An Update of NETL's Carbon Capture and Sequestration Program

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Advances of Multi-pollutant and CO_2 Control Technologies
Chicago, IL
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Outline for Presentation

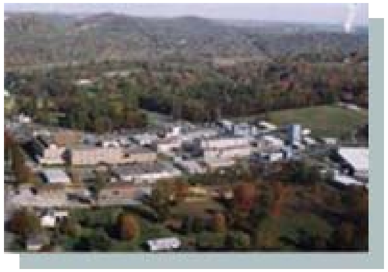
- NETL Overview
- The Issue
- The Solutions
- What is Carbon Capture and Storage (CCS)
- DOE’s Sequestration Program Structure
- CO_2 Capture Research Projects

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**
- **1,100 Federal and support-contractor employees**
- **Research spans fundamental science to technology demonstrations**

Pennsylvania

Oregon



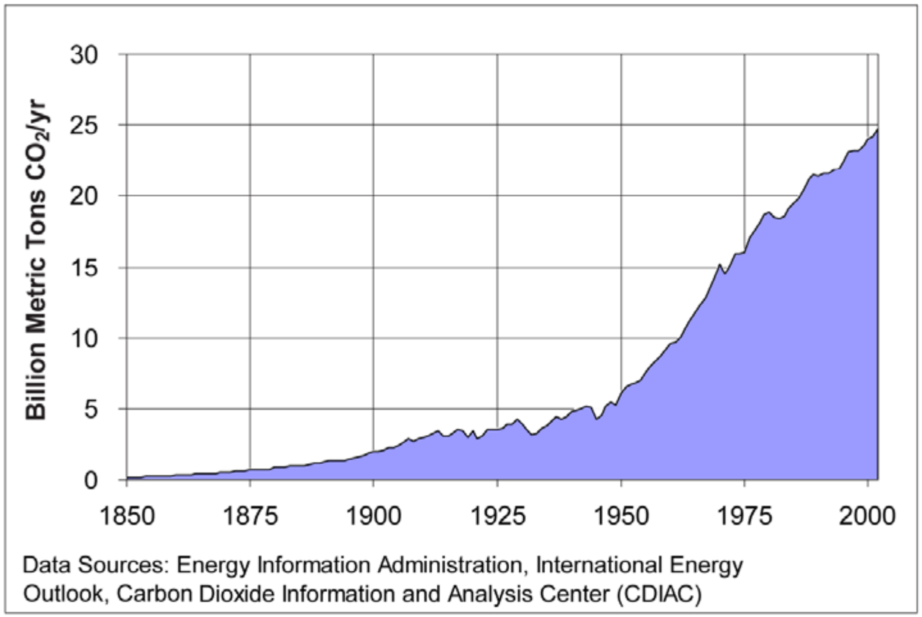
West Virginia

Alaska

Oklahoma

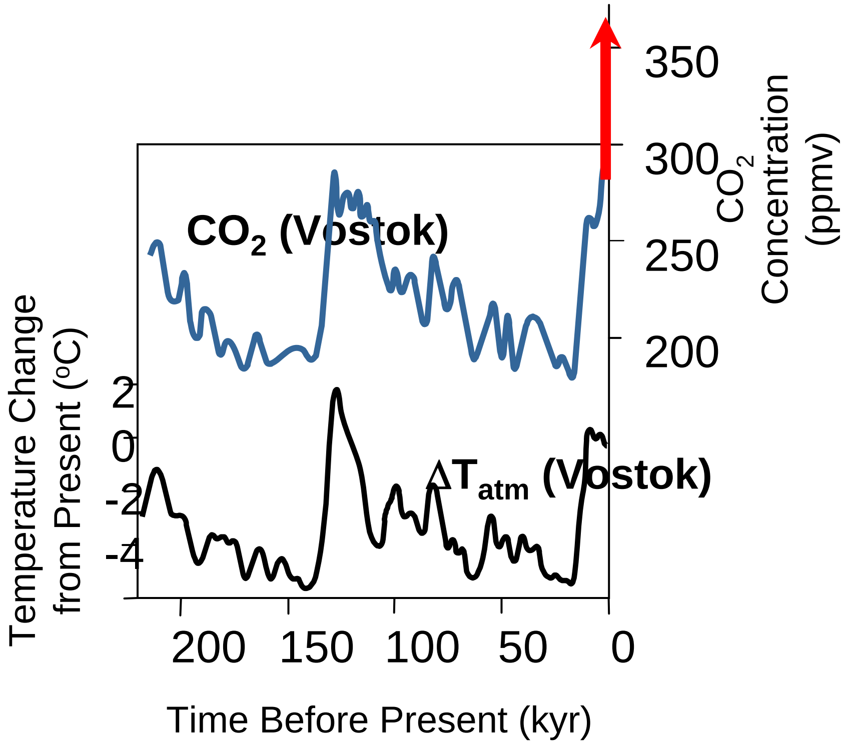
The Issue

CO_2 Concentrations On The Rise



