Oxycombustion Technology Research And The National Energy Technology Laboratory Carbon Sequestration Program

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Prof. Jost O.L. Wendt Honorary Session - Oxycombustion Of Coal III

Salt Lake City, UT

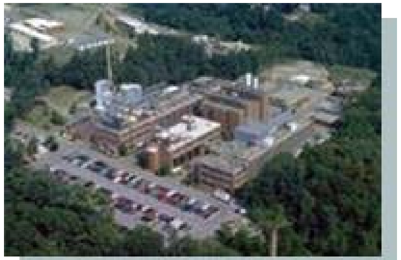
November 7, 2007

Outline for Presentation

- NETL Overview
- Background
- Carbon Sequestration Program
- Oxy-combustion Research
- Systems Analysis

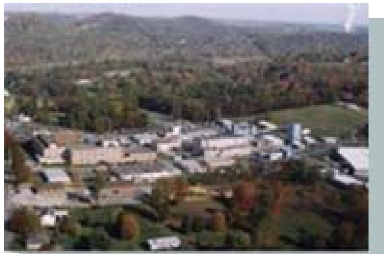
National Energy Technology Laboratory

- **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

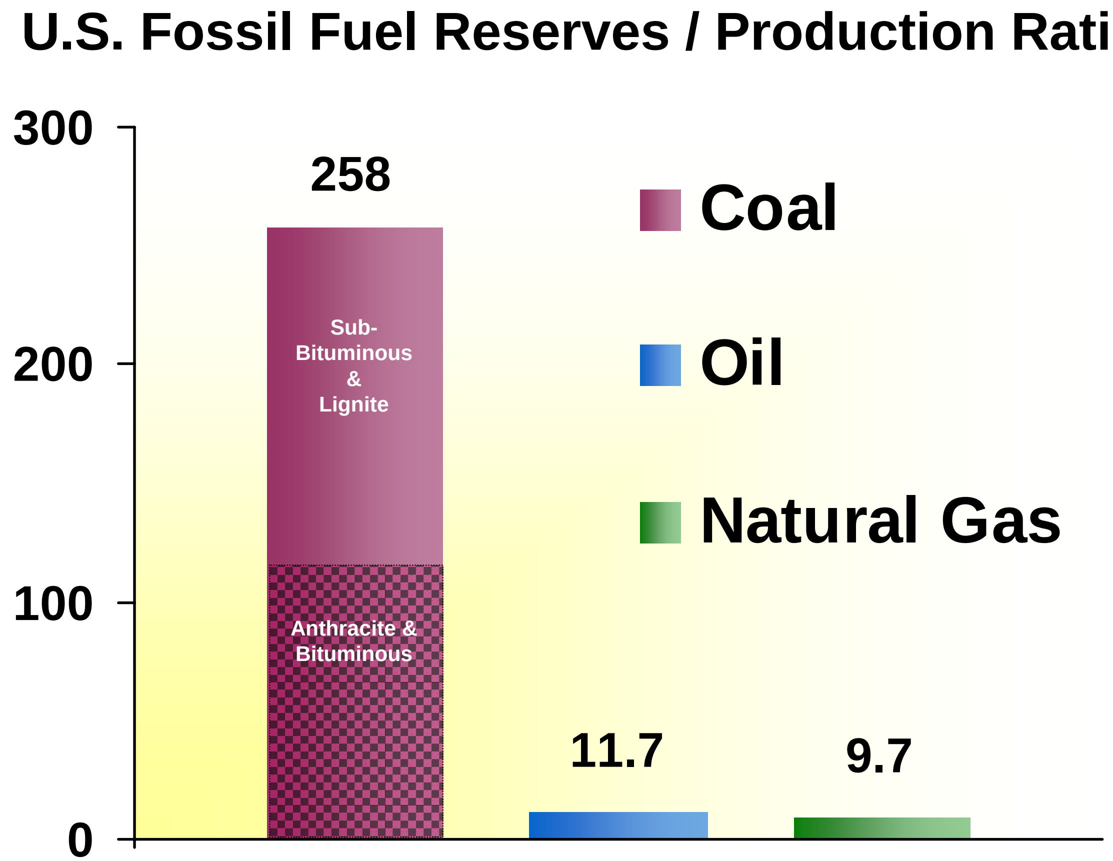


West Virginia

Alaska

Oklahoma

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.

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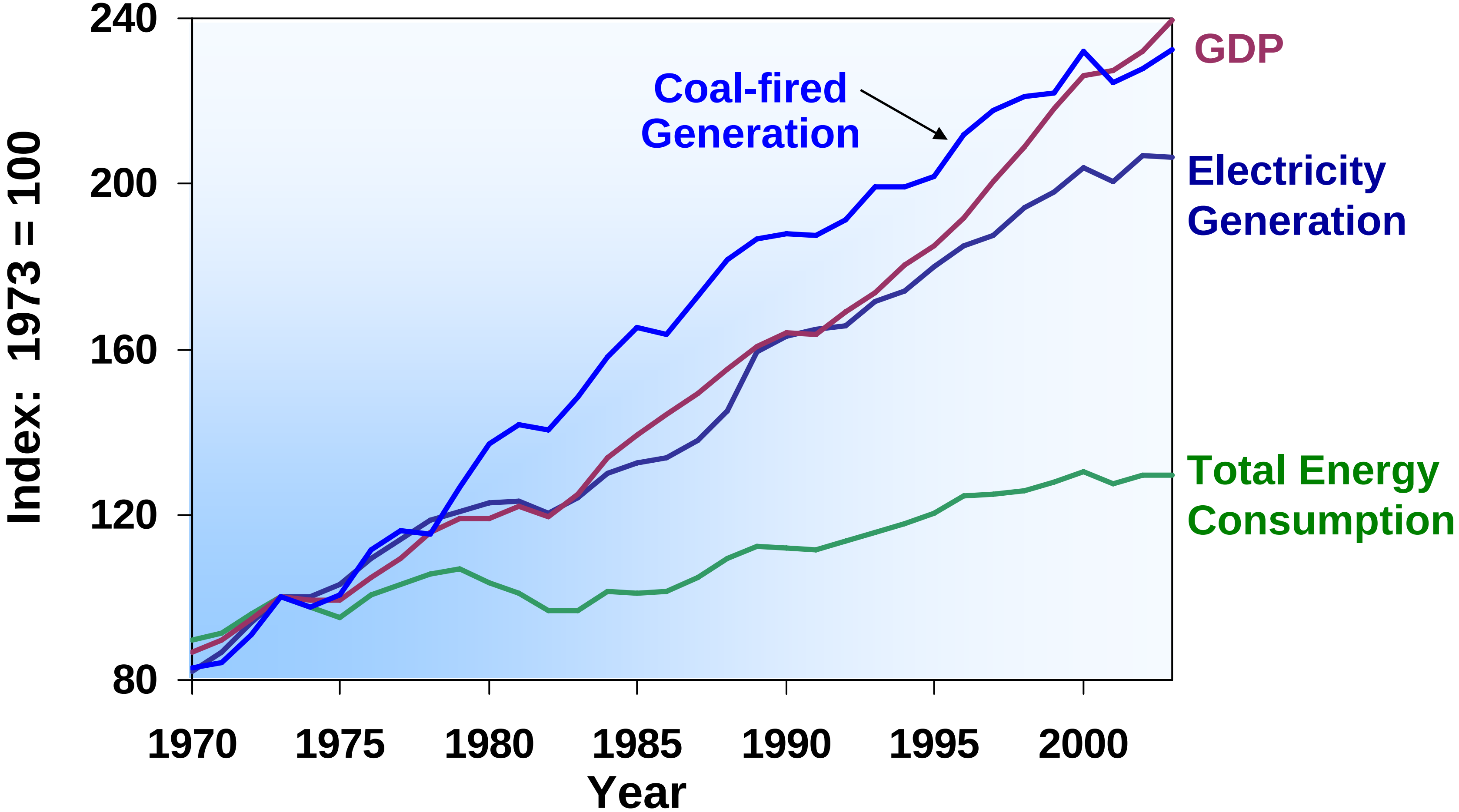
Coal Use Linked to Economic Growth in United States!



