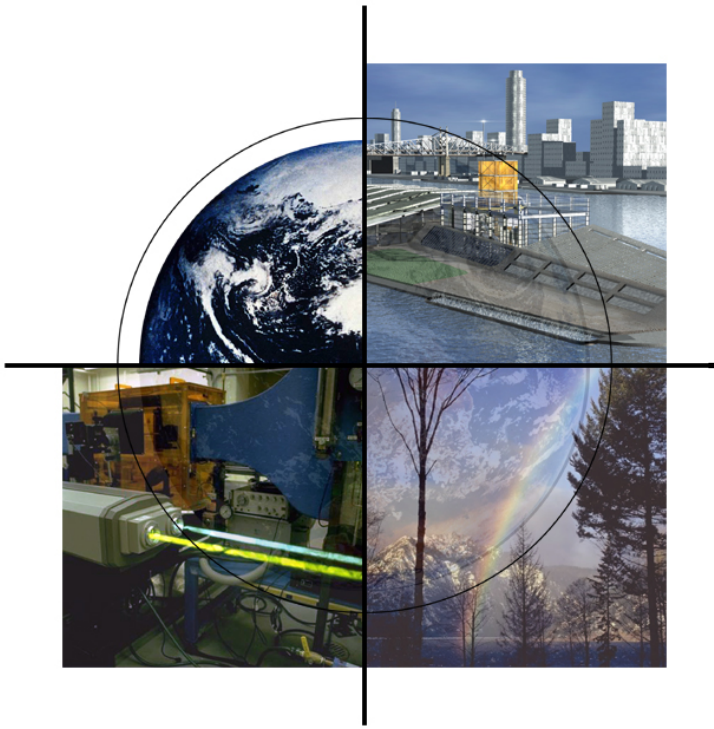
Carbon Capture R&D: DOE/NETL R&D Program



7th Annual Conference on Carbon Capture and Sequestration

May 5-8, 2008
Pittsburgh, PA

Timothy E. Fout
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National Energy Technology Laboratory

