

# An Overview: The U.S. DOE Carbon Sequestration Program



*Southern States Energy Board  
Committee on Coal and Advanced  
Power Systems Meeting*

*January 15, 2003  
Atlanta Georgia*

Sarah M. Forbes  
National Energy Technology Laboratory



# National Energy Technology Laboratory

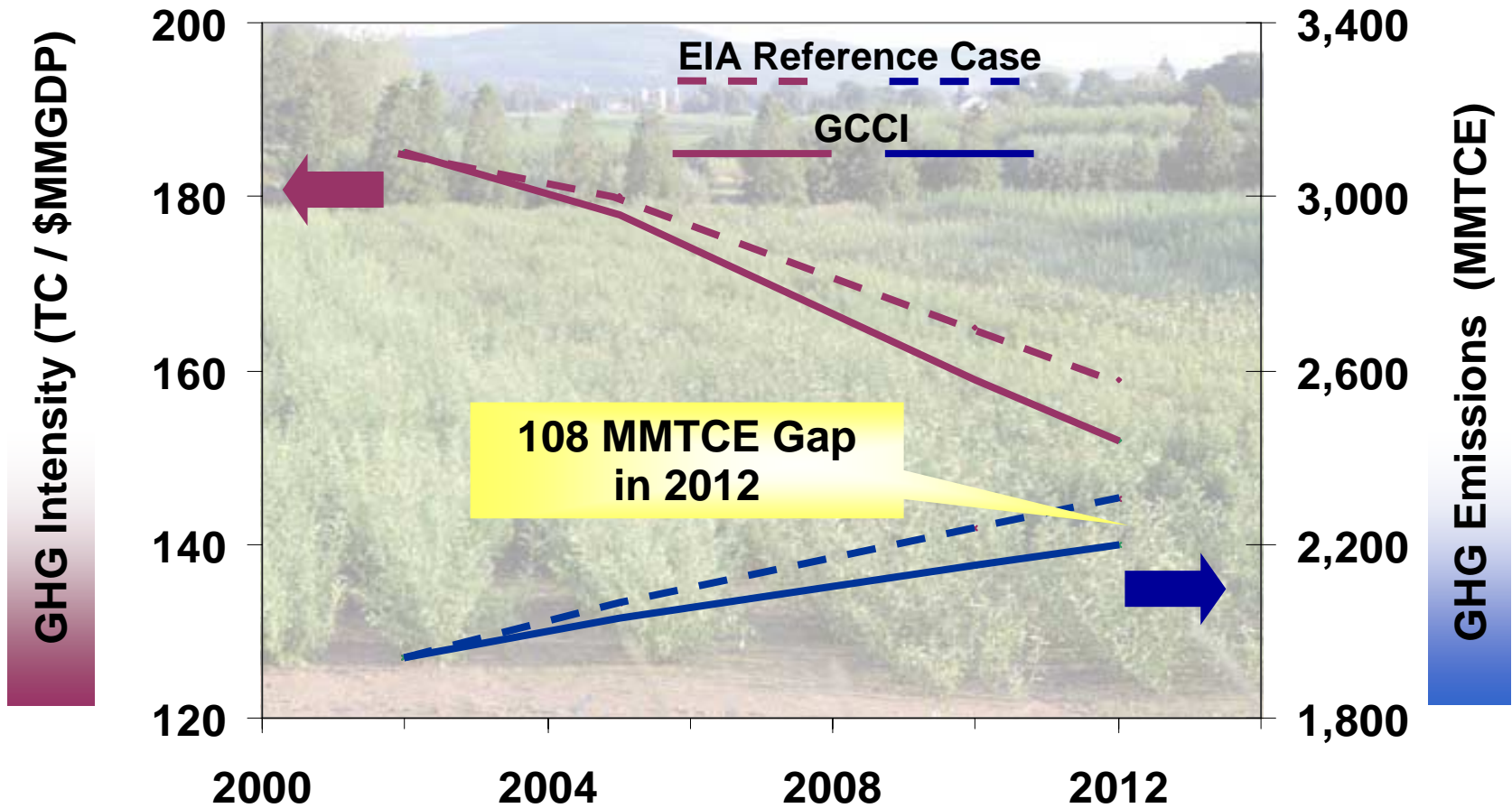


- One of DOE's 17 national labs
- Government owned and operated
- Sites in Pennsylvania, West Virginia, Oklahoma, Alaska
- More than 1,100 federal and support contractor employees
- FY 2002 budget of \$750 million