Worldwide CO_2 Emissions from Fossil Fuel Combustion and Cement Manufacture

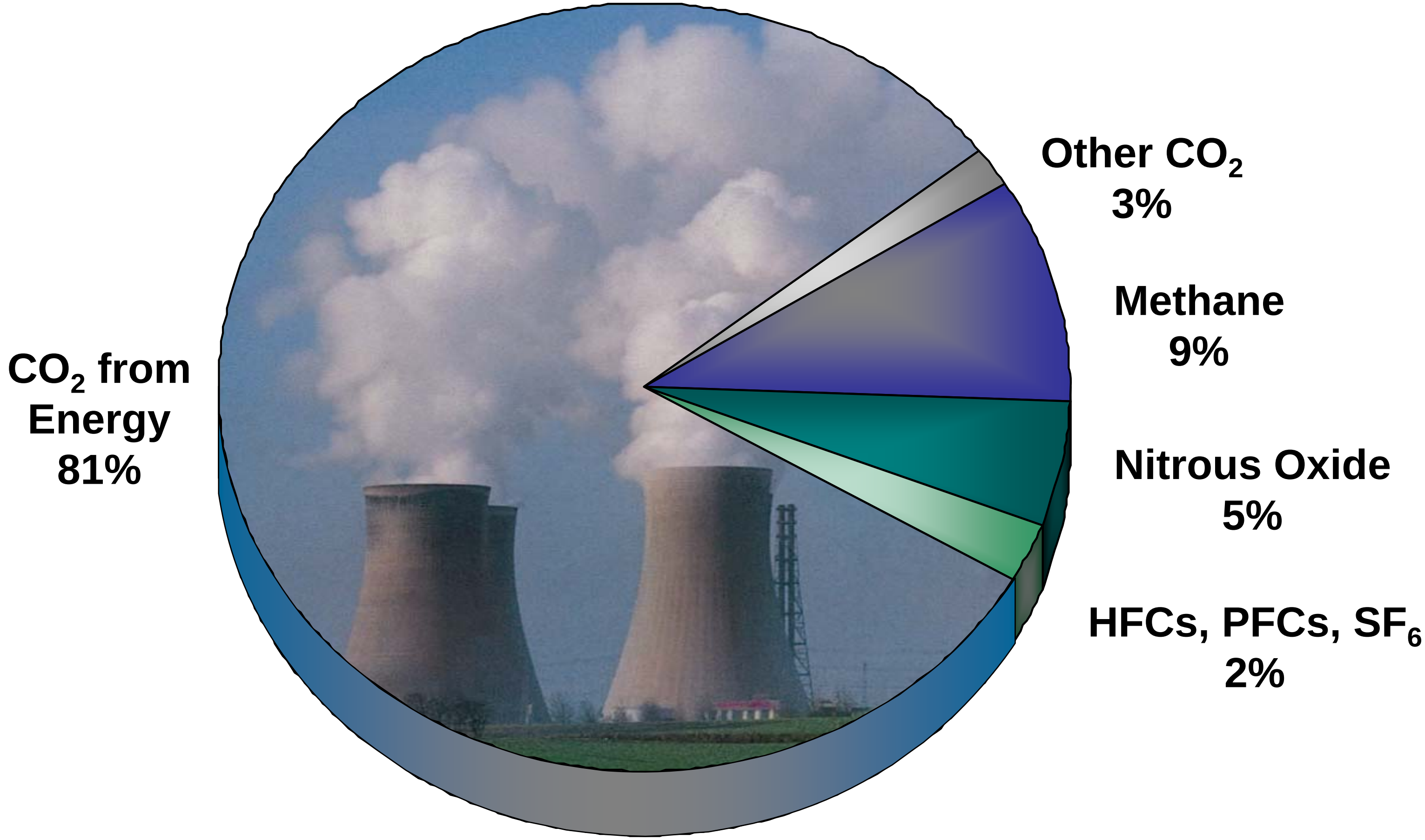
~280 ppm to 381 ppm over last 100 years



CO_2 & CH_4 - The Primary GHG Contributors

United States Greenhouse Gas Emissions

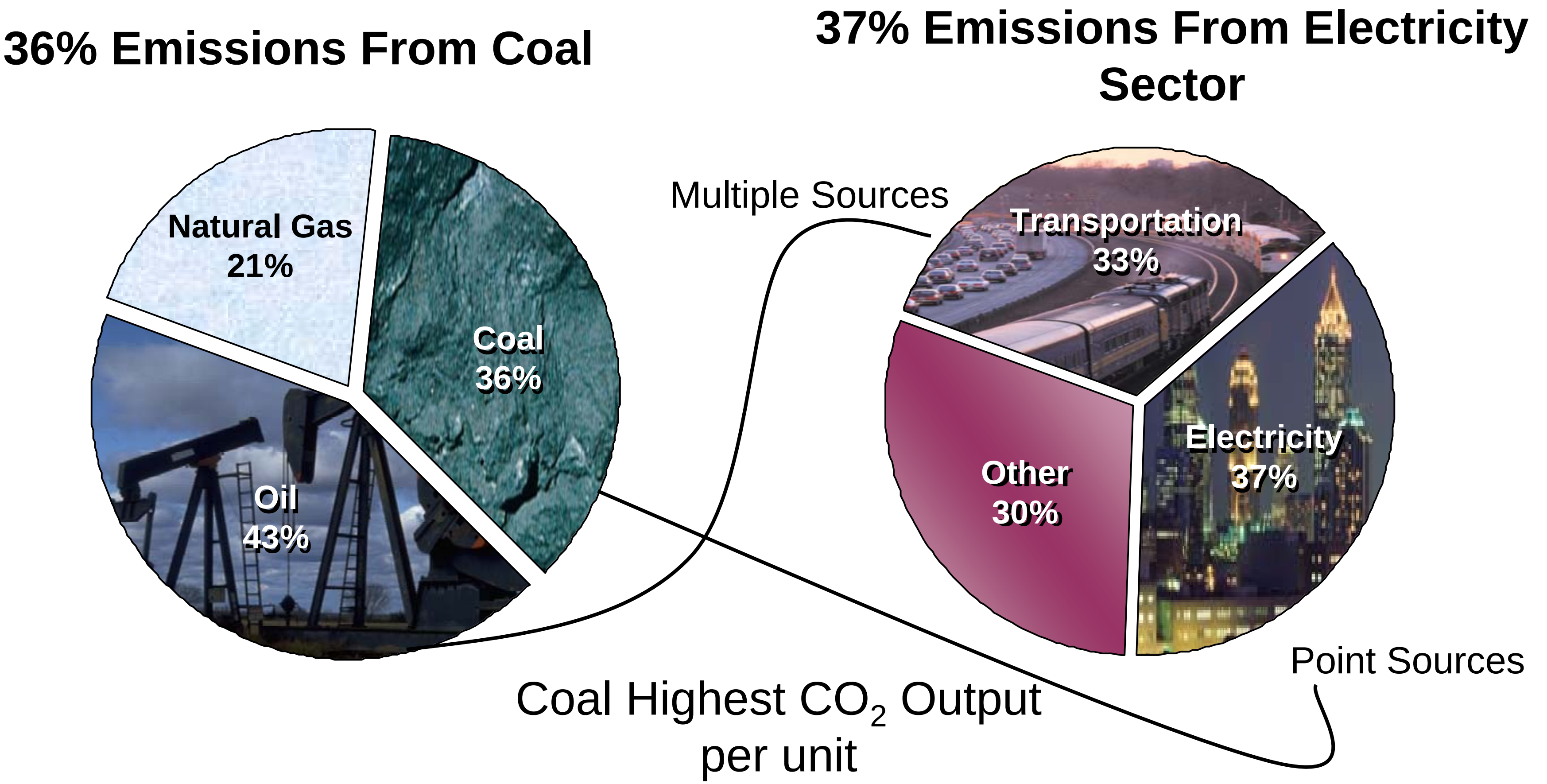
(Equivalent Global Warming Basis)



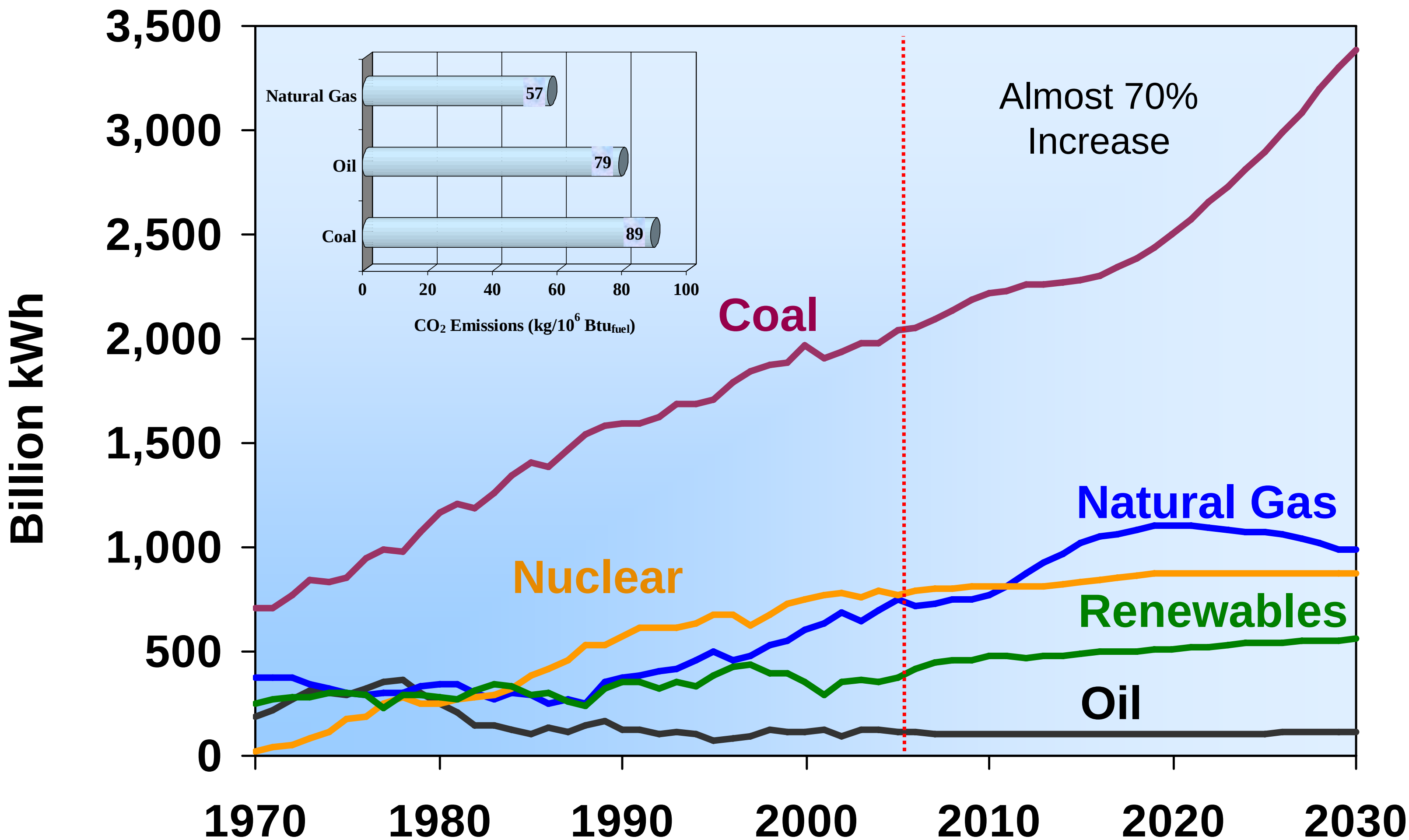
"EIA Emissions of Greenhouse Gases in the U.S.: 2000"

Program Focuses on Coal & Electricity

United States CO_2 Emissions



Coal Dominates Forecast for Power Generation



Annual Energy Outlook 2006

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The Solutions

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**

What is Carbon Sequestration?

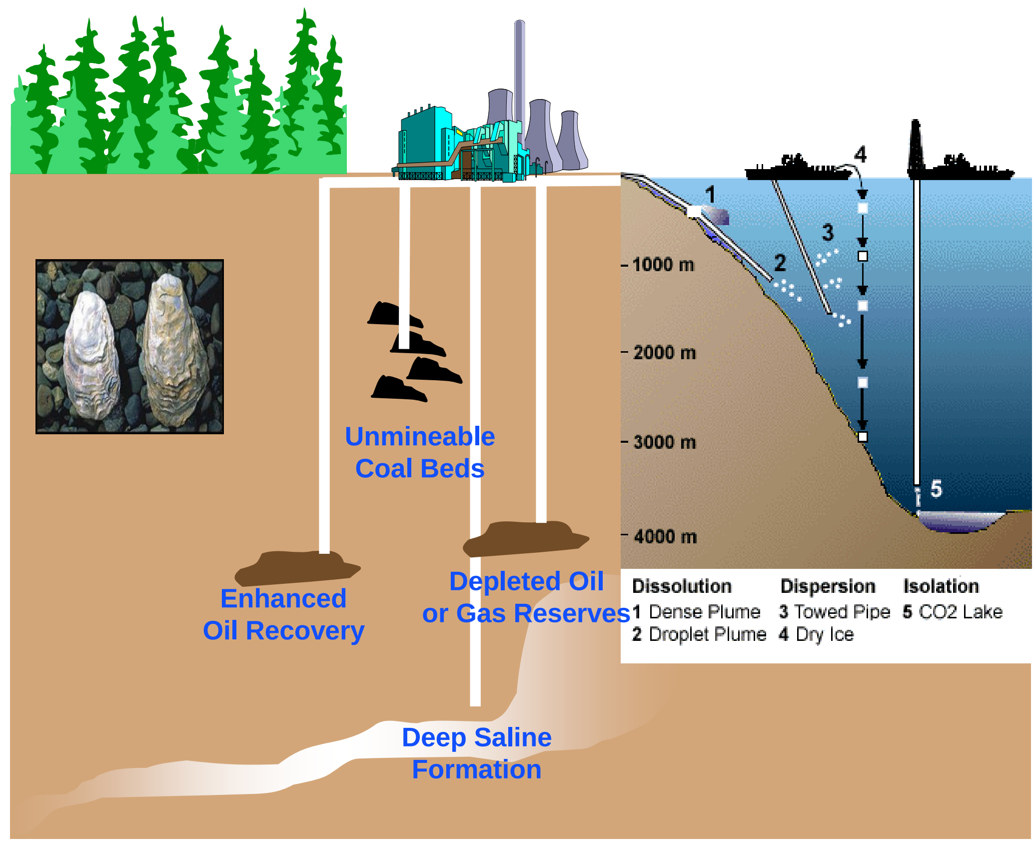
Capture and storage of CO_2 and other Greenhouse Gases that would otherwise be emitted to the atmosphere