Technological Carbon Management Options

Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

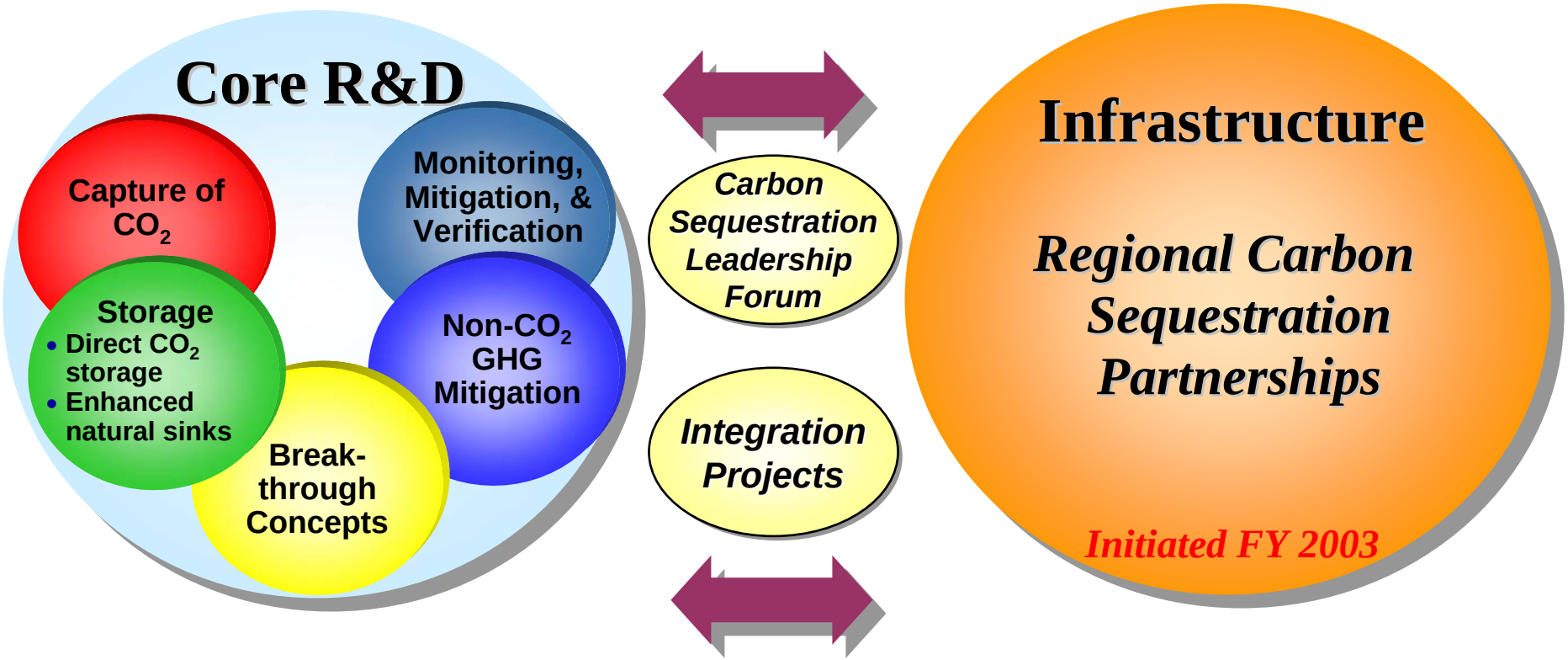
Sequester Carbon

- Capture & Store
- Enhance Natural Sinks

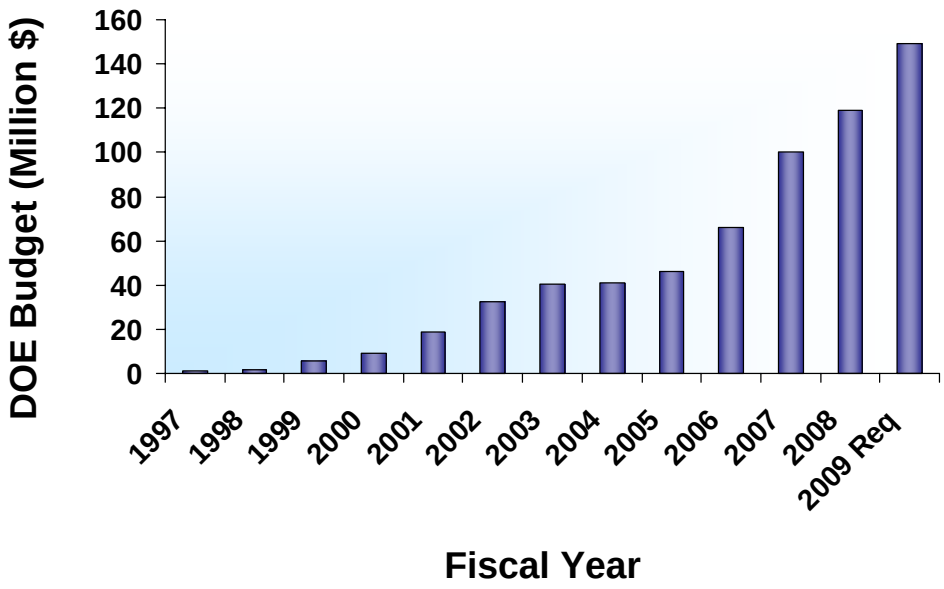
All options needed to:

- Affordably meet energy demand
- Address environmental objectives

DOE's Sequestration Program Structure



Sequestration Program Statistics FY2008



Strong industry support

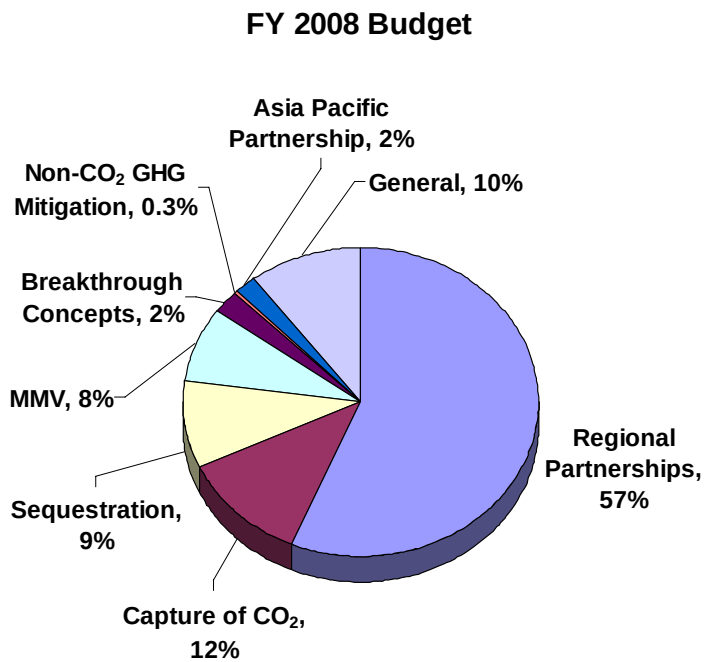
~ 39% cost share on projects

Federal Investment to Date

~ $481 Million

Diverse research portfolio

~ 70 Active R&D Projects



Separation & Capture of CO_2 from Coal-Based Power Plants

Issues

- Demonstrated technology is costly & energy-intensive
- Scale-up
- Market Considerations/Readiness
- Reliance on Enabling Technologies
- Integration
- Regulatory Framework

Research Areas

- Pre-Combustion
- Post-Combustion
- Oxy-Combustion

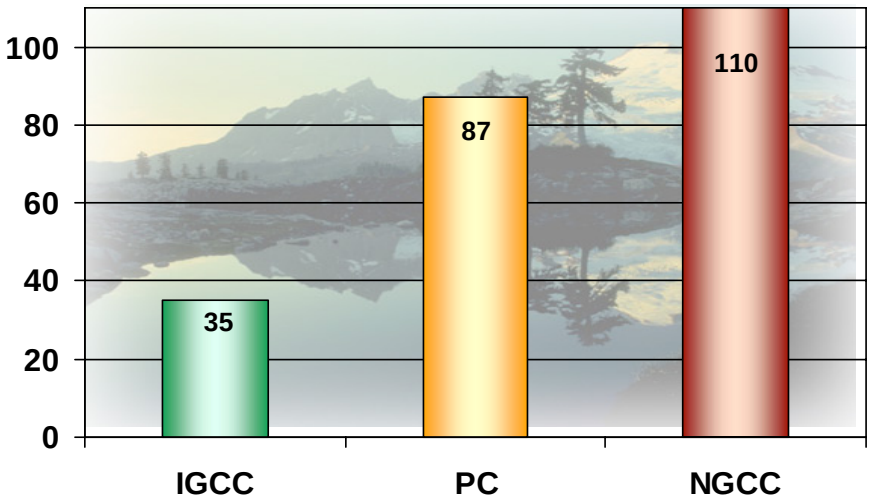
CO_2 Capture Is Expensive !

- 5–30% parasitic energy loss
- 35–110% increase in capital cost
- 30–80% increase in cost of electricity

Currently refining cost target for PC plants considering potential improvements in:

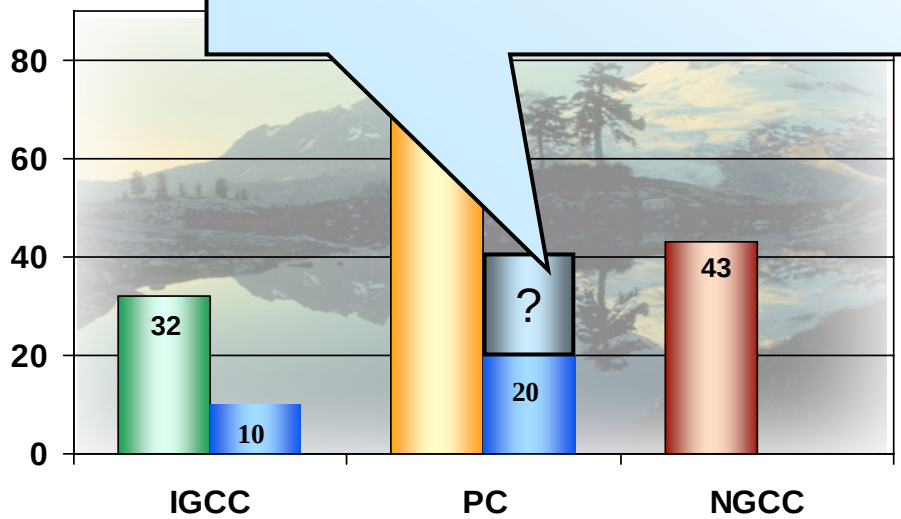
- Capital cost
- Fixed operating cost
- Variable operating cost
- Energy cost
- Transport, storage & monitoring costs

Effect of CO_2 Capture on Capital Cost
(% Increase Resulting From CO_2 Capture)



Note: CO_2 capture costs based on use of Selexol process for IGCC and MEA for PC and NGCC.