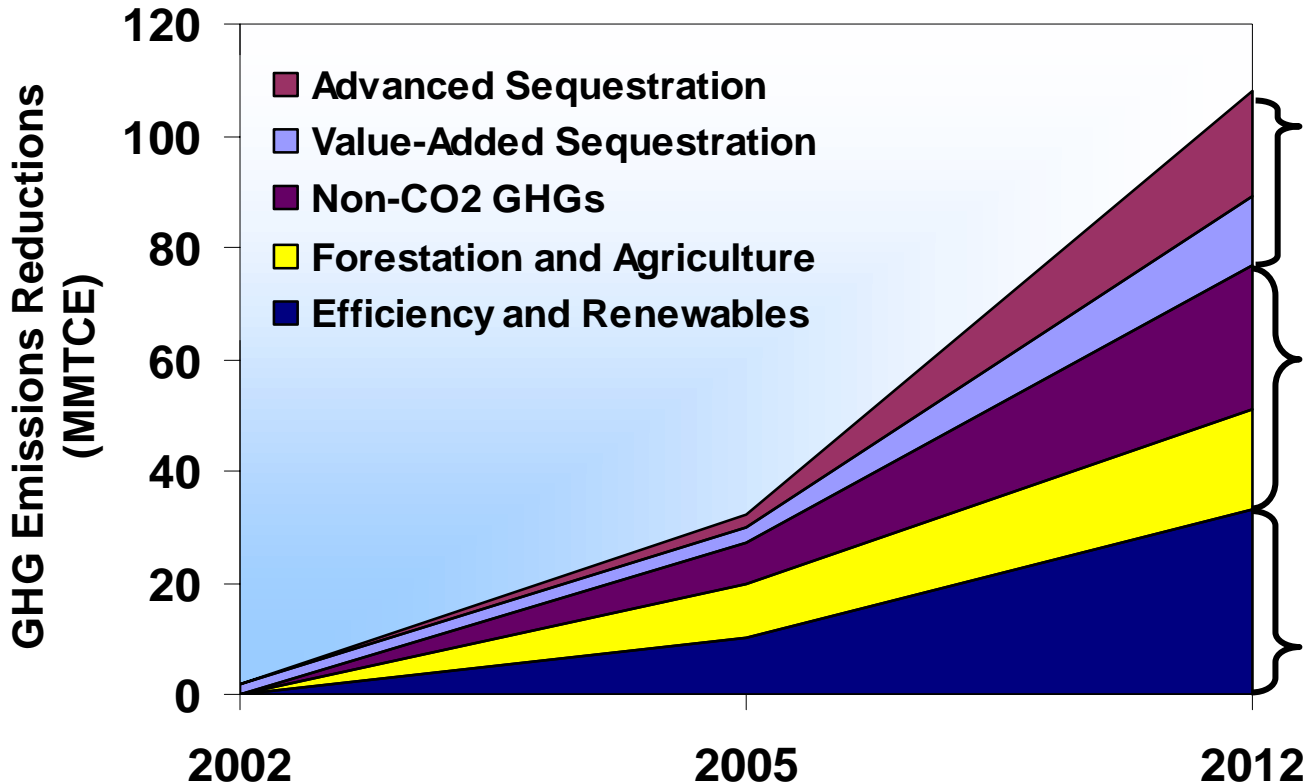
# GCCI Goal

*18% Reduction in Greenhouse Gas Intensity*



# Carbon Sequestration Contributes to GCCI Goal

## *Plausible Scenario to Meet GCCI Goal*



**Reductions due to sequestration program**

**Reduction benefit shared with EPA/AG others**

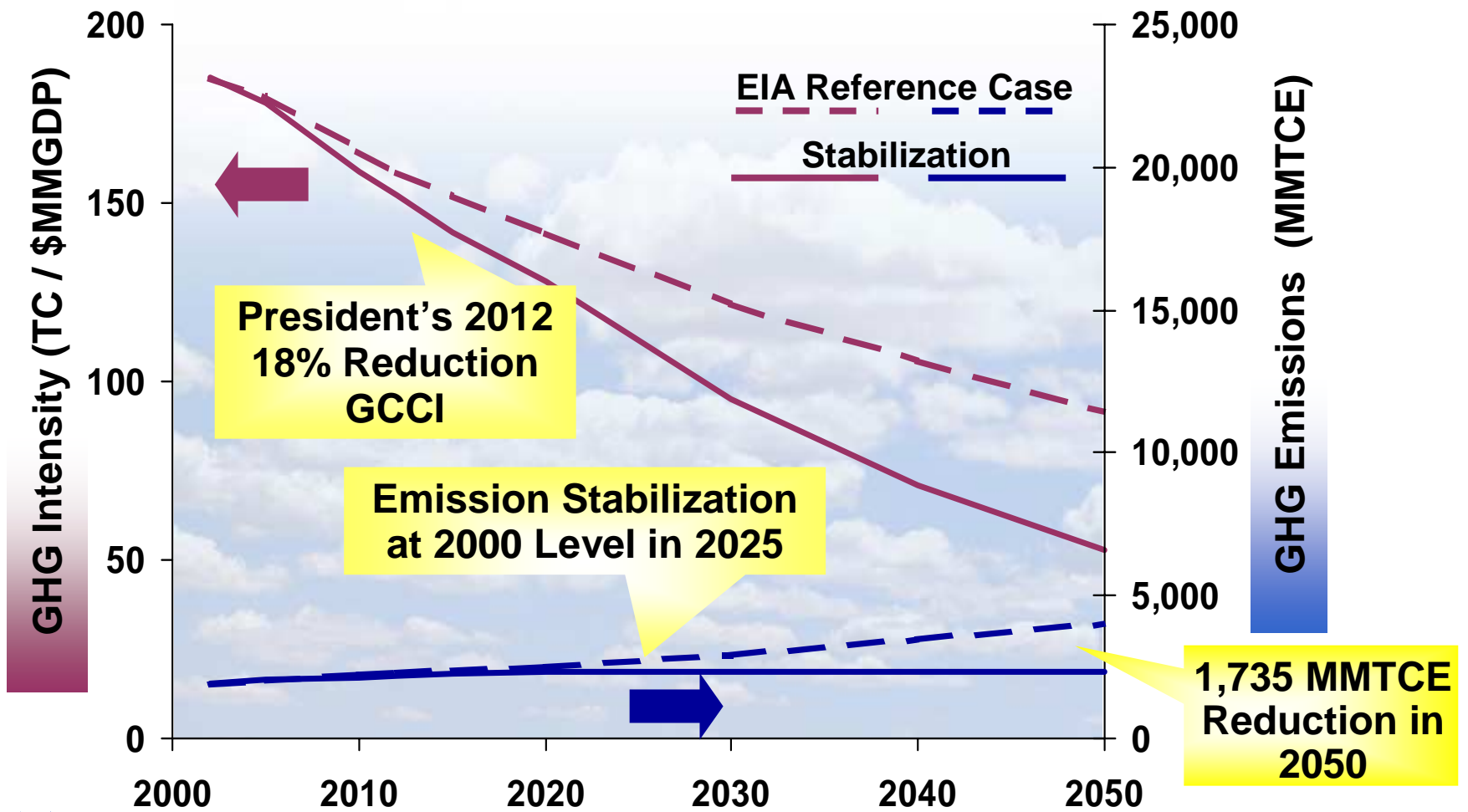
**Reductions unrelated to sequestration, but includes coal**