Capture can occur:

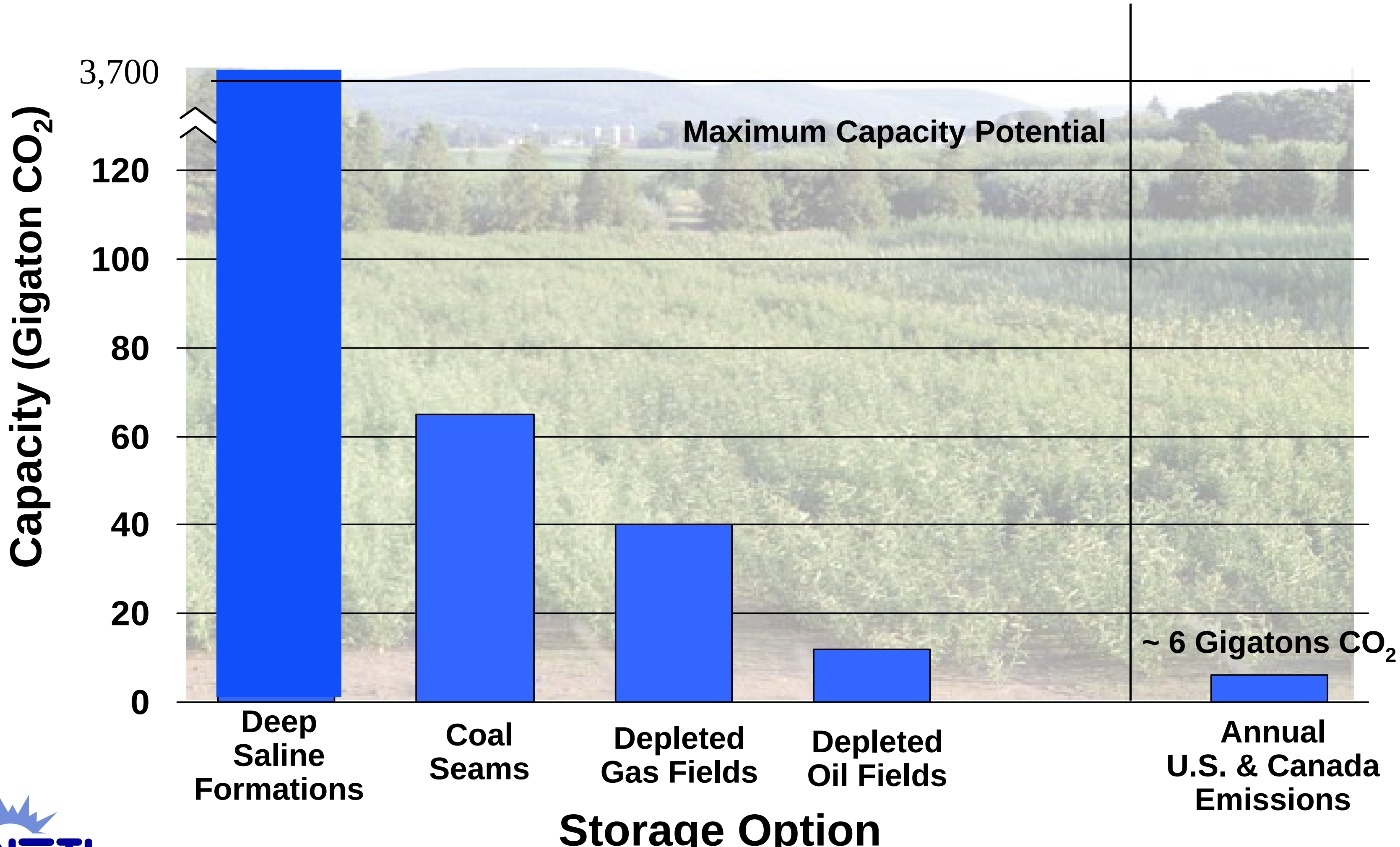
- at the point of emission
- when absorbed from air

Storage locations include:

- underground reservoirs
- converted to solid materials
- trees, grasses, soils, or algae
- dissolved in deep oceans



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

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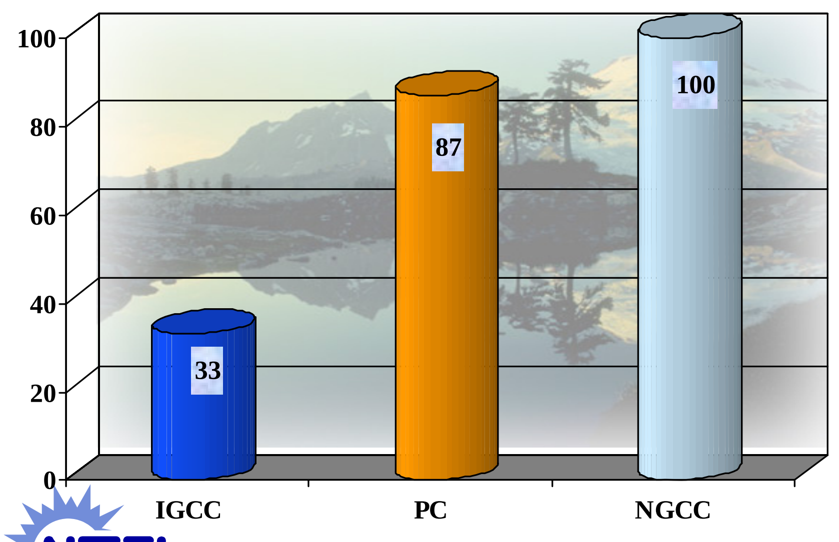
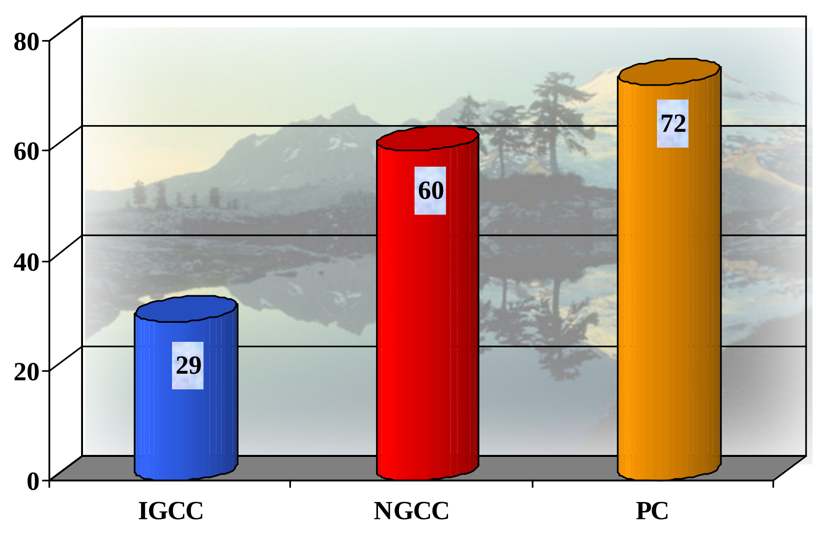
Current "Best Case" Technologies Costly
Using State-of-the-Art Scrubbing Technologies

- 5 to 30% Parasitic energy loss
- 30 to 100% Increase in capital cost
- 30 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)



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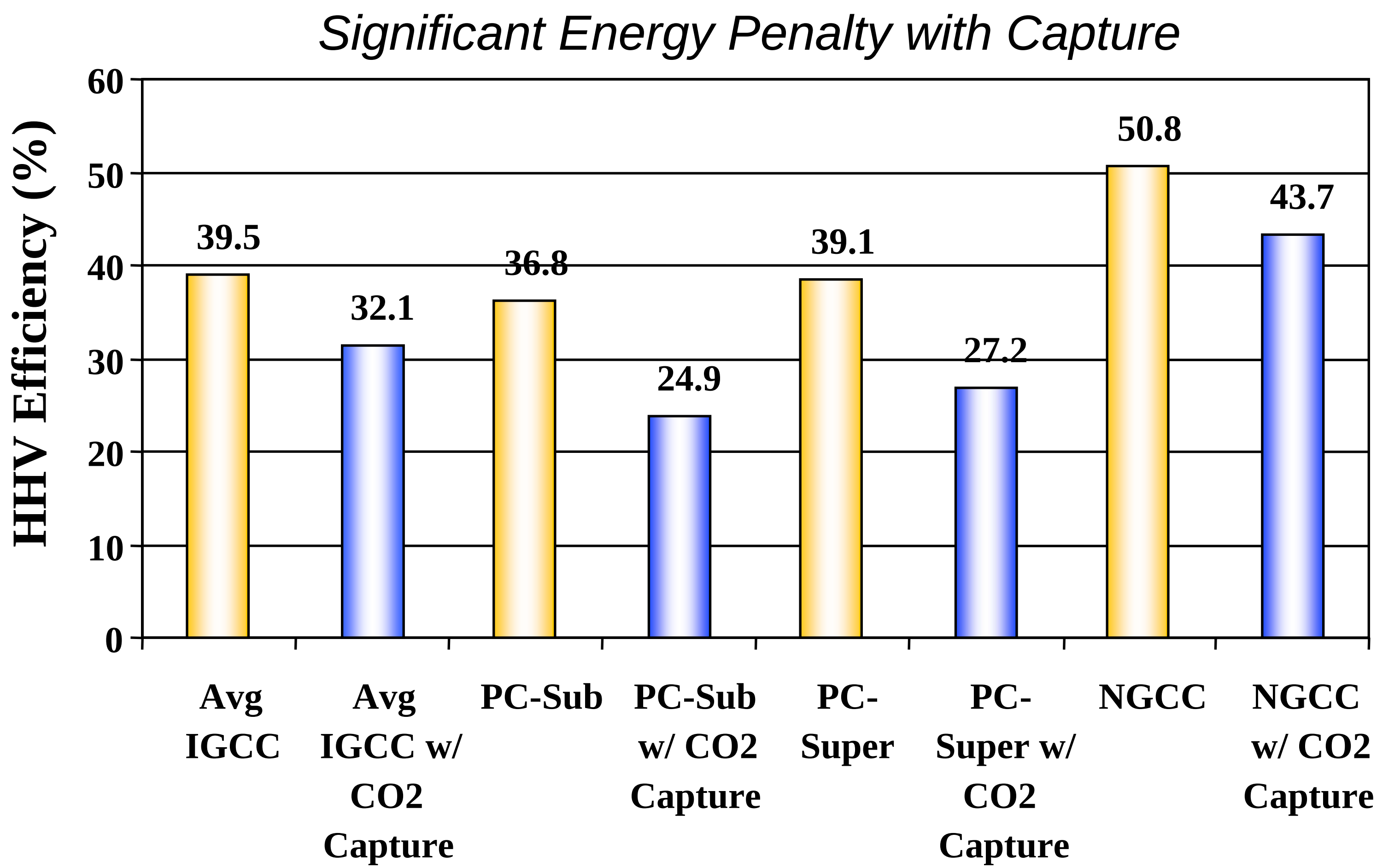
Efficiency Comparison