Effect of
(% I



Source: *Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity; NETL, May 2007.*

Carbon Capture RD&D Challenges

Pre-combustion
(Synthesis Gas)

- Loss of CO_2 pressure due to flash regeneration
- Cooling / refrigeration of syngas to accommodate low operating temperatures; reheating prior to combustion
- H_2 losses, particularly in membranes
- Sulfur-tolerant materials / membranes

Post-combustion
(Flue Gas)

- Low-pressure flue gas dilute in CO_2
- Steam requirement for thermal regeneration (amines)
- High compression costs and large loads due to CO_2 produced at low pressure
- Flue gas contaminants

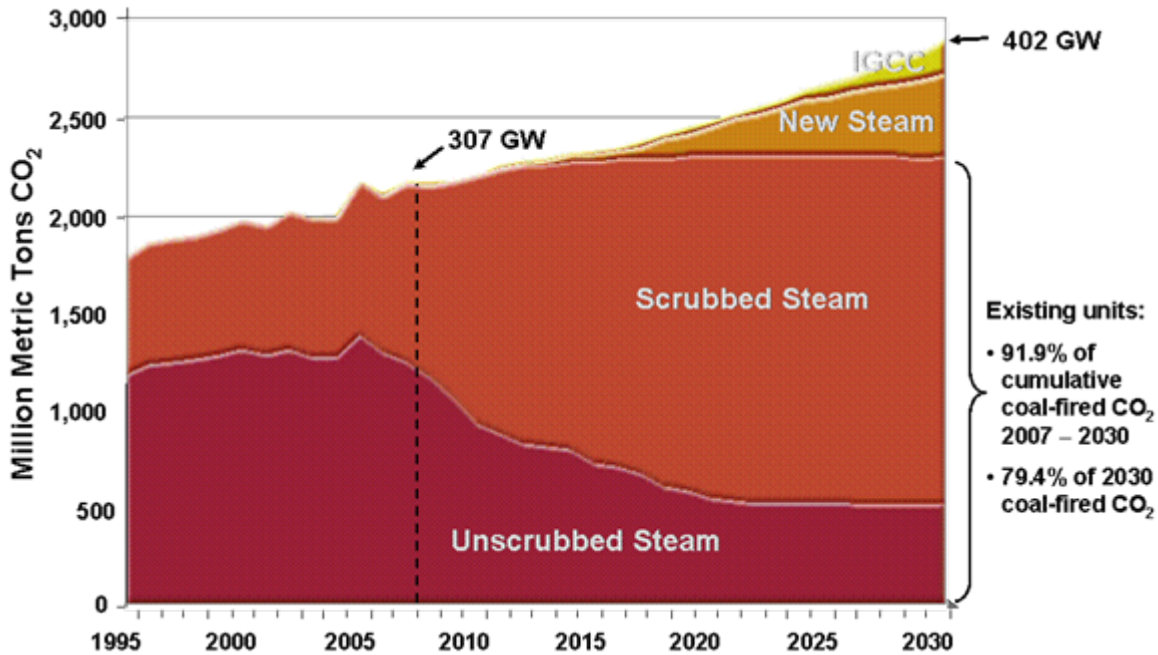
Oxy-Combustion
(OxyFuel)

- Cost of O_2 production and materials
- Cooled CO_2 recycled to control combustion temperatures