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

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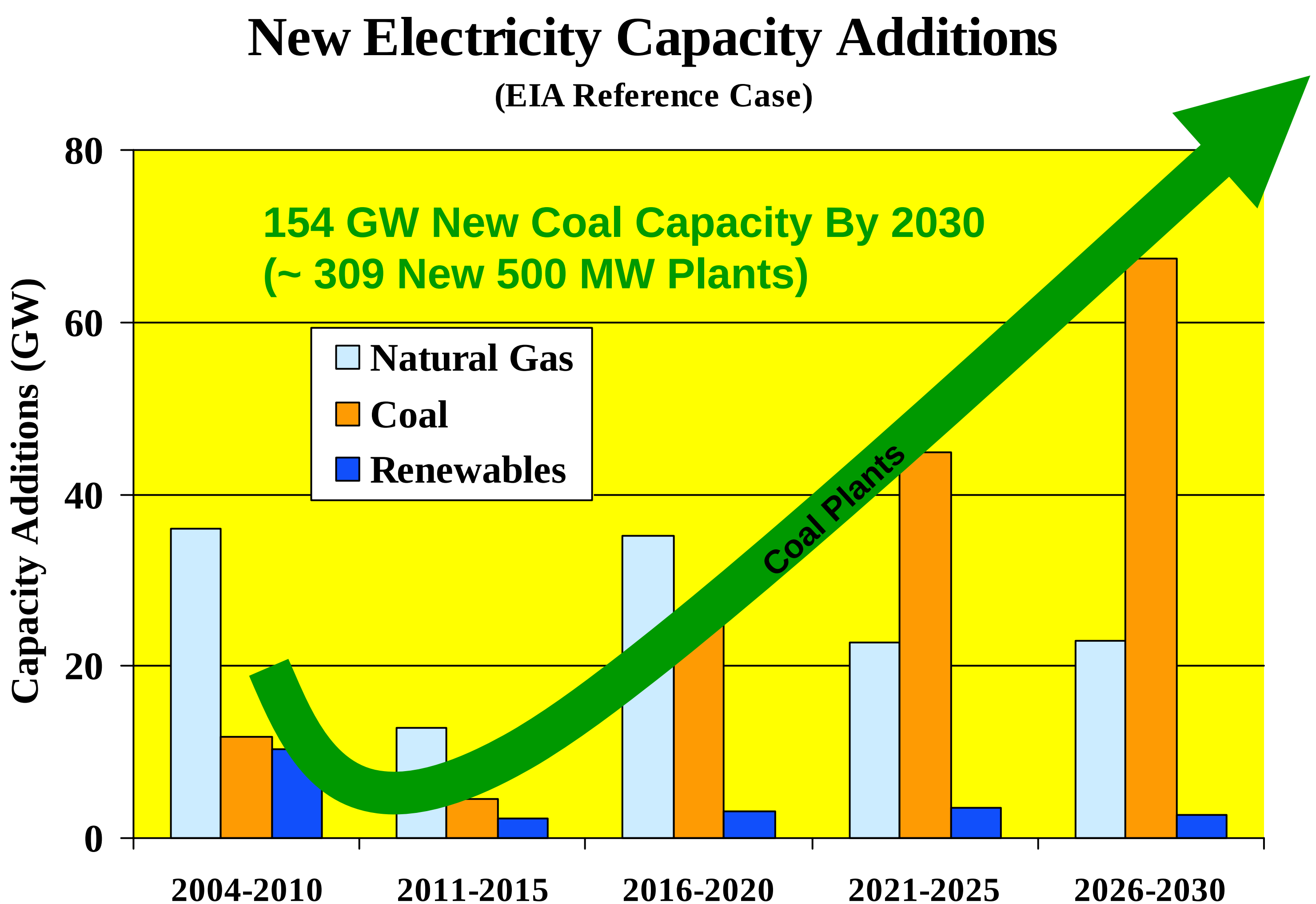
GDP: U.S. DOC, Bureau of Economic Analysis Energy & Electricity: EIA, Annual Energy Review 2003

Coal Dominates U.S. Power Generation Forecast

(Accounts for 50% of New Capacity Additions)



Source: Data Derived From EIA Annual Energy Outlook 2006

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?

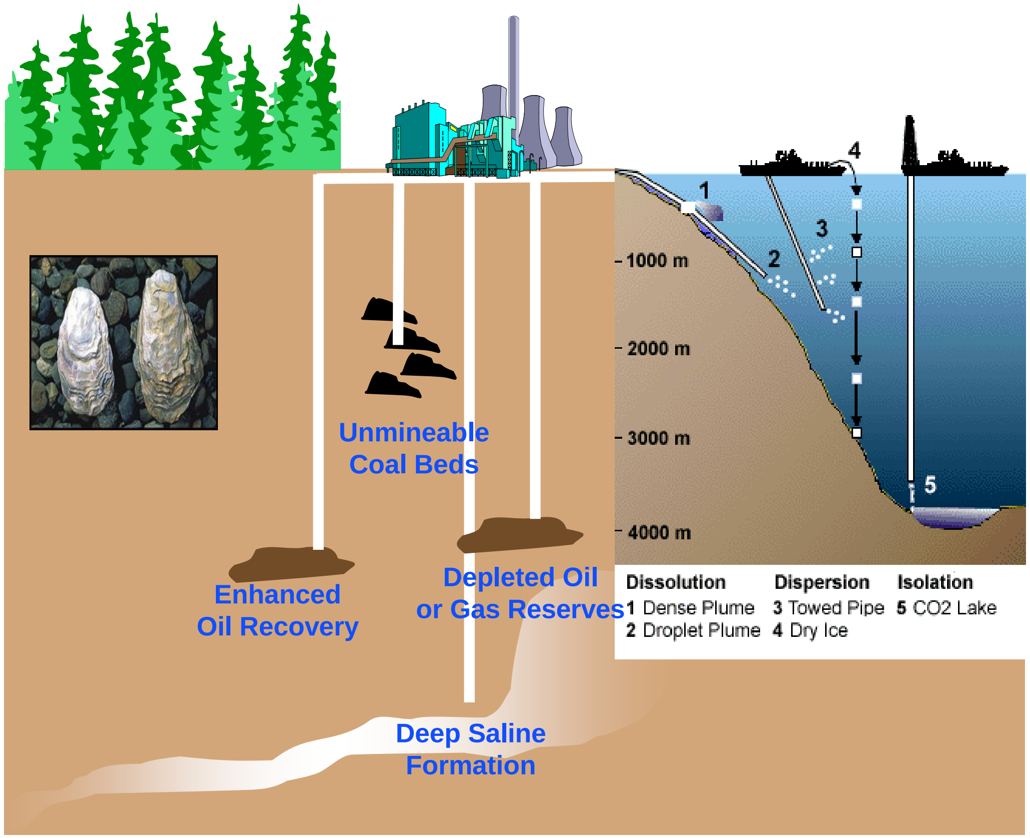
Capture and storage of CO_2 and other Greenhouse Gases that would otherwise be emitted to the atmosphere

Capture can occur:

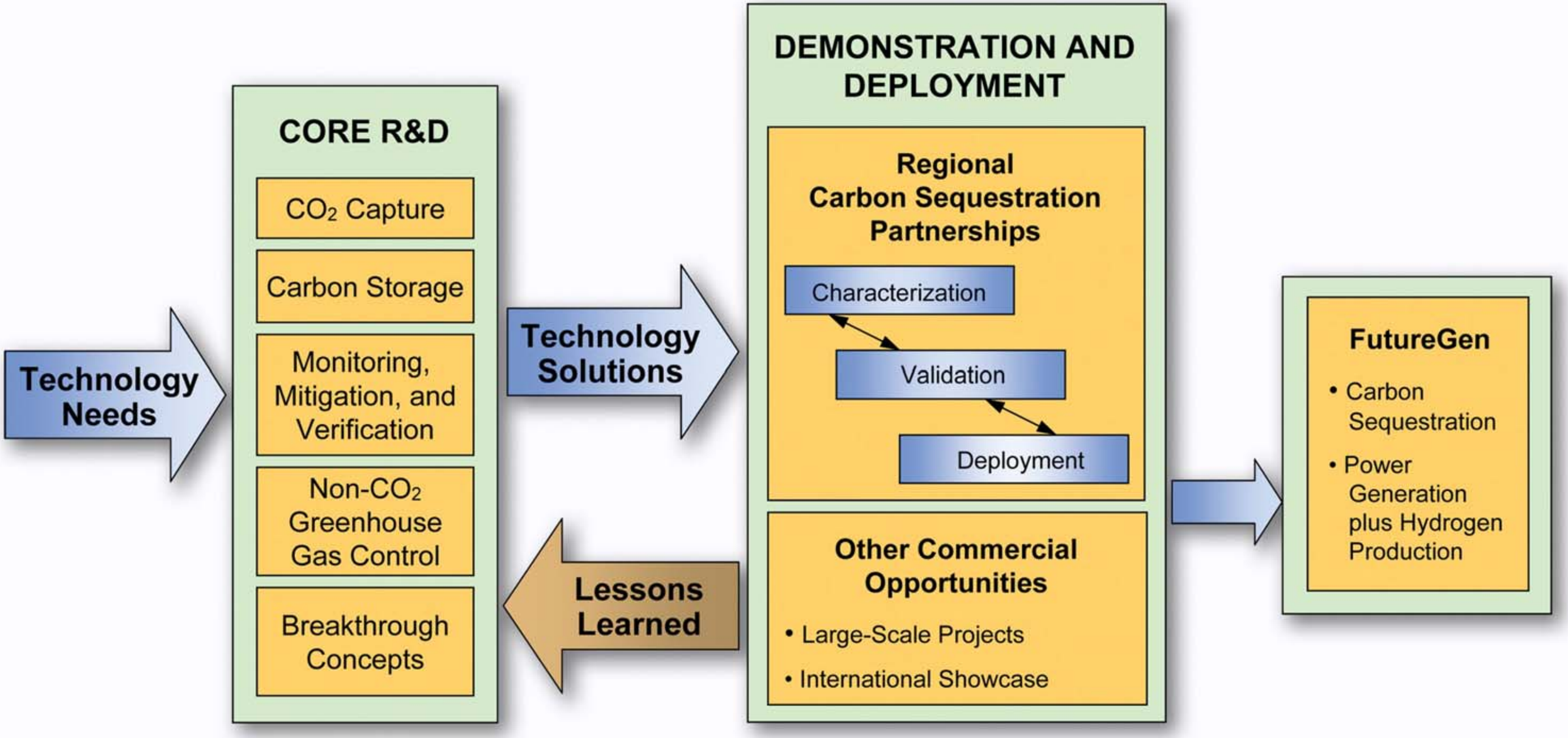
- at the point of emission
- when absorbed from air

Storage locations include:

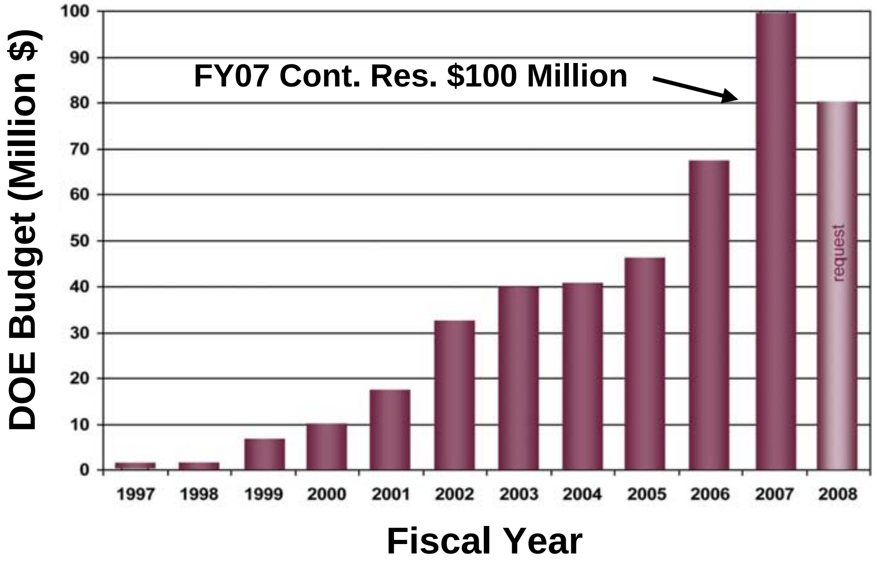
- underground reservoirs
- converted to solid materials
- trees, grasses, soils, or algae
- dissolved in deep oceans



Carbon Sequestration Program Structure



U.S. DOE's Carbon Sequestration Program Statistics



Strong industry support

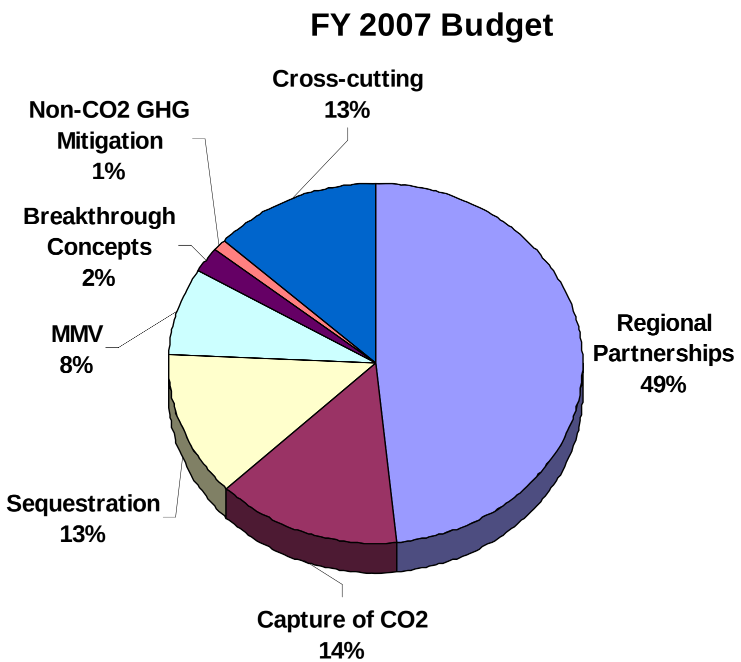
~ 39% cost share on projects

Federal Investment to Date

~ $360 Million

Diverse research portfolio

~ 70 Active R&D Projects



FY2008 Energy and Water Appropriations

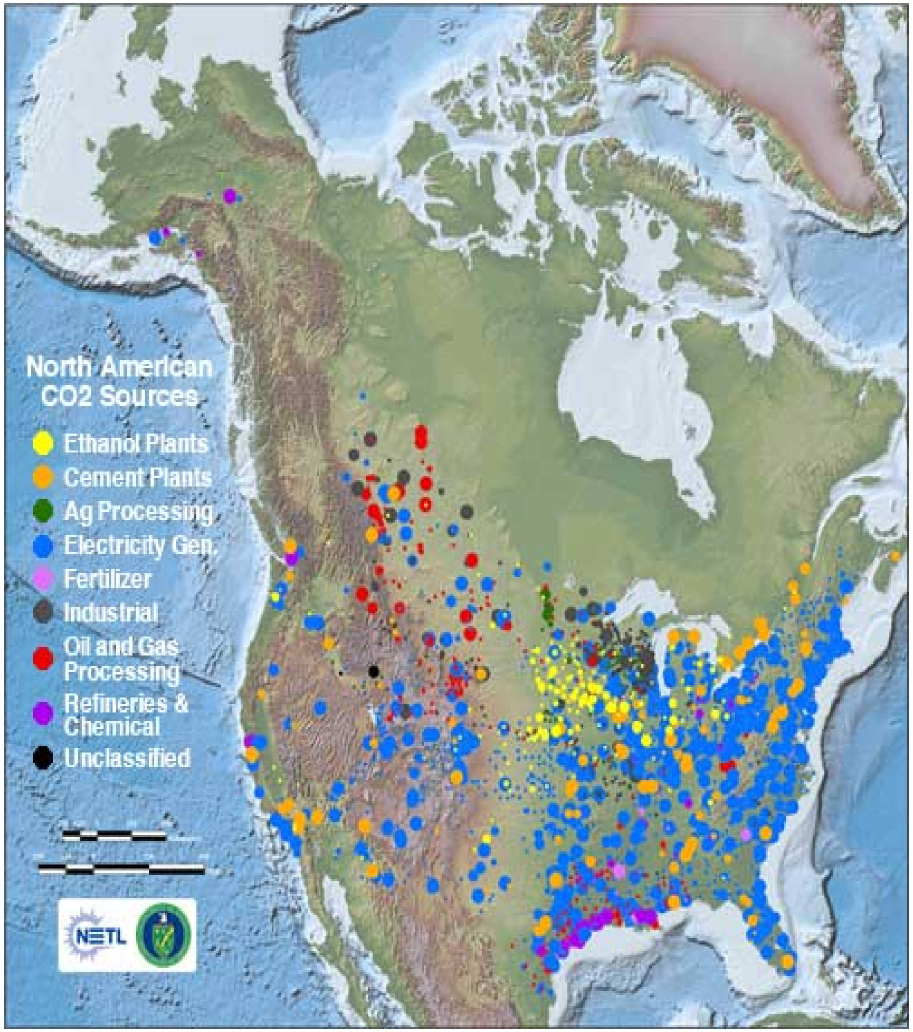
- Sequestration
  - **$131,577,000** House HR2641***Not yet law***
    - Large scale injection projects
  - **$132,000,000** Senate S1751 ***Not passed by Senate yet***
- Innovations for Existing Plants
  - "The Committee provides **$50,000,000** for innovations at existing plants… The Committee directs the Department to focus R&D efforts on CO_2 capture technology for existing pulverized coal (PC) combustion plants, to include efforts on high-strength materials for heat intensive operations, plant efficiency, and oxy-fuel combustion PC retrofit technology." House HR2641 ***Not yet law***
  - "The recommendation includes **$34,000,000** for Innovations for Existing Plants. Because carbon capture from existing plants is a substantial ongoing challenge to the existing fleet, the Innovations for Existing Plants program is directed to consider carbon capture as a future focus of this program…" Senate S1751 ***Not passed by Senate yet***