- Repowering
- Retrofit
- Vision 21



# Possible Pathway to Stabilization

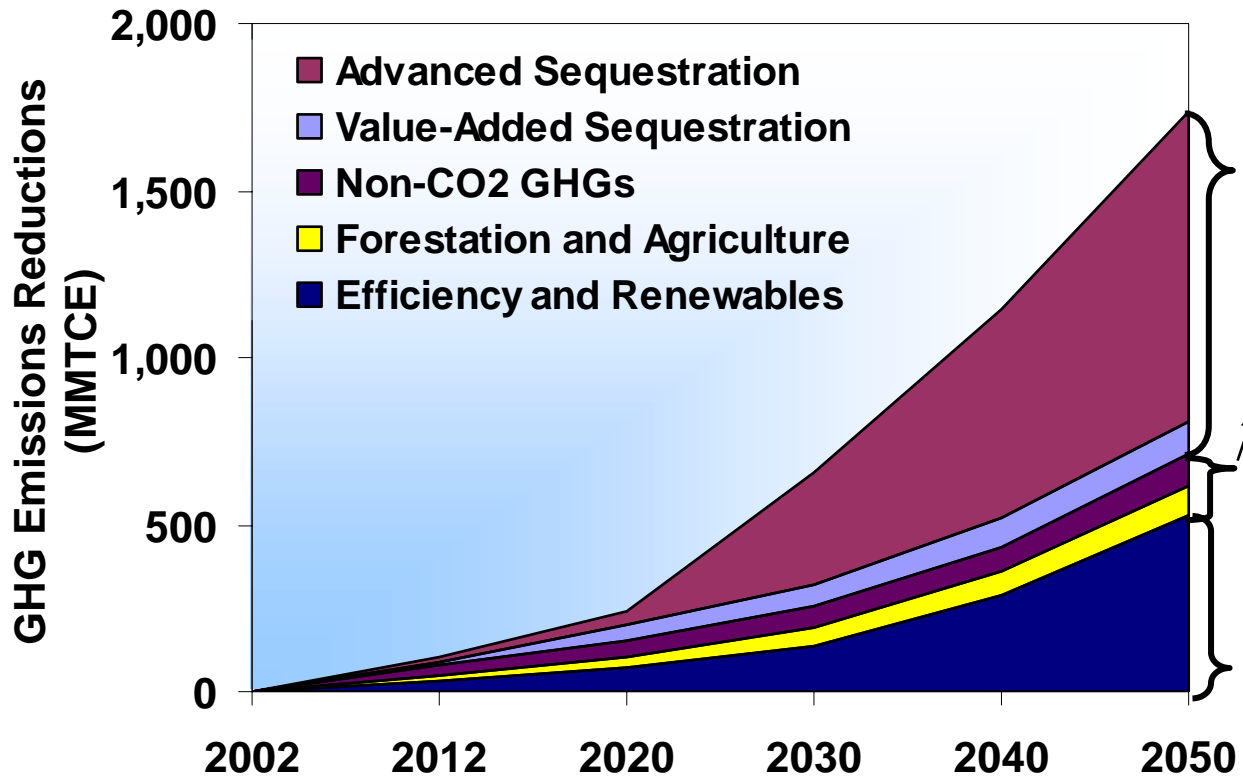
## *A Significant Undertaking*



EIA Annual Energy Outlook 2002; EPA special studies;  
DOE/FE/NETL Sequestration Benefits Model

# Carbon Sequestration Must Play Key Role

## *Plausible Scenario to Stop GHG Emissions Growth*



Reductions due to sequestration program

Reduction benefit shared with EPA/AG others

Reductions unrelated to sequestration, but includes coal

- Repowering
- Retrofit
- Vision 21





# Capture and Sequestration Options

*Direct Sequestration*  
< 10% Increase in Cost of Energy



Capture and storage

Oil & Gas Reservoirs

Unmineable Coal Seams

Saline Formations

Oceans

Stable Solids

Useful Products

Fuels

*Indirect Sequestration*  