CO_2 Capture for Existing Plants

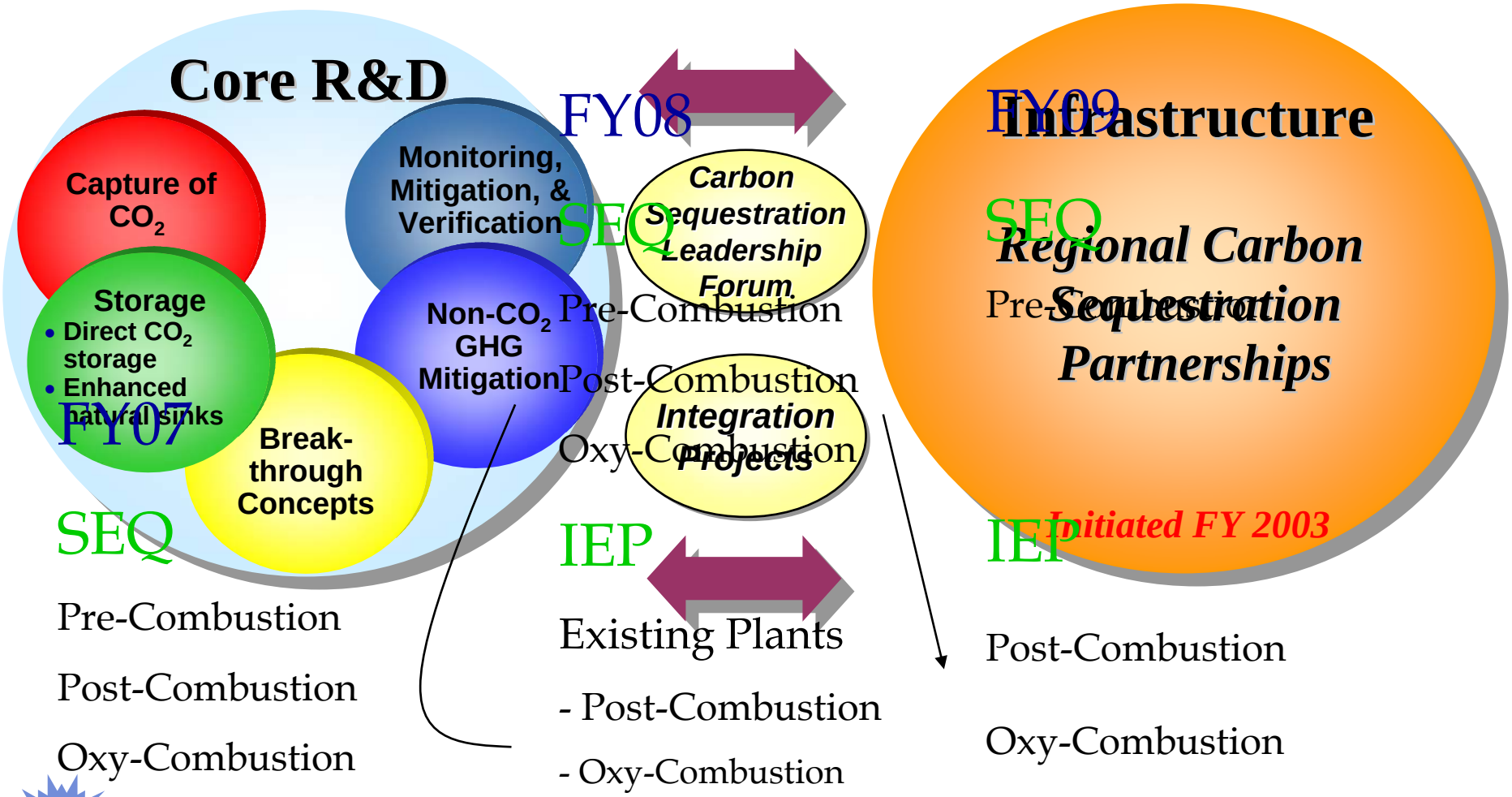
- **Coal-fired power plants will continue to dominate CO_2 emissions from fossil fuel power generation**