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

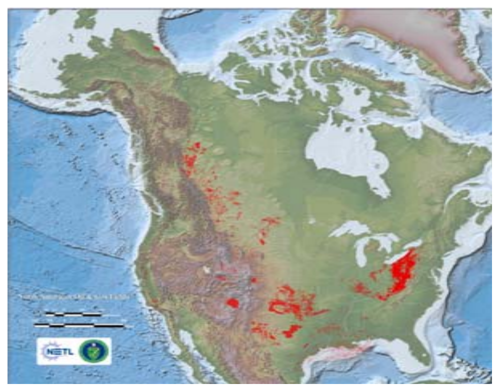
CO_2 Sources (Giga Tons)

	CO_2 Emission	Number of Facilities
CO_2 Sources	3.81	4,365

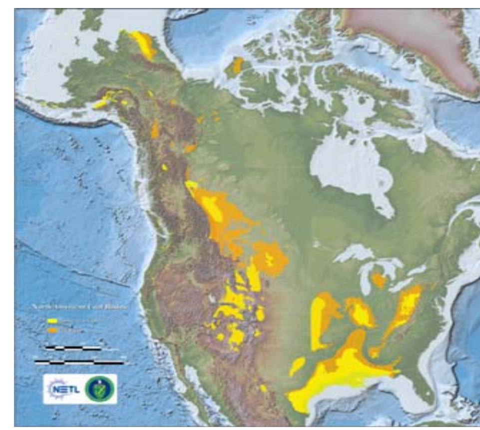
North American CO_2 Storage Potential (Giga Tons)

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

Saline Formations



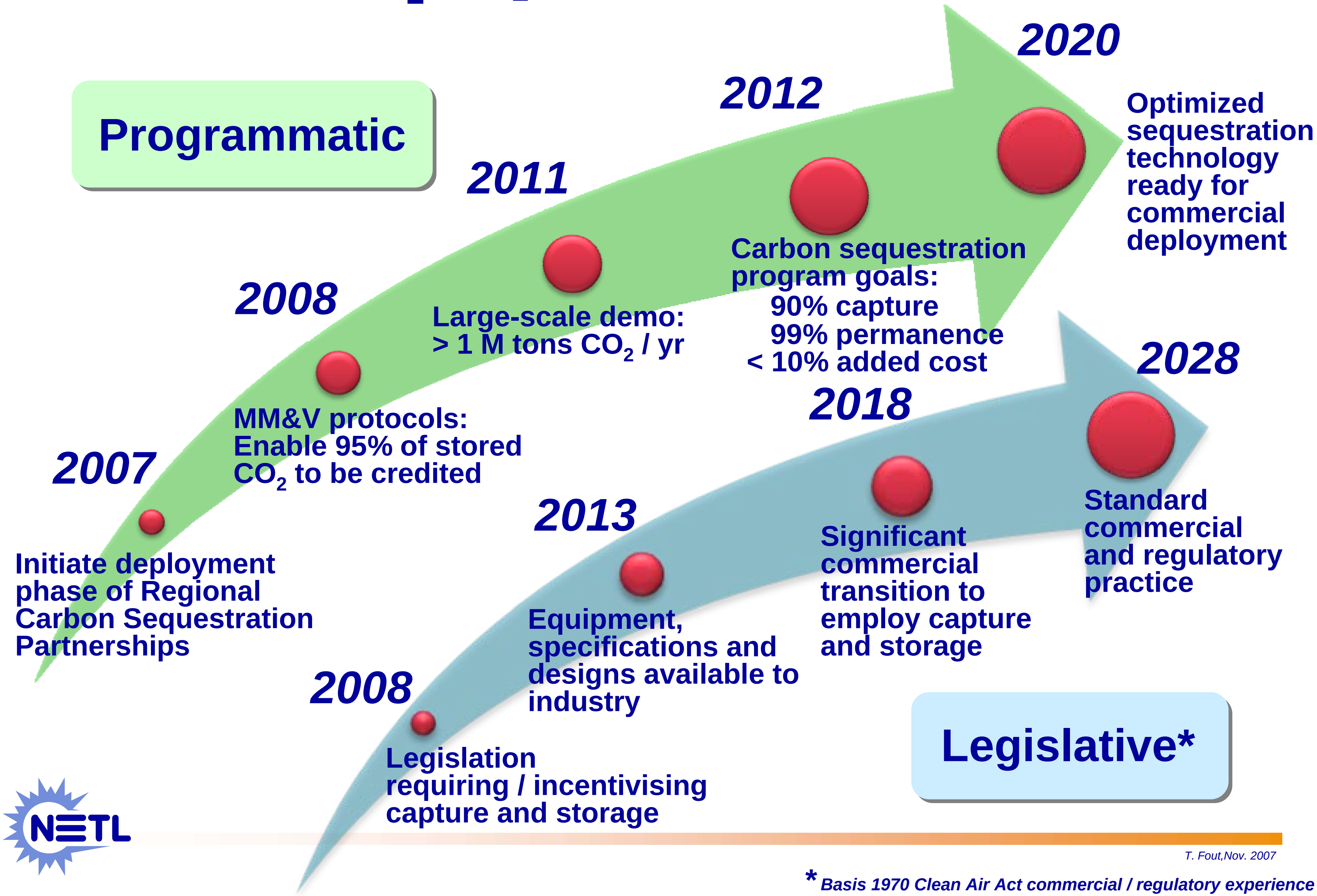
Unmineable Coal Seams



Oil and Gas Fields

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

CO_2 Sequestration Timelines



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Basis 1970 Clean Air Act commercial / regulatory experience