< \$10/ton Carbon Sequestered



Remove CO<sub>2</sub> from atmosphere

Forestation

Mineralization

Agricultural Practices

Ocean Fertilization

*Advanced Concepts*  
Convert CO<sub>2</sub>



# Program Goals

## *Technology Options for GHG Management*

**Possess scientific understanding of sequestration options and provide cost-effective, environmentally-sound technology options that lead to reduced GHG intensity and stabilization of atmospheric CO<sub>2</sub>**

### *Create Sequestration Options*

- Reduce CO<sub>2</sub> emissions by 90% with < 10% increase in cost of energy services for capture, transport, storage
- Establish measurement, monitoring & verification protocols for accounting and assurance of permanence

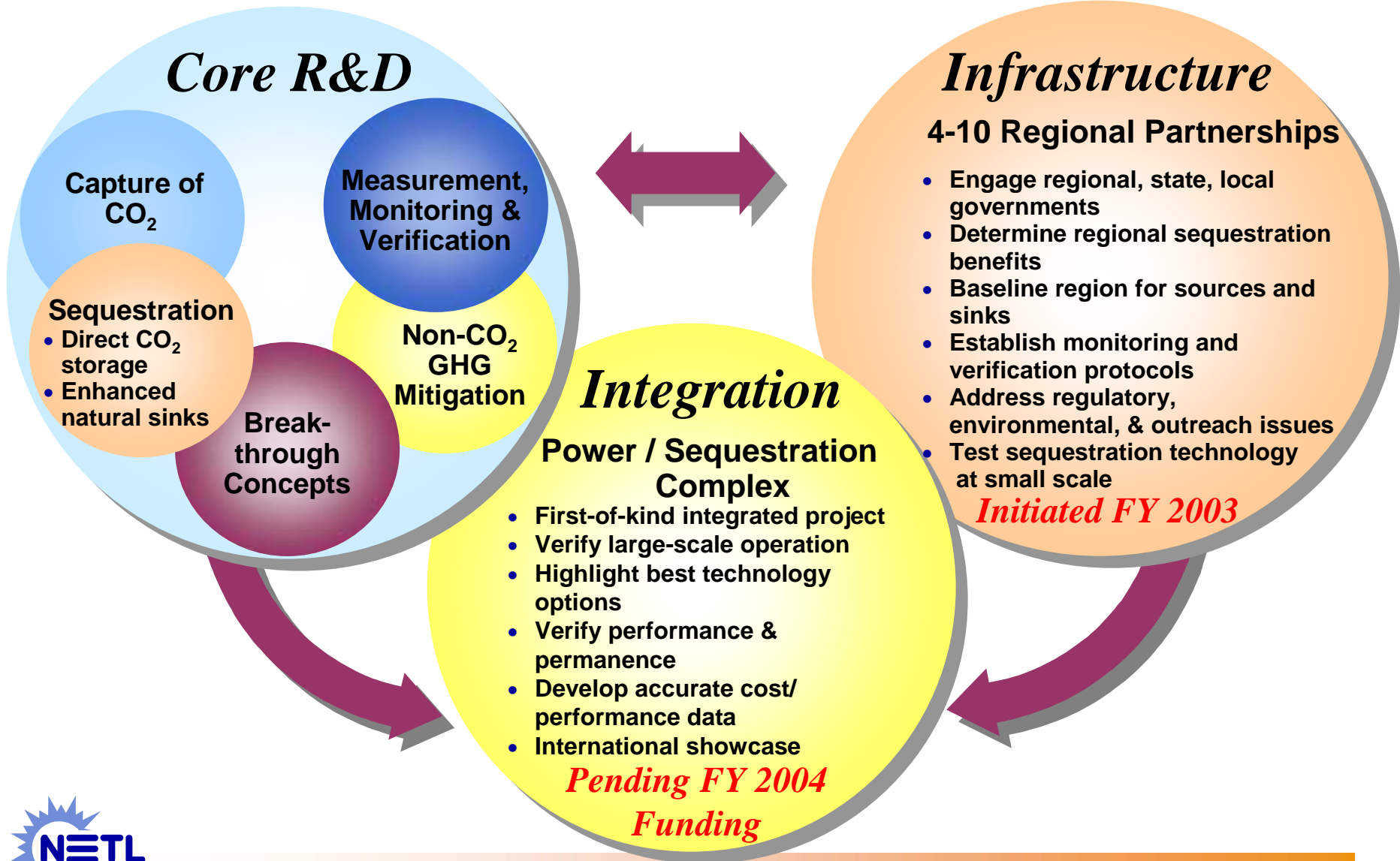
### *Support Global Climate Change Initiative*