Projected CO_2 Emissions from Fossil Fuel Power Generation

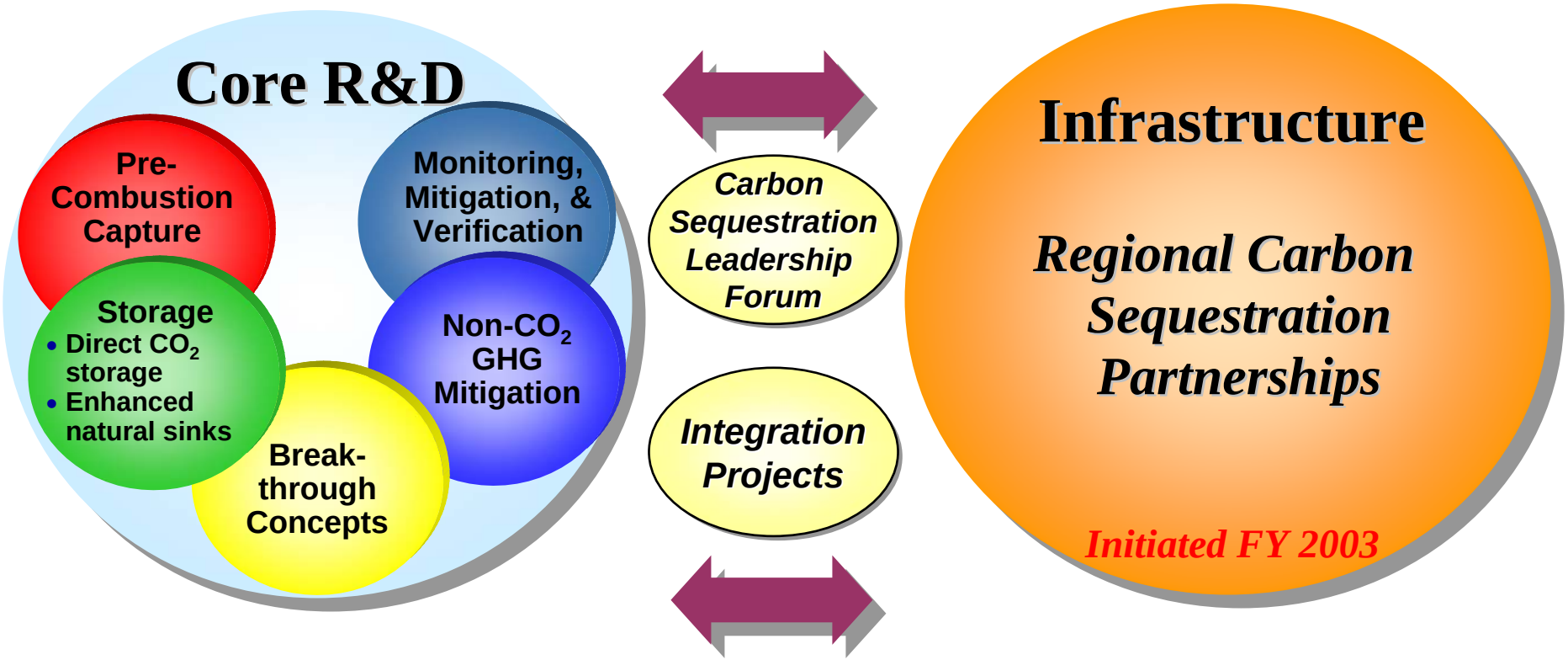


Source: EIA, Annual Energy Outlook 2008 Revised Early Release, March 2008

Capture Transition

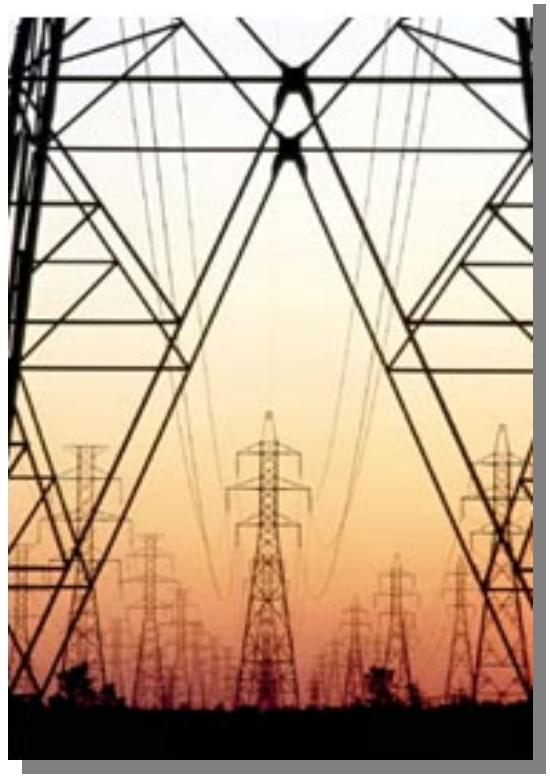


DOE's Sequestration Program Structure



FY08 CO_2 Capture Funding Opportunity

- *Funding Opportunity Announcement DE-PS26-08NT00134*
- *"Carbon Dioxide Capture and Separation Technology Development For Application To Existing Pulverized Coal-Fired Power Plants"*
- Technical areas:
  - Post-Combustion Capture
  - Oxy-Combustion
  - Chemical Looping
- ~ $30 million total funding available
  - *5 to 15 projects @ $150k to $5M each*
- *Applications were due April 10, 2008*
- *Project selections by end of July 2008*
- *Project awards by end of September 2008*