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/*

Why the Need to Focus on the CO_2 Capture Program Objectives

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

Need for further R&DD to minimize the cost and externalities impact due to CO_2 Capture and Storage.

Current Energy Penalty of CO_2 BACT MEA Absorption System

Source: U.S. DOE Carbon Capture and Separation Program: A Program Synopsis, Jose' Figueroa and Sean Plasynski

DOE Carbon Sequestration Program

Addressing Both Capture and Sequestration

Sequestration Program Goals

Develop Technology Options for GHG Management That...

- **Are safe and environmentally acceptable**
- **Separation and Capture R&D Goals**
  - **2007 have two technologies < 20% (45% PC based) increase in Cost of Energy *****
  - **2012 developed two technologies < 10% (20% PC based) increase Cost of Energy**
- **Sequestration/Storage R&D Goals**
  - **2012 predict CO_2 storage capacity with +/- 30% accuracy**
  - **Develop best practice reservoir management strategies that maximize CO_2 trapping**
- **Monitoring, Mitigation & Verification**
  - **2012 ability to verify 95% of stored CO_2 for credits (1605b)**
  - **CO_2 material balance to >99%**

*** **technologies identified and ready to move to demonstration (~4yrs) and then deployment (~4 yrs) – IGCC 20% and PC 45%**

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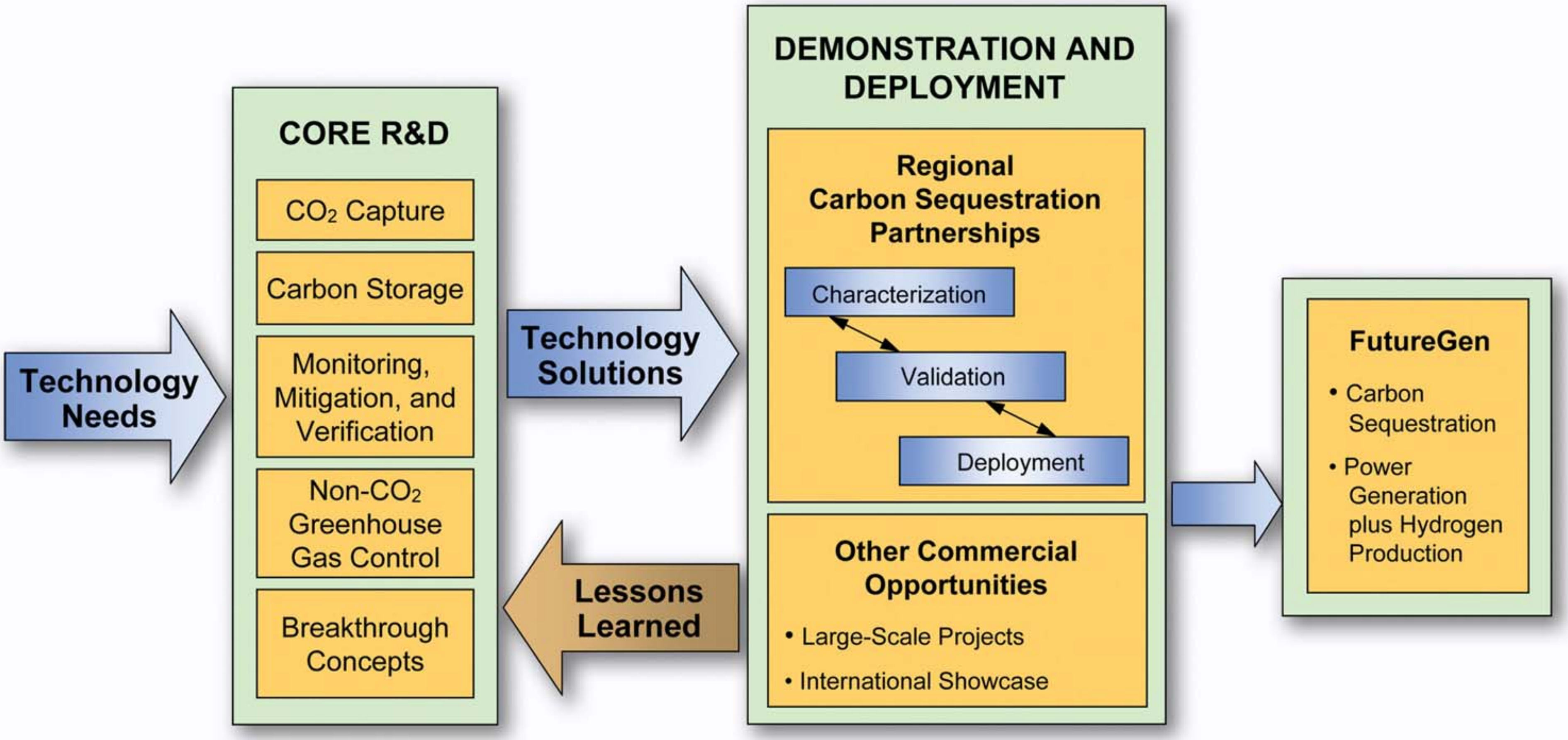
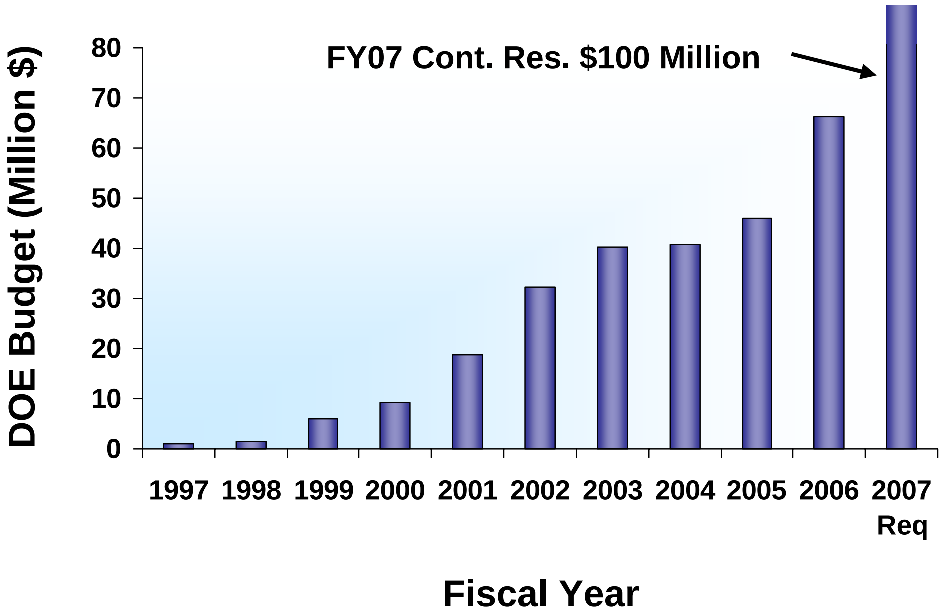
Carbon Sequestration Program Structure



Sequestration Program Statistics FY2007

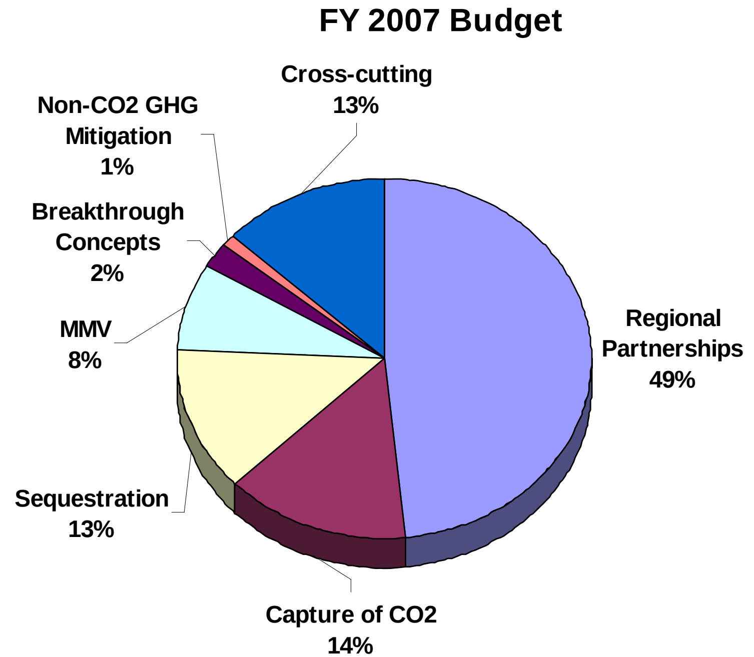


Strong industry support

~ 39% cost share on projects

Federal Investment to Date

~ $360 Million



Diverse research portfolio

~ 70 Active R&D Projects

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Regional Carbon Sequestration Partnerships
"Developing the Infrastructure for Wide Scale Deployment"