- Contribute to 2012 goal of reducing carbon intensity by 18%
- Provide portfolio of commercially ready technologies for 2012 assessment



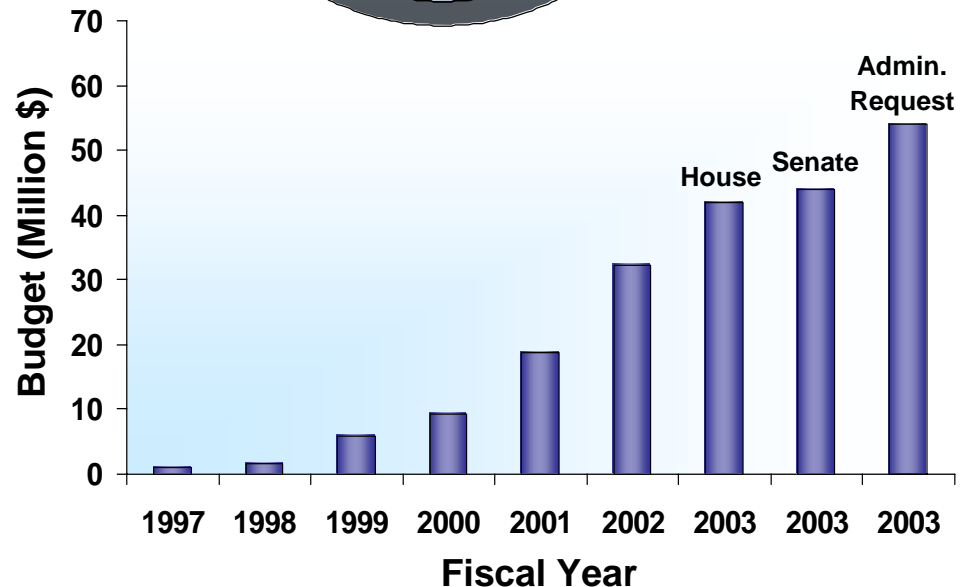
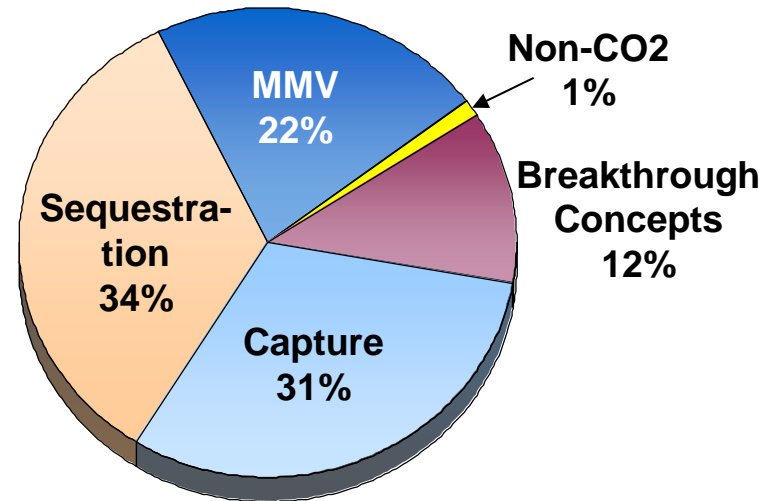