Technology Pathways
Separation & Capture of CO_2

Issue

- **Demonstrated technology is costly**

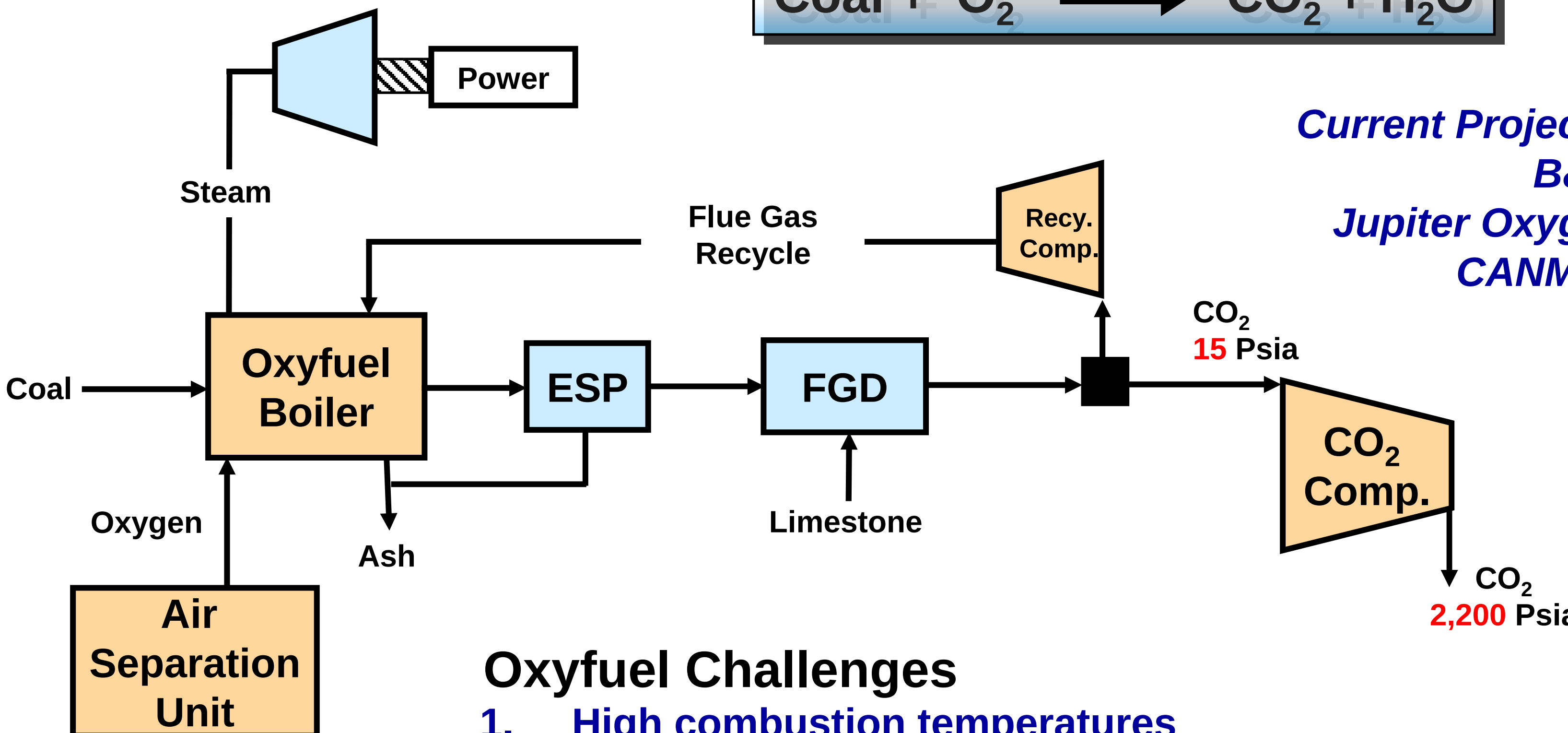
Pathways

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

Pulverized Coal Oxycombustion

$Coal + O_2 \rightarrow CO_2 + H_2O$

Current Projects:
B&W
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

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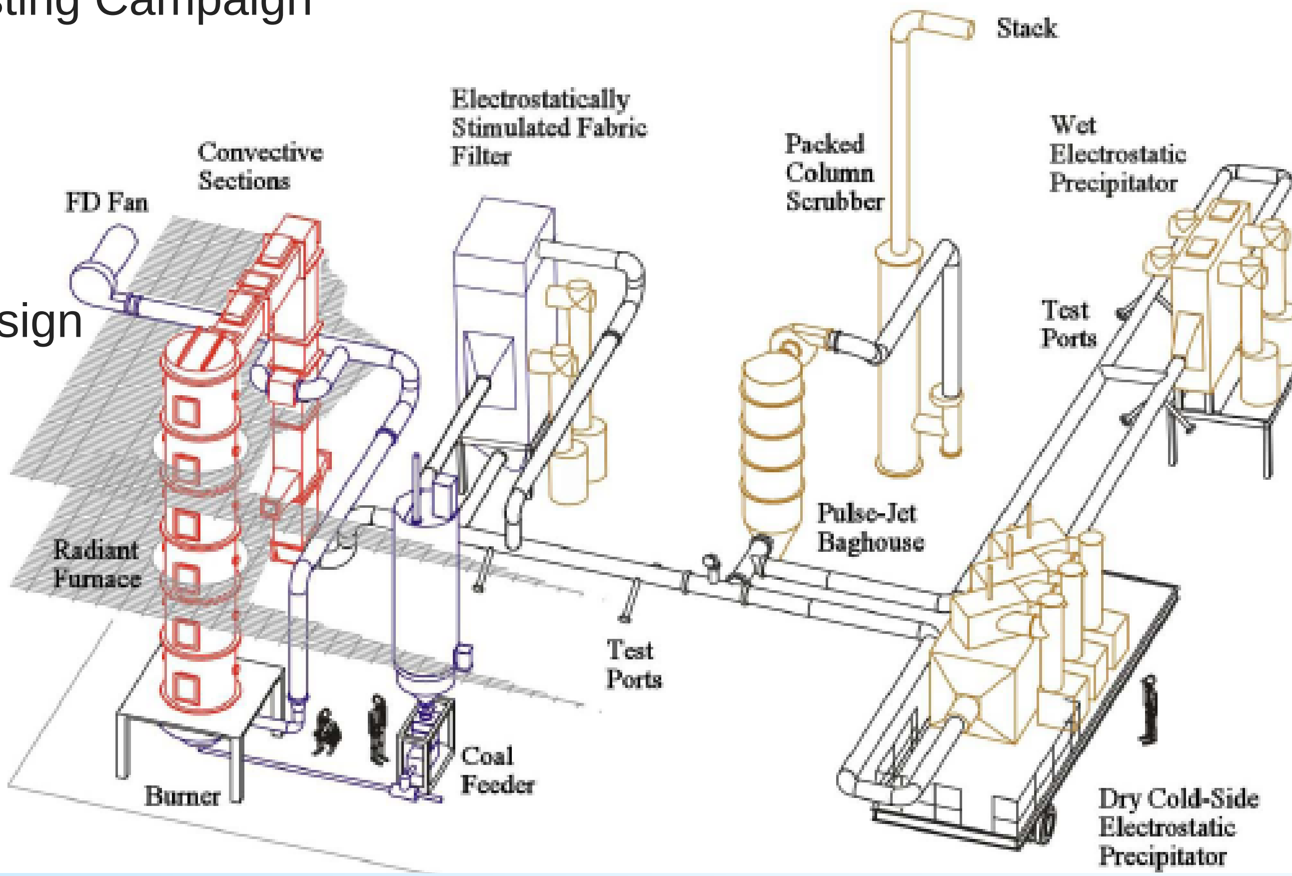
Oxygen-Fired CO_2 Recycle for Application to Direct CO_2 Capture from Coal-Fired Power Plants

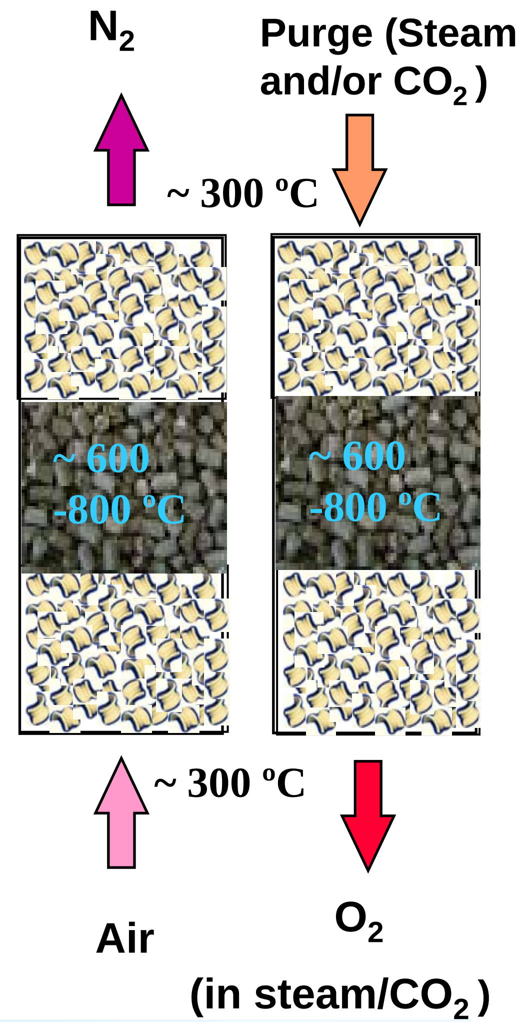
- **Retrofit existing combustion facility for oxy-combustion**
  - Design and Install Recycle Loop
  - Parametric Testing Campaign
- **Status:**
  - Recycle Loop Design Completed
  - Oxy-combustion Burner Design Completed
  - CFD underway



Participants: Southern Research Institute, Maxon, DTE Energy, The BOC Group, Doosan Babcock, REI

Ceramic Autothermal Recovery

- Process Features
  - Uses oxygen "storage" property of perovskites at high temperatures. Highly selective O_2 extraction.
  - Based on conventional pelletized materials
  - Cyclic steady state process. Perovskite alternately exposed to feed air and regeneration gas flows.
  - Partial pressure swing (using a sweep gas) enables production of an O_2-enriched stream
  - Internal regenerative heat transfer