Carbon Capture Research Pathways
Chemical Solvents

Process Description

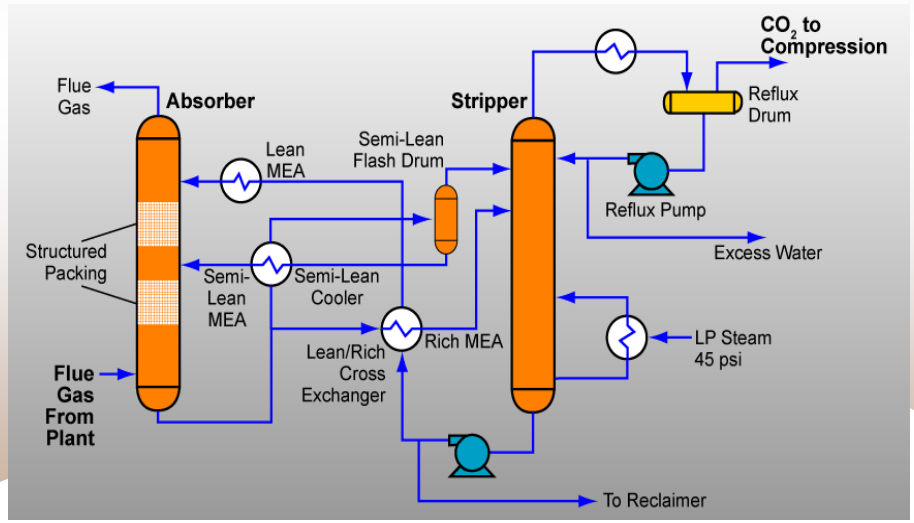
- Reversible chemical reaction(s) between CO_2 and aqueous absorbent solution
- Mature technology (MEA) at smaller scale

Potential Technology Solutions

- Improved solvents (carbonates, hindered amines, ammonia, etc.)
- Blended and promoted solvents

Research Focus

- ✓ Low solvent cost
- ✓ High CO_2 loading capacity
- ✓ Improved reaction kinetics
- ✓ Non-corrosive
- ✓ No solvent degradation
- ✓ Low regeneration energy



Source: DOE/NETL

Primary Research Partners

POWERSPAN Clean Energy Technology

NETL

Carbon Capture Research Pathways
Physical Solvents

Process Description

- Bulk phenomenon where liquids absorb a gaseous species from a gas mixture
- Most effective with high CO_2 partial pressure (IGCC systems)
- Mature technology (Selexol™ & Rectisol®) at smaller scale

Research Focus

- Ionic Liquids (ILs)
  - ✓ High thermal stability
  - ✓ Low volatility
  - ✓ High CO_2 solubility
  - ✓ Separation media for H_2 and CO_2
  - ✓ High unit cost

Primary Research Partners

UNIVERSITY OF NOTRE DAME

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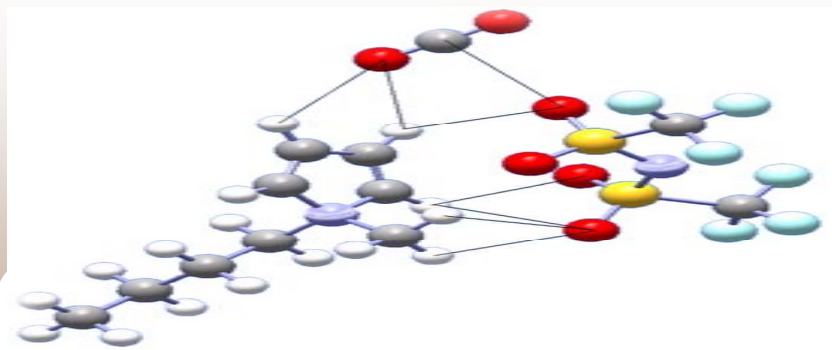
R&D Progress

Over 19x increase in CO_2 solubility for physical ILs and 40x increase in CO_2 solubility for ILs with chemical complexation when compared to ILs available at the beginning of the project



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Carbon Capture Research Pathways
Chemical Sorbents

Process Description

- Chemical adsorption involves bonding with a solid sorbent
- Low moisture content reduces regeneration steam requirements

Research Focus

- Solid regenerable CO_2 sorbents
  - ✓ Durable
  - ✓ High selectivity
  - ✓ Multiple regeneration cycles
  - ✓ High CO_2 adsorption capacity
  - ✓ Low cost

Primary Research Partners

RTI INTERNATIONAL

THE UNIVERSITY OF AKRON 1870

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Potential Technology Solutions

- Sodium & potassium oxides
- Carbonates
- Amine-enriched sorbents (Zeolites)

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Carbon Capture Research Pathways
Physical Sorbents