# Carbon Sequestration Program Structure



# Portfolio Overview

- **Diverse research portfolio**
  - 64 external projects
  - 18 focus area projects
  - BP & IEA consortia
- **Strong industry support**
  - ~ 40% cost share
- **Total portfolio ~ \$100M**



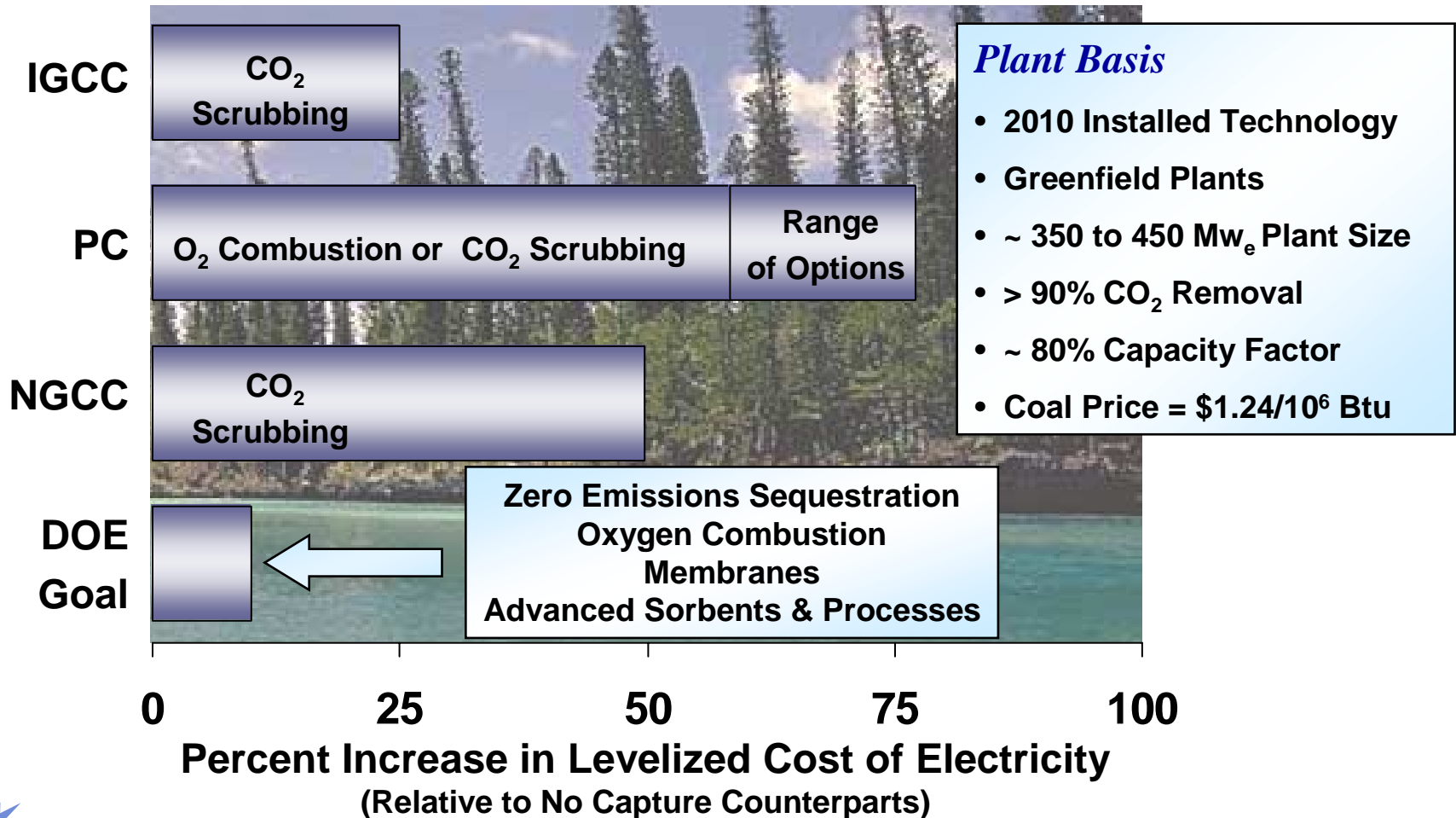
# Technology R&D Pathways

<i>Capture</i>	<ul style="list-style-type: none"><li>• Post-combustion Capture</li><li>• Oxygen combustion</li><li>• Pre-combustion capture</li><li>• Chemical looping</li></ul>
<i>Sequestration</i>	<ul style="list-style-type: none"><li>• Depleting oil reservoirs</li><li>• Unmineable coal seams</li><li>• Saline formations</li><li>• Enhanced terrestrial uptake</li><li>• Ocean (injection, fertilization)</li></ul>
<i>MM&amp;V</i>	<ul style="list-style-type: none"><li>• Advanced soil carbon measurement</li><li>• Subsurface measurements</li><li>• Remote sensing/above-ground MM&amp;V</li><li>• Fate and transport models</li></ul>
<i>Breakthrough Concepts</i>	<ul style="list-style-type: none"><li>• Advanced Capture</li><li>• Bio-accelerated sequestration</li><li>• Niches</li></ul>