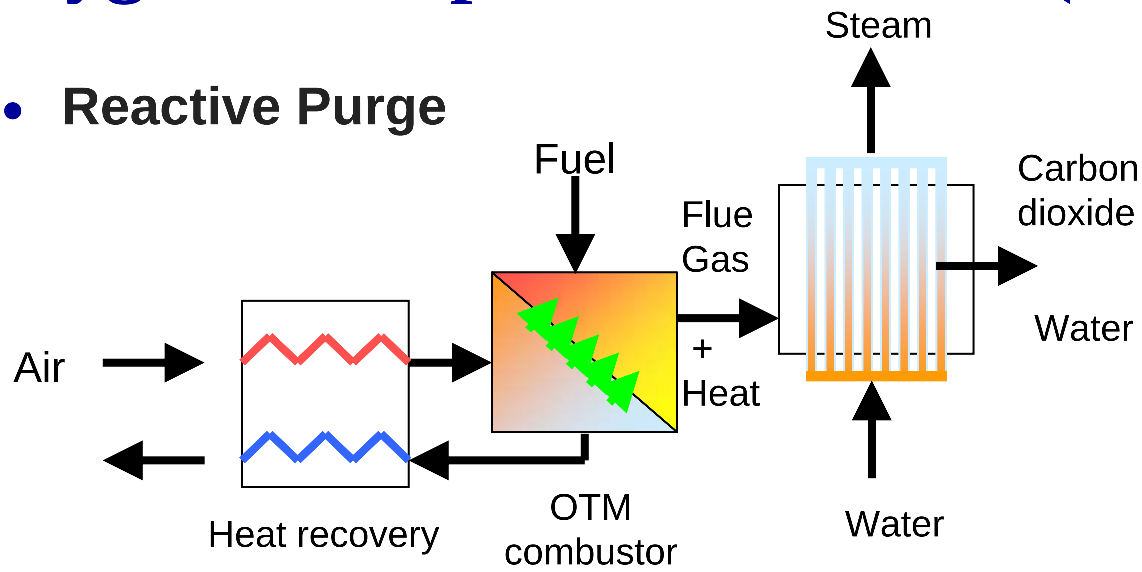


Perovskite Samples

Participants: The BOC Group, Alstom, WRI

Oxygen Transport Membranes (OTM)

- **Reactive Purge**



- **Oxy-fuel combustion technology. Natural Gas approach depicted. Coal based concepts under development.**
- **Increase in thermal efficiency from ~87 % to ~95% (HHV)**
- **CO_2 product ready for sequestration**
- **Ultra Low NO_x emissions**
- **1/10th the power consumption for oxygen separation from air compared to a cryogenic ASU.**

Participants: Praxair, University of Utah

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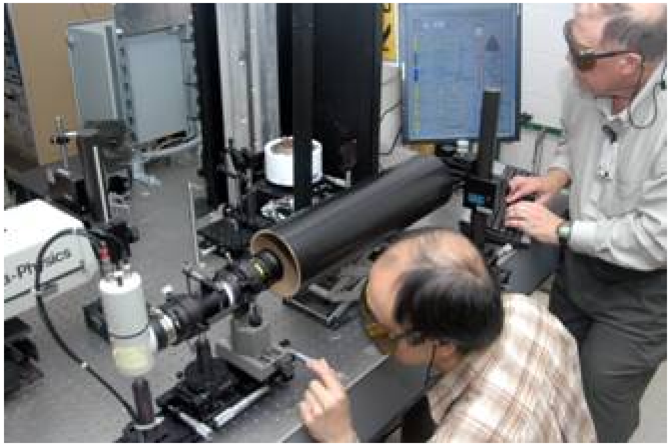
Graphic from Praxair Presentation, 2/15/06 NETL Pittsburgh

NETL/Office of Research and Development Oxy-Combustion Activities

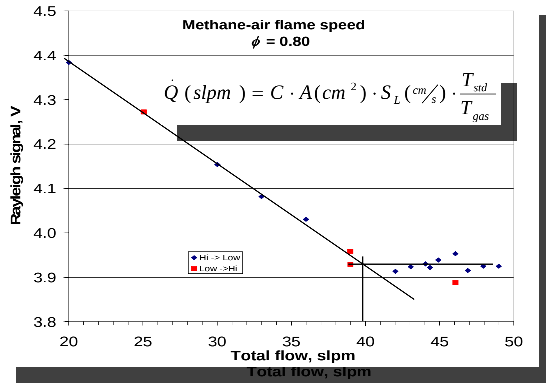
- **PC Coal and Turbine Power Cycles**

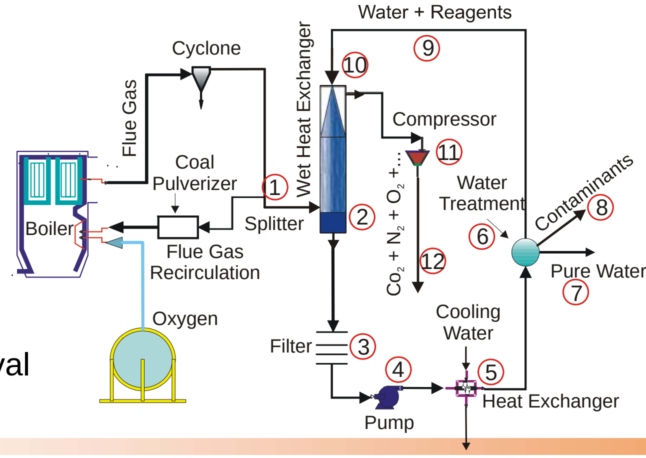
  Overall objective: development of improved and validated modeling tools for oxy-combustion systems



- **Approach combines modeling, lab tests, and field work**

Measurement of Oxy-Fuel Laminar Flame Speeds

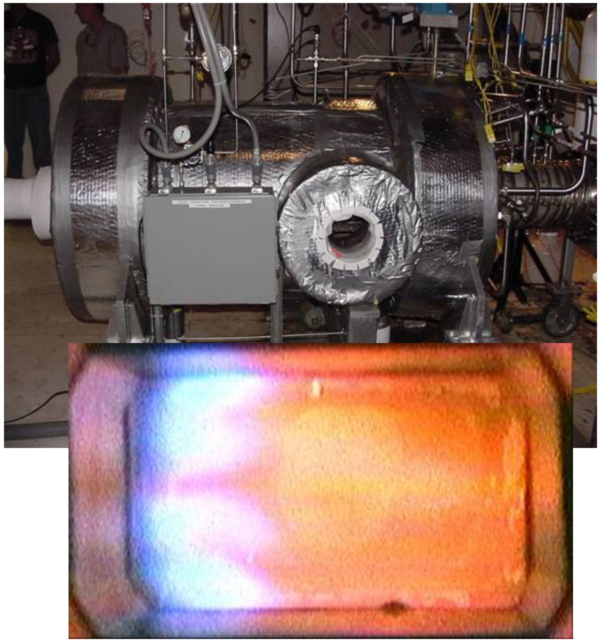




The Integrated Pollutant Removal (IPR) Process for CO2 Capture

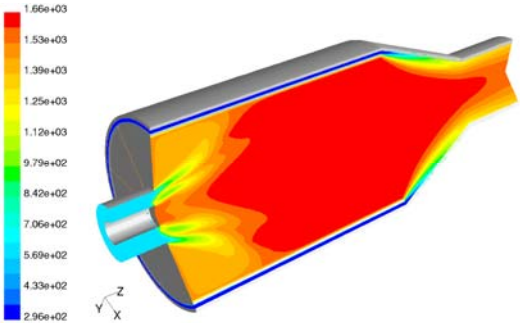
NETL/Office of Research and Development Oxy-Combustion Activities – cont'd

- **Obtain fundamental combustion data and radiative properties of oxy-flames**
  - Laminar flame speeds
  - Radiative properties/heat transfer in high steam environments and validation data sets
- **Systems-level modeling –**
  - test, demonstration and full scales Develop improved modeling/ simulation tools
- **Develop and validate CFD models for oxy-fired PC combustion**
- **Assess materials performance in oxy-combustion environments**
- **Develop approaches to capture CO_2 from oxy-fuel combustion products**