Process Description

- Physical adsorption of CO_2 on solid adsorbents by weak surface forces
- Adsorption capacity increases with CO_2 partial pressure
- Regeneration via TSA or PSA

Research Focus

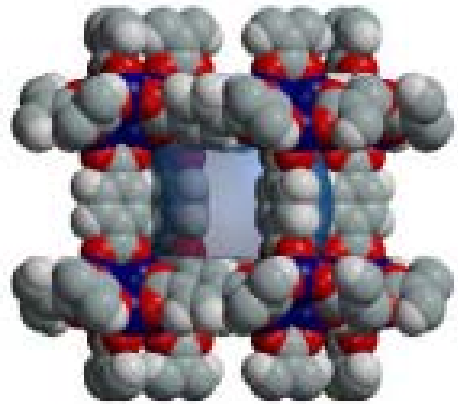
- Metal organic frameworks (MOFs)
  - ✓ Hybrid organic/inorganic ordered structures w/ high porosity
  - ✓ High thermal stability
  - ✓ High adsorption capacity
  - ✓ High selectivity
  - ✓ Customized sorption properties
  - ✓ Good adsorption/desorption rates

Primary Research Partner

UOP
A Honeywell Company

Future Work

- Evaluate hydrothermal stability
- Synthesis, forming, and scale-up
- Process design and economics



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Carbon Capture Research Pathways
Membranes

Process Description

- Diffusion via a physical or chemical interaction between the membrane and CO_2
- Selectivity and permeability are key
- Most effective with high CO_2 partial pressure (IGCC systems)

Research Focus

- More efficient CO_2 membranes
  - ✓ Durable
  - ✓ Improved selectivity
  - ✓ Thermal and physical stability
  - ✓ Sulfur tolerance

Potential Technology Solutions

- Polymers (PBI)
- Metals (palladium)
- Facilitated transport
- Molecular seives
- Gas absorption membranes
- Carbonic anhydrase enzyme
- Ionic liquids

Primary Research Partners

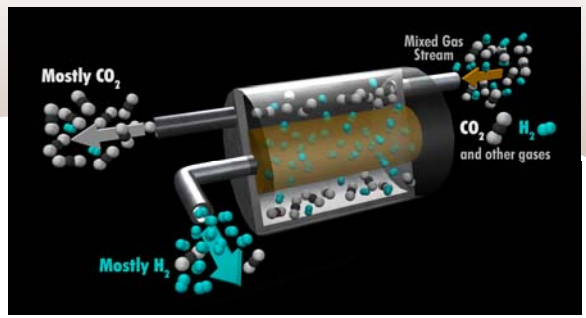
Carbozyme Inc.

Los Alamos NATIONAL LABORATORY EST. 1943

NETL

SRI International

MTR



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Carbon Capture Research Pathways
Advanced Oxycombustion Technologies

Process Description

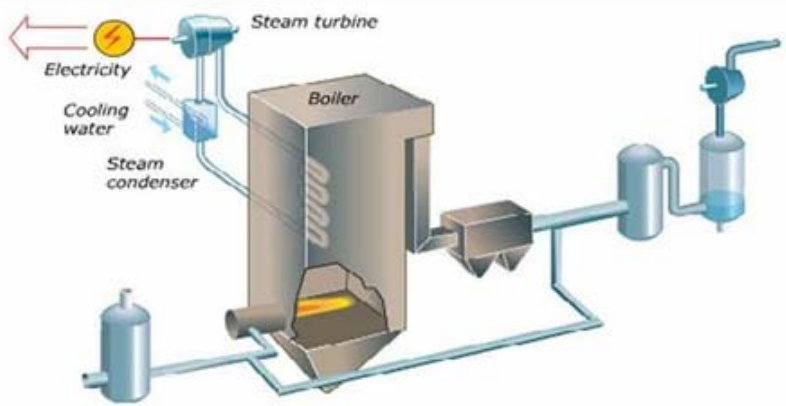
- Combustion in pure O_2 to produce flue gas that is comprised of H_2O and CO_2
- CO_2 separation via H_2O condensation

Research Focus

- Reduce O_2 production costs
- Improved oxyfuel boilers
  - ✓ Compact design
  - ✓ Advanced materials and burners
- Retrofit options
- Reduce flue gas recycle
- Co-sequestration

Potential Technology Solutions

- Oxygen Transport Membranes (OTM)
- Ceramic Autothermal Recovery (CAR)
- Integrated Pollutant Removal
- Chemical Looping



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