Characterization Phase

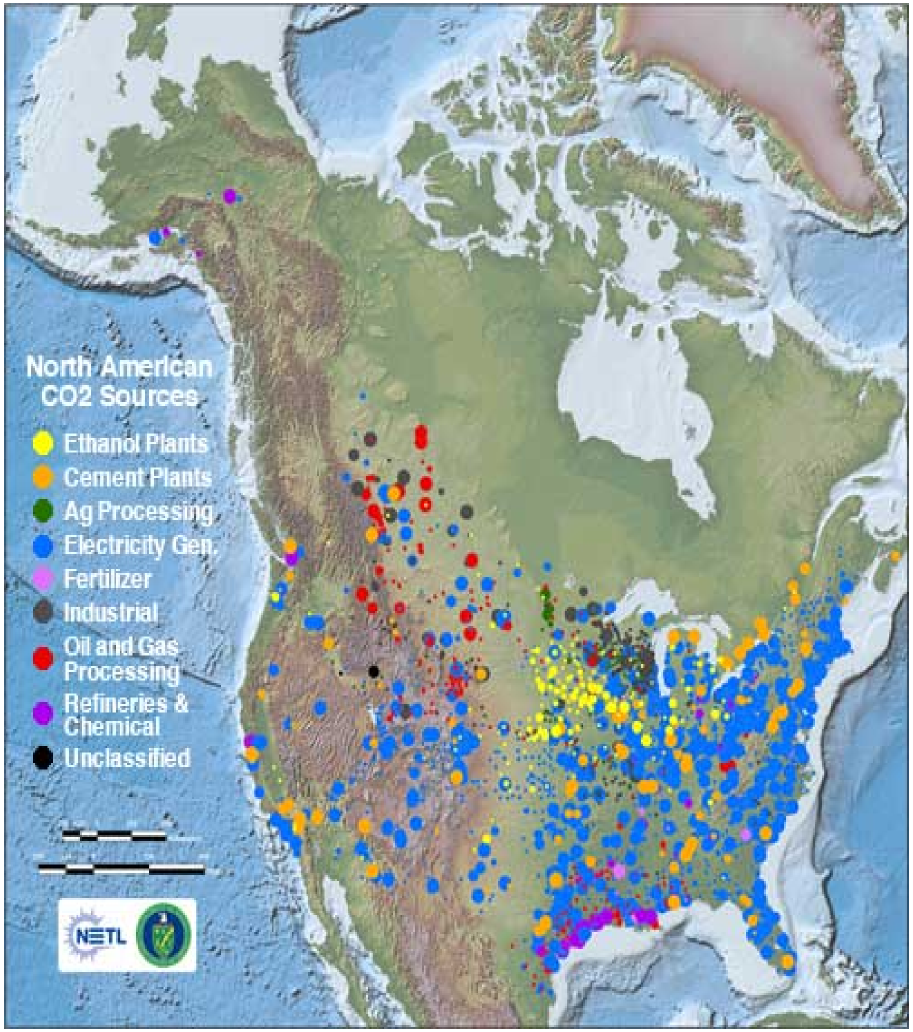
- **24 months (2003-2005)**
- **7 Partnerships (40 states)**
- **~$15M DOE funds**

Validation Phase

- **4 years (2005 - 2009)**
- **Field validation tests**
  - 25 Geologic
  - 11 Terrestrial
- **~$110M DOE funds**