Reheat Combustor Demonstration

– NETL/NASA/CES



Study Matrix

Case	CO_2 Capture	Steam psig/°F/°F	Oxidant	NOx Control	CO_2 Purity	Storage
1	None	3500/1110/1150[a]	Air	0.07 lb/10^6Btu - Low NOx Burners - Over-fired Air - SCR	N/A	Saline Formation
2	None	4000/1350/1400[b]			N/A	
3	Econamine	3500/1110/1150			~100%	
4	Econamine	4000/1350/1400			~100%	
5	Cryogenic ASU Oxyfuel	Supercritical 3500/1110/1150	95 mol% O_2	0.07 lb/10^6Btu - Low NOx Burners - Over-fired Air - Flue Gas Recycle	Spec. A	
5A			99 mol% O_2		Spec. B	
5B			95 mol% O_2		Spec. B*	
5C			95 mol% O_2		Spec. C	
6	Cryogenic ASU Oxyfuel	Ultrasupercritical 4000/1350/1400	95 mol% O_2		Spec. A	
6A					Spec. C	
7	Membrane ASU Oxyfuel	Supercritical 3500/1110/1150	~100 mol% O_2		Spec. B	
7A					Spec C	

[a]Steam conditions for the supercritical (SC) power plant cases (available now)
[b]Steam conditions for the ultra-supercritical (USC) power plant cases (2015-2020)

ASU: Air Separation Unit
SCR: Selective Catalytic Reduction

CO_2 Purity

Specification A: Raw flue gas product using 95 mol% oxygen → Saline Formation
Specification B: Raw flue gas product using 99 mol% oxygen → Saline Formation
Specification C: Raw flue gas product using 95 mol% oxygen and treated to meet EOR Spec.

	EOR	Saline Formation
Pressure (psia)	2200	2200
CO_2	>95 vol%	not limited[1]
Water	dehydration[2] (0.015 vol%)	dehydration[2] (0.015 vol%)
N_2	<4 vol%	not limited[1]
O_2	<40 ppmv	<100 ppmv
Ar	< 10 ppmv	not limited
NH_3	<10 ppmv	not limited
CO	< 10 ppmv	not limited
Hydrocarbons	<5 vol%	<5 vol%
H_2S	<1.3 vol%	<1.3 vol%
CH_4	<0.8 vol%	<0.8 vol%
H_2	uncertain	uncertain
SO_2	<40 ppmv	<3 vol%
NOx	uncertain	uncertain

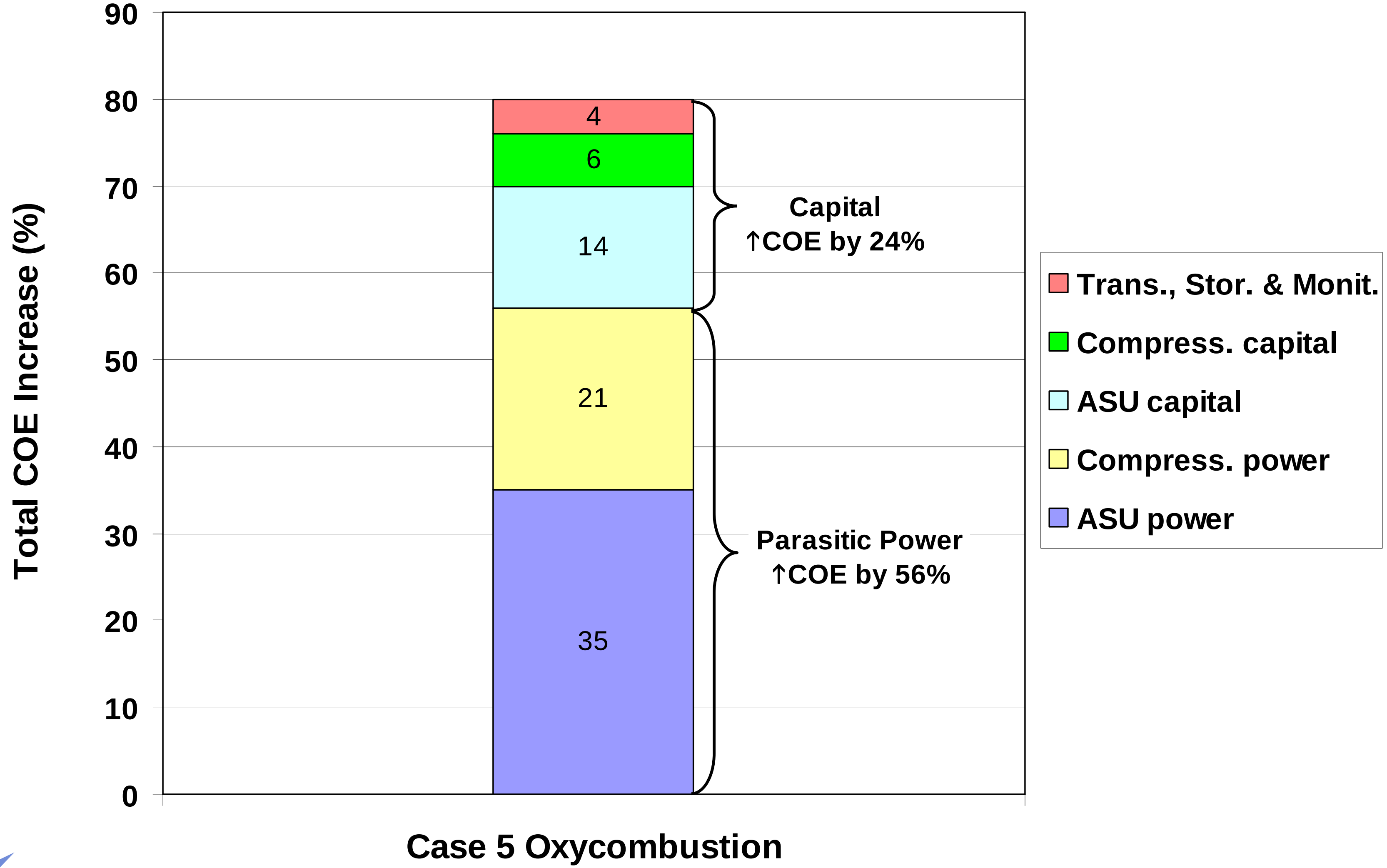
1: These are not limited, but their impacts on compression power and equipment cost need to be considered.
2: Dehydration process, such as a glycol absorber, is required.

Supercritical Oxyfuel Combustion
Key Points

- **Going from 95% to 99% O_2 purity results in:**
  - Less than 0.5% increase in ASU auxiliary load (130.5 MW to 131 MW)
  - A 9% increase in ASU capital cost ($509/kWe to $555/kWe)
  - A 4 Megawatt decrease in CO_2 compression and purification auxiliary power (78.5 to 74.5 MW) → Results in a slightly higher net power plant efficiency.

Bottom Line: The CO_2 compression and purification auxiliary power savings—due to the use of a higher purity oxidant—is offset by a 9% increase in ASU capital cost resulting in a negligible advantage in going from 95 to 99% oxygen purity.