# Separation and Capture

## *A Challenging Task Ahead*



# Separation and Capture Highlights

## *Many Advanced Integrated Schemes Emerging*

### *Coal Gasification*

**CO<sub>2</sub> Hydrates  
Membranes  
Advanced Scrubbers  
Inexpensive Oxygen**



### *Pulverized Coal*

**Oxygen Combustion  
Membranes  
Advanced Scrubbers  
New Sorbents  
Mineral Carbonation**

### *Pathways to Zero Emissions*

**Producing a concentrated stream of CO<sub>2</sub> at high pressure:**

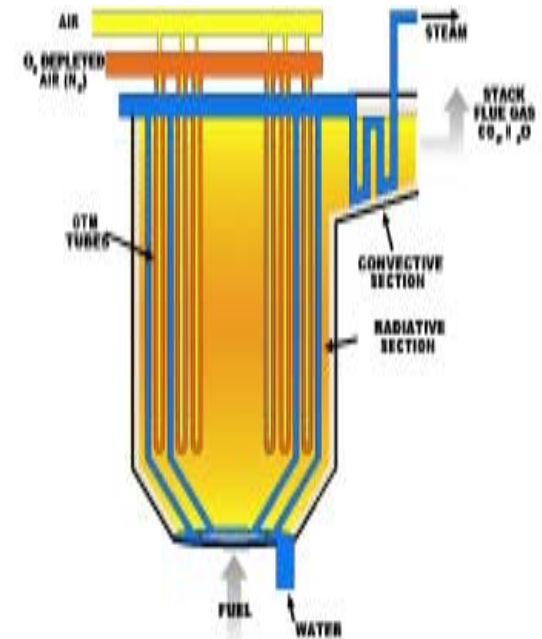
- Improves sequestration economics
- Reduces energy penalty



# Separation and Capture Highlights

## *Oxyfuel Technology & Oxygen Transport Membrane*

- Membrane and seal assembly ready for bench scale integration
- Significant reduction in power & cost reduction to generate O<sub>2</sub>
- Integrates air separation using oxygen transport membrane & O<sub>2</sub> combustion
- Combustion in an oxygen environment resulting in a flue gas with a high CO<sub>2</sub>
- Materials and system integration barriers



*Participants: Praxair and Alstom Power*



# Separation and Capture Highlights

## *Thermally Optimized Membrane*

- First ever fabrication of polymeric membrane selective up to 350 °C
- Technique developed to test long-term membrane performance
- Thermally optimized (polybenzimidazolesintered metal support)
- Potential application in many gas separation processes