Deployment Phase

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

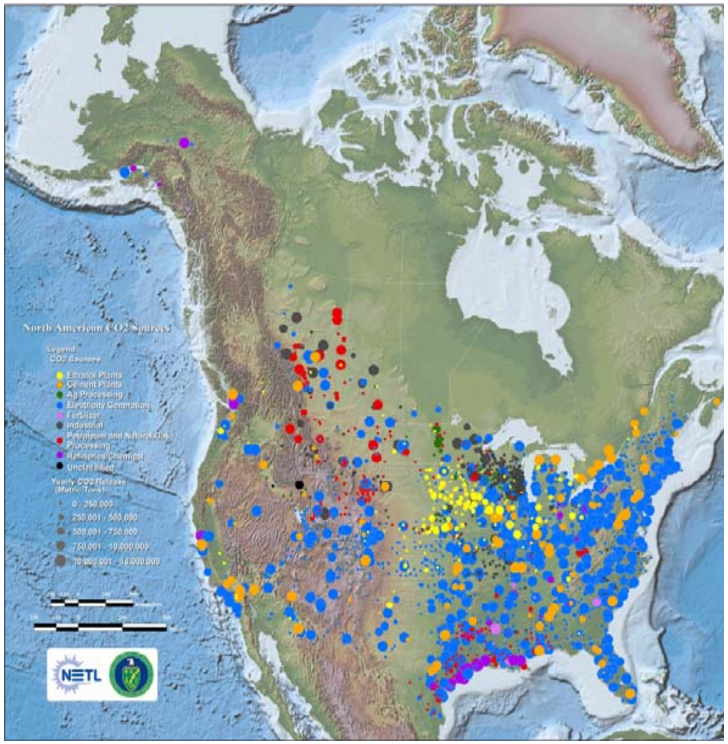


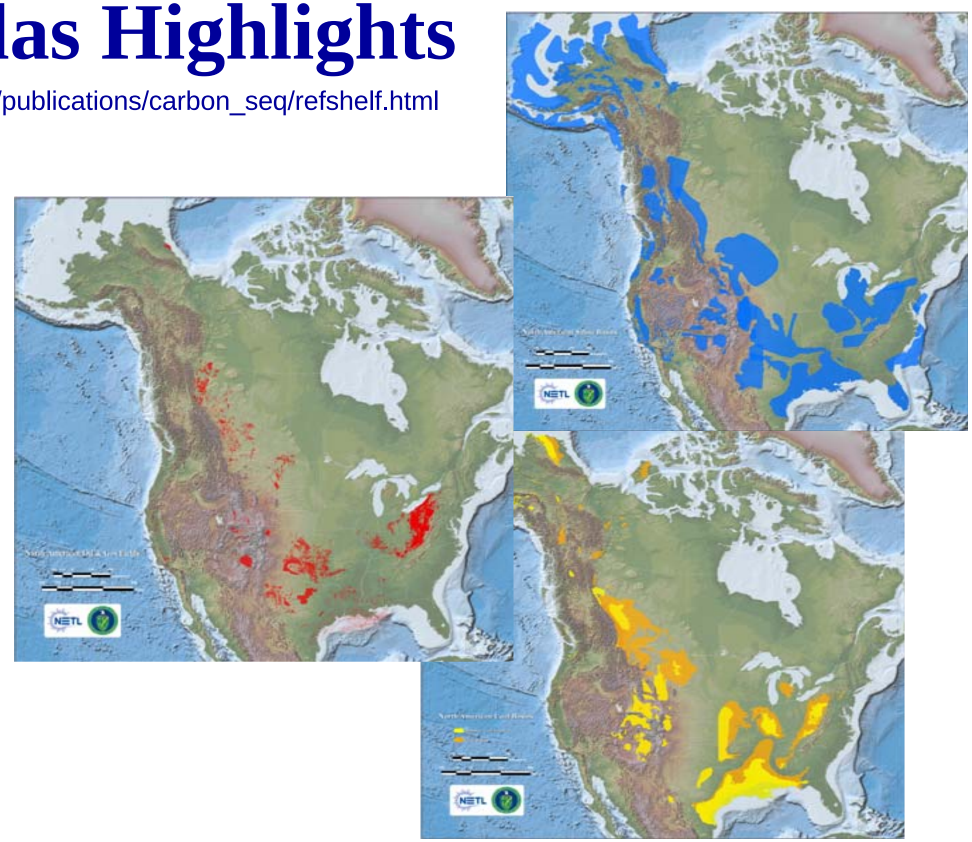
National Atlas Highlights

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

CO_2 Sources Documented in NatCarb

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





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

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

Technology Pathways
Separation & Capture of CO_2

Issue

- Demonstrated technology is costly

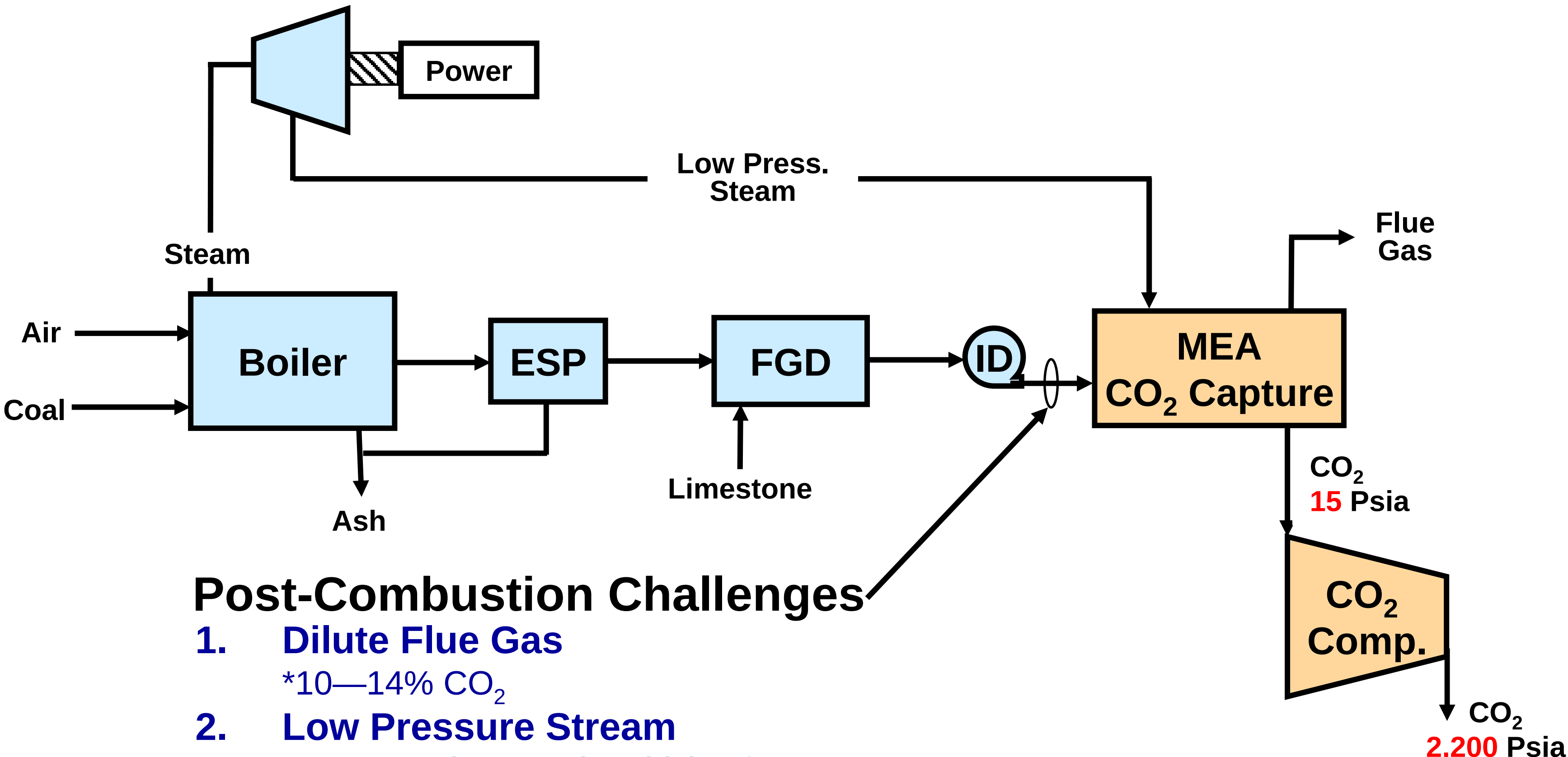
Pathways

- Post-combustion capture
- Pre-combustion capture
- Oxycombustion
  - Chemical looping

Post Combustion

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)**

Dry Carbonate Process for Flue Gas Capture

- **Regenerable Sodium-based Sorbent**
- **Modest temperature of operation**
  - CO_2 capture (carbonation) at ~ 60°C (140°F)
  - CO_2 release (decarbonation) ~120°C (250°F)
- **90% CO_2 removal demonstrated in pilot-scale, transport reactor in 10 to 20 seconds of residence time**
- **Preliminary economic analysis**
  - Approx. 20% increase in COE
- **Current work on scale up testing with actual flue gas**

Integrated Testing Facility (RTI)

Participants: RTI, BOC Gases, EPRI, EPA, ARCADIS, ADA-ES, Solvay Chemicals, and Süd Chemie

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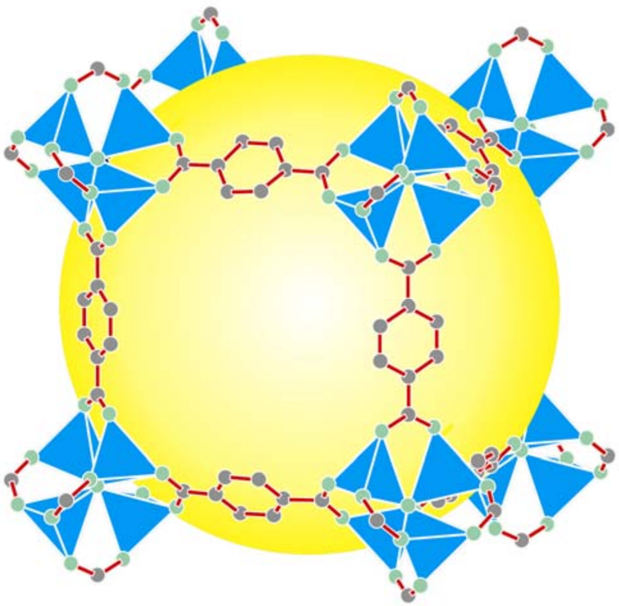
Metal Organic Frameworks for CO_2 Capture

- **Hybrid organic/inorganic structures - scaffolds of metal hubs linked together with struts of organic compounds**
- **Highly porous - structure designed to maximize surface area. (one gram of a MOF has the surface are of a football field)**
- **Thermally stable**
- **Adjustable chemical functionality**
- **Can be made in large quantities from low-cost ingredients, such as zinc oxide and terephthalate**
- **Current work will select an optimum MOF configuration and conduct scale-up experimentation and evaluation under actual flue gas conditions**

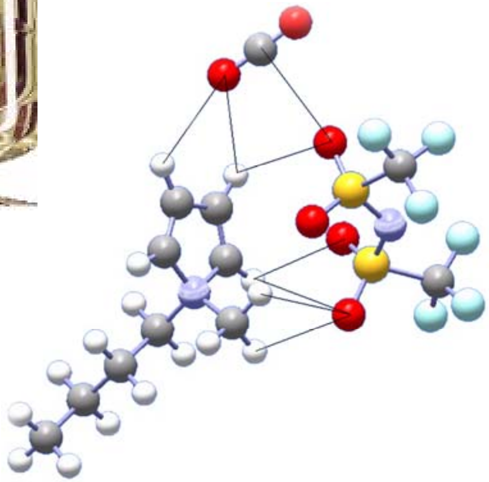


MOF - 5

Participants: UOP LLC, Vanderbilt University, University College London, EPRI

Ionic Liquids as Novel Absorbents

- **Ionic liquids (ILs): salts that are liquid at room temperature**
  - Do not evaporate
  - Can absorb large amounts of CO_2
- **Success at Basic Research Stage**
  - Significant improvement in CO_2 solubility and selectivity
  - May allow for capture of both SO_2 and CO_2
- **Future Work**
  - Selection of optimal ILs and scale-up for testing with actual flue gas compositions
  - Supported liquid membranes (with NETL)



Participants: University of Notre Dame, DTE Energy, Babcock and Wilcox, Trimeric, Merck KGaA, NETL

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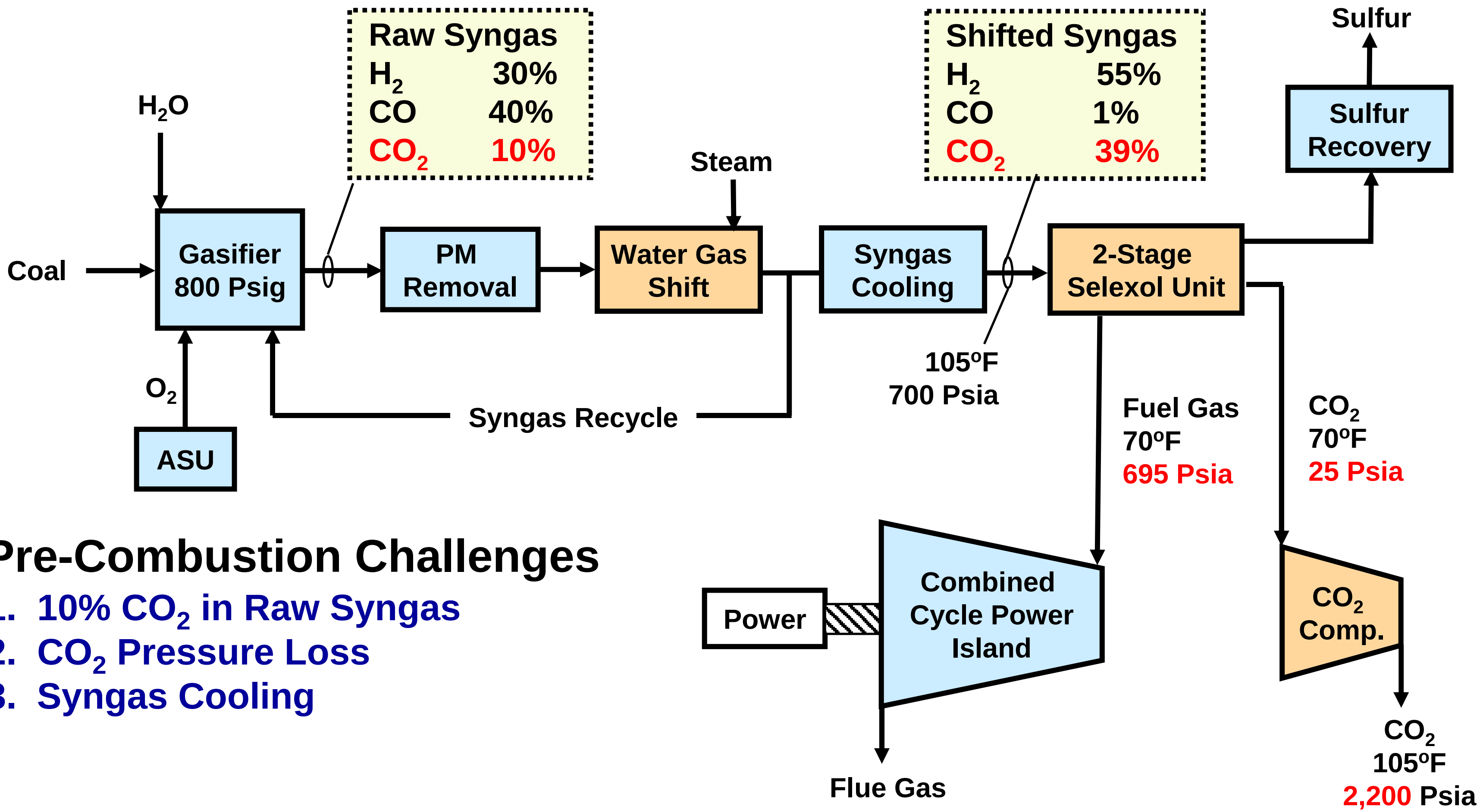
Pre-combustion