Oxyfuel COE Increase Distribution



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

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

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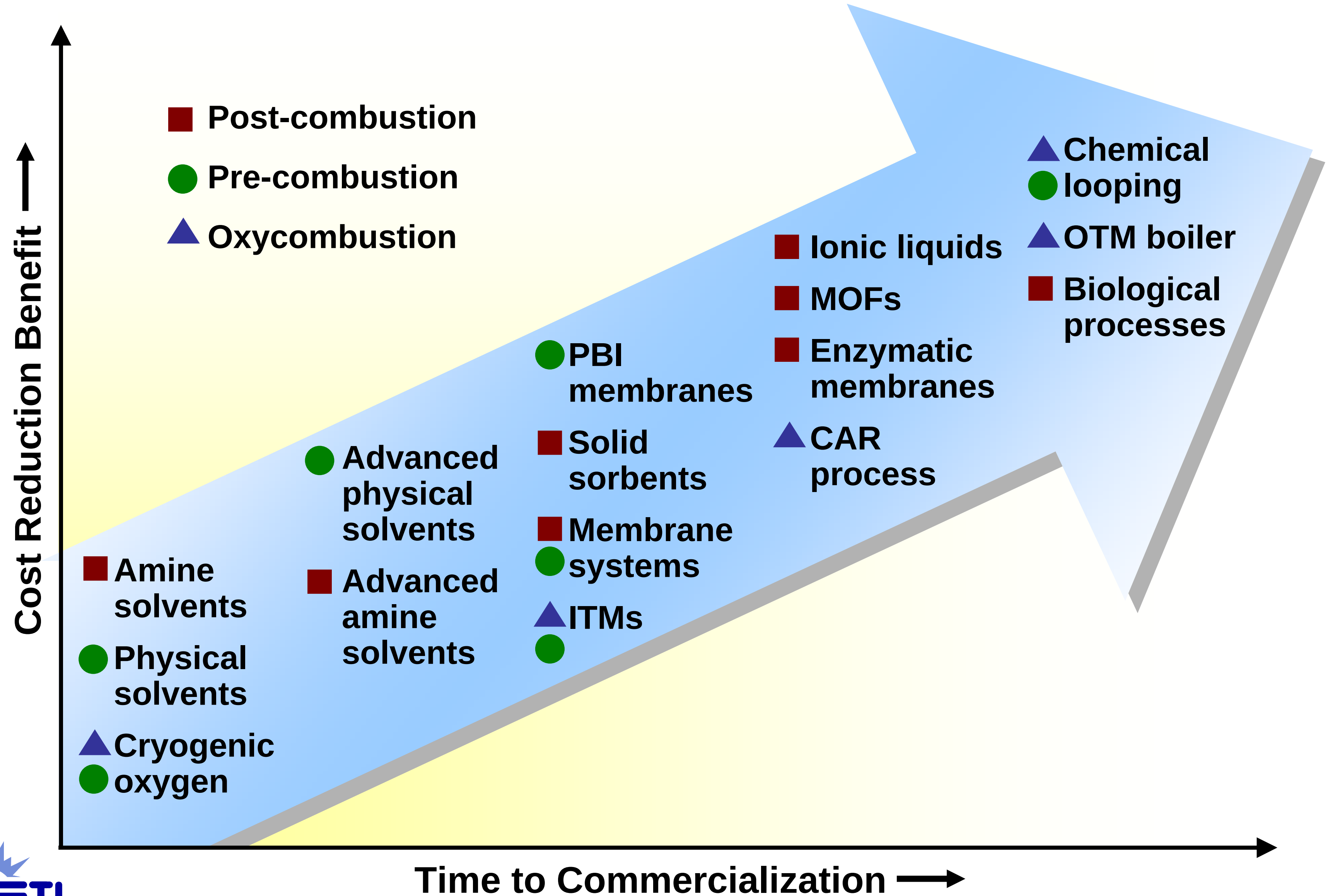
Innovation Advances



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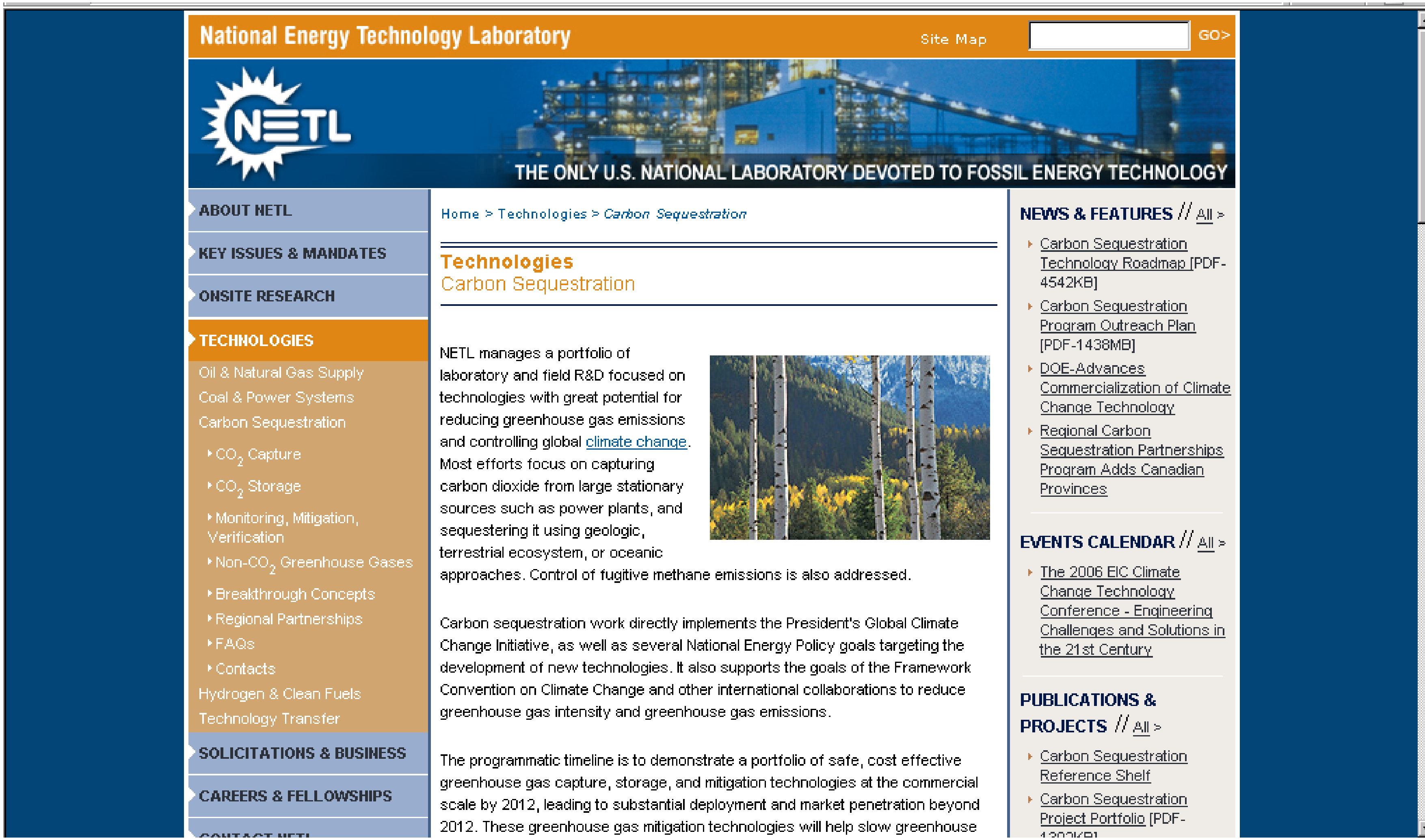
Figueroa JD, et al., *Advances in CO_2 Capture Technology—The U.S. Department of Energy's Carbon Sequestration Program, Int. J. Greenhouse Gas Control*, 2007

Additional Information



National Energy Technology Laboratory

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NETL

THE ONLY U.S. NATIONAL LABORATORY DEVOTED TO FOSSIL ENERGY TECHNOLOGY

ABOUT NETL
KEY ISSUES & MANDATES
ONSITE RESEARCH
TECHNOLOGIES
Oil & Natural Gas Supply
Coal & Power Systems
Carbon Sequestration
- CO_2 Capture
- CO_2 Storage
- Monitoring, Mitigation, Verification
- Non-CO_2 Greenhouse Gases
- Breakthrough Concepts
- Regional Partnerships
- FAQs
- Contacts

Hydrogen & Clean Fuels
Technology Transfer
SOLICITATIONS & BUSINESS
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Home > Technologies > *Carbon Sequestration*

Technologies
Carbon Sequestration

NETL manages a portfolio of laboratory and field R&D focused on technologies with great potential for reducing greenhouse gas emissions and controlling global climate change. Most efforts focus on capturing carbon dioxide from large stationary sources such as power plants, and sequestering it using geologic, terrestrial ecosystem, or oceanic approaches. Control of fugitive methane emissions is also addressed.

Carbon sequestration work directly implements the President's Global Climate Change Initiative, as well as several National Energy Policy goals targeting the development of new technologies. It also supports the goals of the Framework Convention on Climate Change and other international collaborations to reduce greenhouse gas intensity and greenhouse gas emissions.

The programmatic timeline is to demonstrate a portfolio of safe, cost effective greenhouse gas capture, storage, and mitigation technologies at the commercial scale by 2012, leading to substantial deployment and market penetration beyond 2012. These greenhouse gas mitigation technologies will help slow greenhouse

NEWS & FEATURES // All >
- Carbon Sequestration Technology Roadmap [PDF-4542KB]
- Carbon Sequestration Program Outreach Plan [PDF-1438MB]
- DOE-Advances Commercialization of Climate Change Technology
- Regional Carbon Sequestration Partnerships Program Adds Canadian Provinces

EVENTS CALENDAR // All >
- The 2006 EIC Climate Change Technology Conference - Engineering Challenges and Solutions in the 21st Century

PUBLICATIONS & PROJECTS // All >
- Carbon Sequestration Reference Shelf
- Carbon Sequestration Project Portfolio [PDF-

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