Pre-Combustion Current Technology

IGCC Power Plant with CO_2 Scrubbing



Pre-Combustion Challenges

1. 10% CO_2 in Raw Syngas
2. CO_2 Pressure Loss
3. Syngas Cooling

Source: *Evaluation of Innovative Fossil Fuel Power Plants with CO2 Removal,* DOE/EPRI, 1000316

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Thermally Optimized Membranes

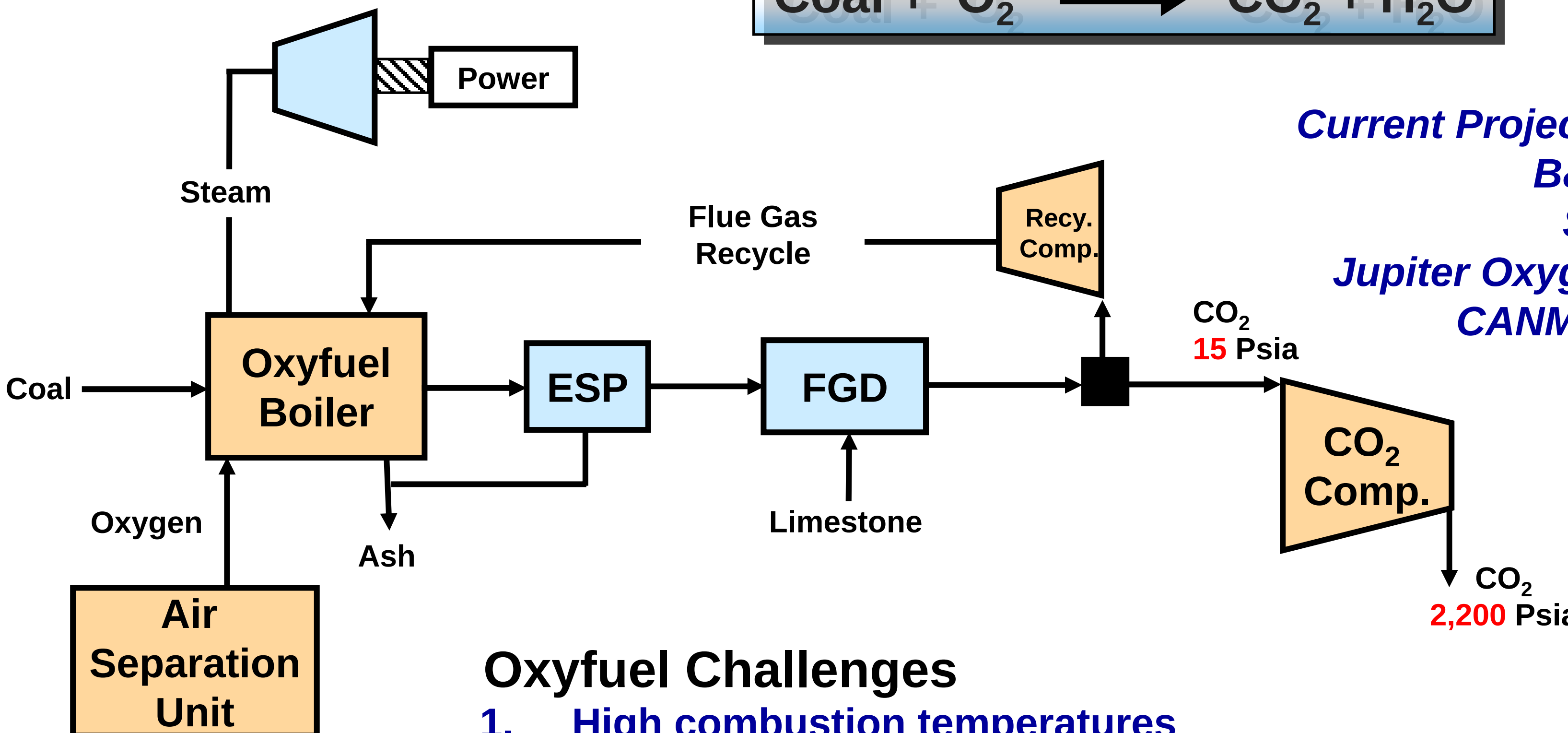
- **Develop high-temperature polymer membranes for more efficient separation of CO_2 from syngas streams**
- **Functional sites added to the structure of a polymer chain to facilitate transfer of CO_2 through the membrane**
- **Membranes operate at temperatures of 100 to 400ºC to take advantage of enhanced gas diffusion**
  - "Tune" CO_2 permeability as a function of temperature
- **Chemical resistance of polymer will maximize membrane life**

Participants: SRI Intl, LANL, BP Alternative Energy America, Southern Company, Visage Energy, Enerfex, Whitefox Technologies

Oxy-combustion

Pulverized Coal Oxycombustion

Coal + O_2 → CO_2 + H_2O



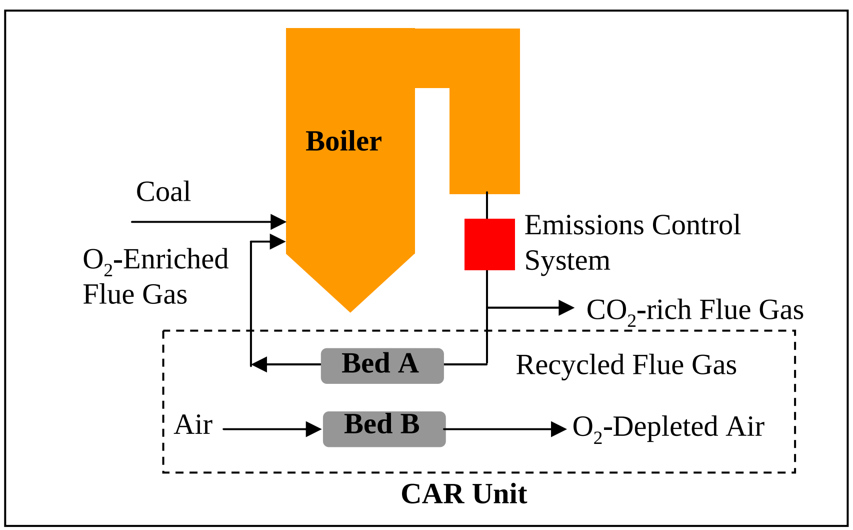
Current Projects:
B&W
SRI
Jupiter Oxygen
CANMET

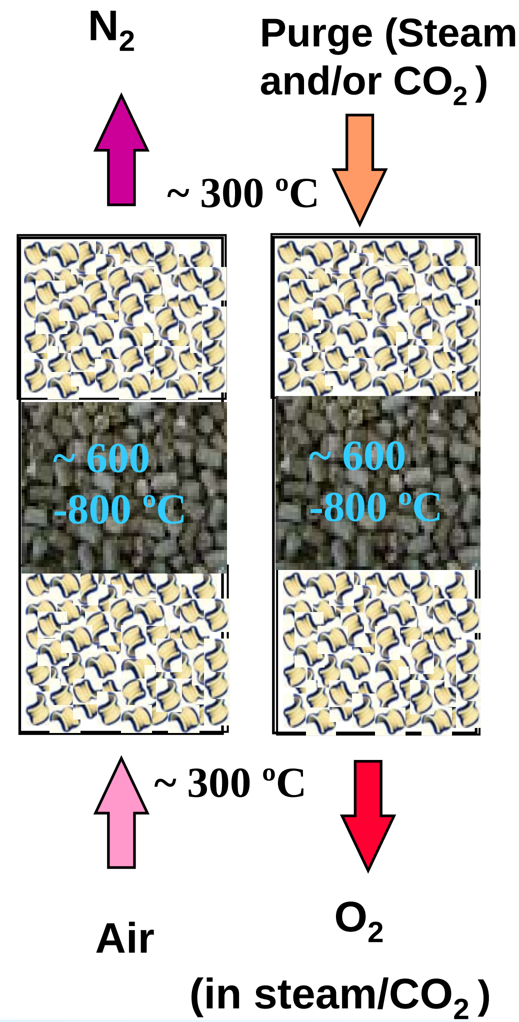
Oxyfuel Challenges

1. **High combustion temperatures**
   *Boiler materials of construction issues
   *Requires large amounts of flue gas recycle
2. **Cryogenic oxygen production is expensive and energy intensive**
   *Opportunity for oxygen membranes

Ceramic Autothermal Recovery

- **High temperature (T > 550 ºC), Cyclic steady state process; uses perovskites pellets in a fixed-bed**
- **Oxygen-enriched product stream at high temperature: ~ 300 ºC; low purity O_2 (high N_2 rejection); high O_2 recovery**
- **Oxy-fuel combustion for power production**
  - Main Driver: CO_2 sequestration
  - Target ~25% savings compared to O_2 from cryogenic ASU

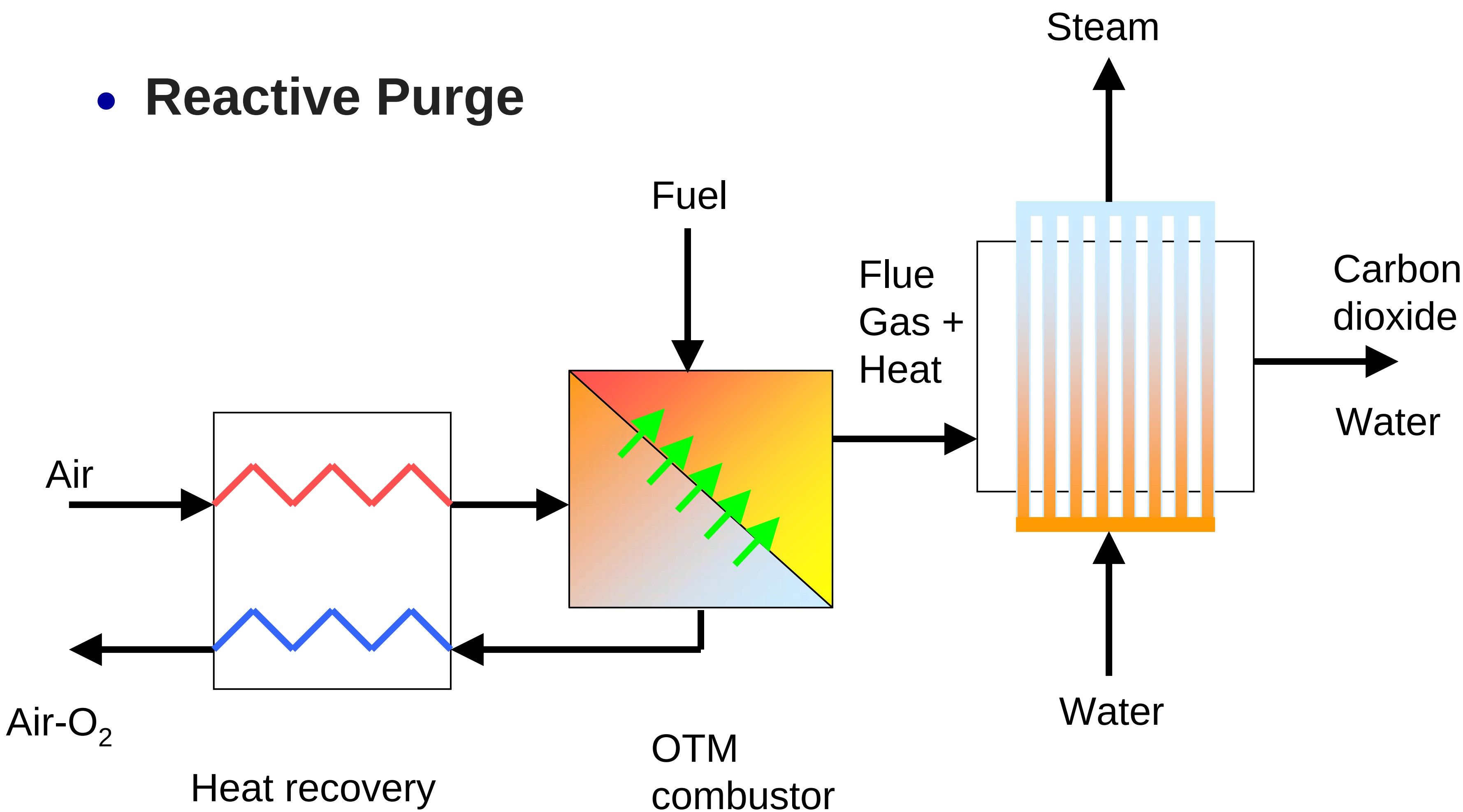




Participants: BOC Gases, Alstom, WRI

Oxygen Transport Membranes

- **Reactive Purge**



Participants: Praxair, University of Utah

Breakthrough Concepts

Recently Selected Breakthrough Capture Technologies

- **Metal Monolithic Amine-grafted Zeolites – University of Akron**

- **High Selectivity/High Flux Membrane System – Membrane Technology and Research, Inc.**

- **2nd Generation of Enzymatic Membranes for Flue Gas CO_2 Separation - Carbozyme**

Summary

Technology Target

- Complete pilot plant testing of precombustion decarbonlation systems
- Complete pilot plant testing of oxy fuel concept
- Complete pilot plant testing of promising post-combustion technology
- Cost-share power plant retrofit with advanced CO_2 capture technology

Open Category

CMU – Modeling framework for carbon management
U. Cal-Davis – Conceptual design – capture and sequestration of CO_2
ANL – Evaluation of CO_2 Capture options

Pre Combustion

- Decarbonization
- Advanced sorbents Hybrid sorbent/membrane systems

LANI/NEXANT - CO_2 Hydrate process for gas separation
NETL – Sorbent development for CO_2 separation and removal
INEEL, LANL- High-temperature polymer membrane
SRI – Polybenzimidazole membranes

Post Combustion

- Chemical and physical sorbents
- Hybrid sorbents/membrane system
- Gas/liquid contactors

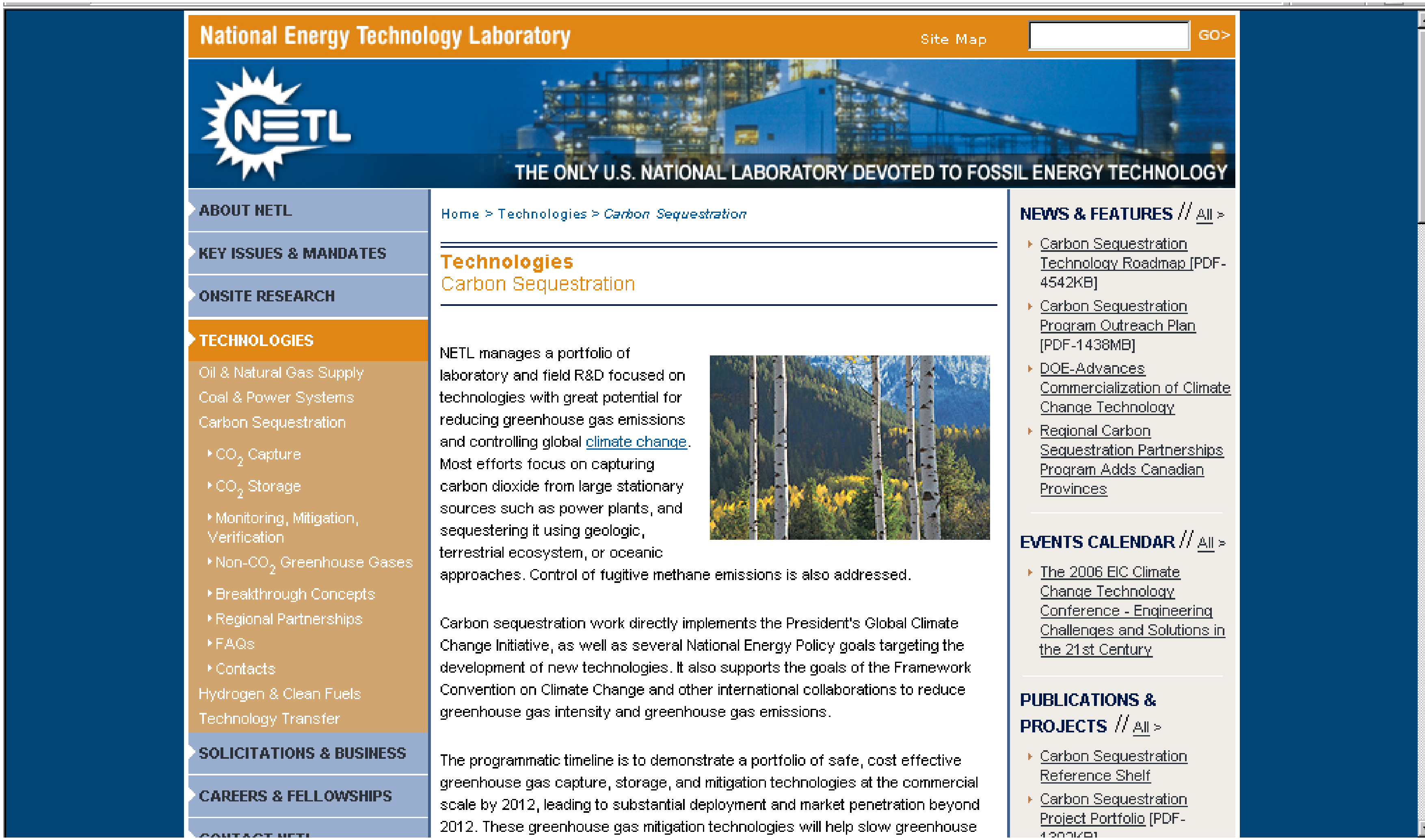
RTI – Dry regenerable CO_2 sorbents
NETL – CO_2 scrubbing with regenerable sorbents
NETL – Novel Amine-enriched sorbents
NETL – Modular CO_2 Capture facility
NETL – Ammonia based process
UT Austin – Absorption with K_2CO_3/Piperazine
Univ. of Notre Dame – Ionic liquids
UOP – Micropourous metal organic Fameworks
Carbozyme – Biomimetic membrane

Oxyfuel

- O_2 – selective membranes
Advanced cooling cycles
Compact boiler

Praxair – Advanced oxy-fuel boilers
Alstom Power – Oxygen firing in CFB boiler
Southern Research– O_2-fired CO_2 recycle
Babcock & Wilcox – Oxycombustion pilot testing
BOC – Low-cost O_2 integrated with oxy-fuel boiler

Additional Information



http://www.netl.doe.gov/technologies/carbon_seq/index.html

Questions ?