*PBI coated metal*

*Participants: LANL, INEEL, Univ. Colorado, Pall, Shell*

# Separation and Capture Highlights

## *Dry Regenerable Sorbents*

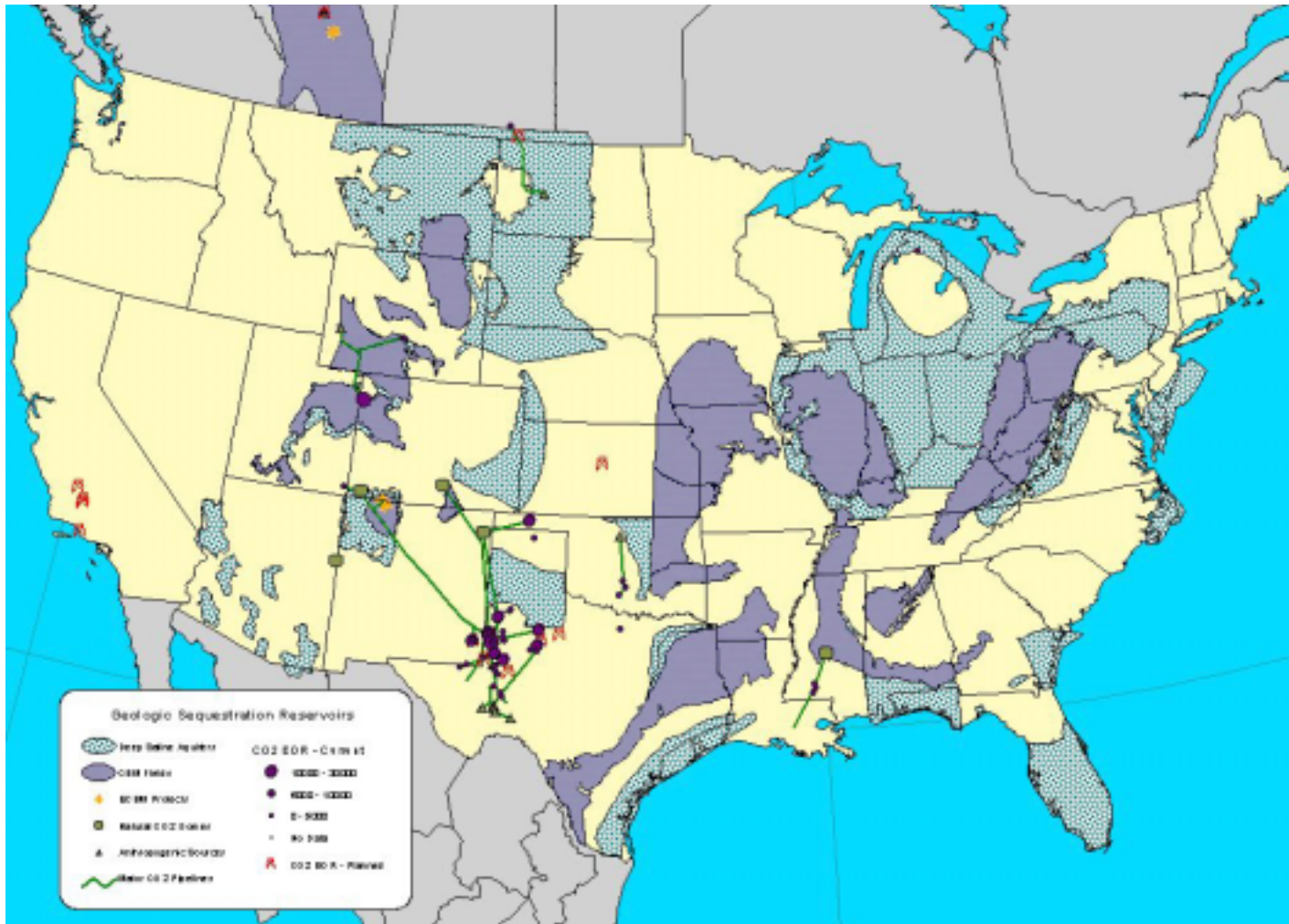
- Sorbent characterized & kinetics understood
- Optimizing process and headed to pilot testing
- Use sodium carbonate, a dry regenerable sorbent
- Little power requirement



*Participants: RTI, LSU, Church & Dwight*



# Geologic Sequestration Options



- Deep Saline Formations
- Deep Coal Seams
- Enhanced Oil Recovery Fields

# Geologic Sequestration Highlights

*(1 Million TPY CO<sub>2</sub>, ~ 100 MW Coal Power Plant)*

## *Weyburn CO<sub>2</sub> EOR Project*

- Pan Canadian Resources
- 200-mile CO<sub>2</sub> pipeline from Dakota Gasification Plant
- 130M barrels oil over 20-year project
- \$28M



## *Sleipner North Sea Project*

- Statoil
- Currently monitoring CO<sub>2</sub> migration
- \$80M “incremental cost”
- \$36–50 / ton CO<sub>2</sub> tax



# Geologic Sequestration Highlights

## *Baselining Sources & Sinks*

Export Header    Export Cumulatives    View Monthly    Shallow EUR    Deep EUR    Decline Curve    Close

**Production Records for Selected Wells**    API # 34007218470000

Operator: RANGE OPERATING COMPANY    Well #:    X Coord: 2469540.47  
 Operator Well #:    Lease:    Y Coord: 713754.82  
 County # ASHTABULA    Township: NEW LYME    Section: 8    Other Sub:     
 Date Plugged:    Date Issued:    Lot:    Fraction:     
 Date Completed:    Producing Formation: RSRN    Field ID: 0  
 1st Year Production Indicated: 1982    Producing Formation 2:     
 Well Comment:   

**Yearly Production for Well**

Year	Oil (bbl)	Gas (mcf)	Water (bbl)	Source:
▶ 1982	673	512068	0	LOWE
1983	155	157457	0	LOWE
1984	0	52999	0	LOWE
1985	148	20772	0	LOWE
1986	0	8916	0	LOWE
1987	0	4876	0	LOWE
1988	94	3413	0	LOWE
1989	0	3793	0	LOWE

Record: 1 of 12

**Initial Production for Well**

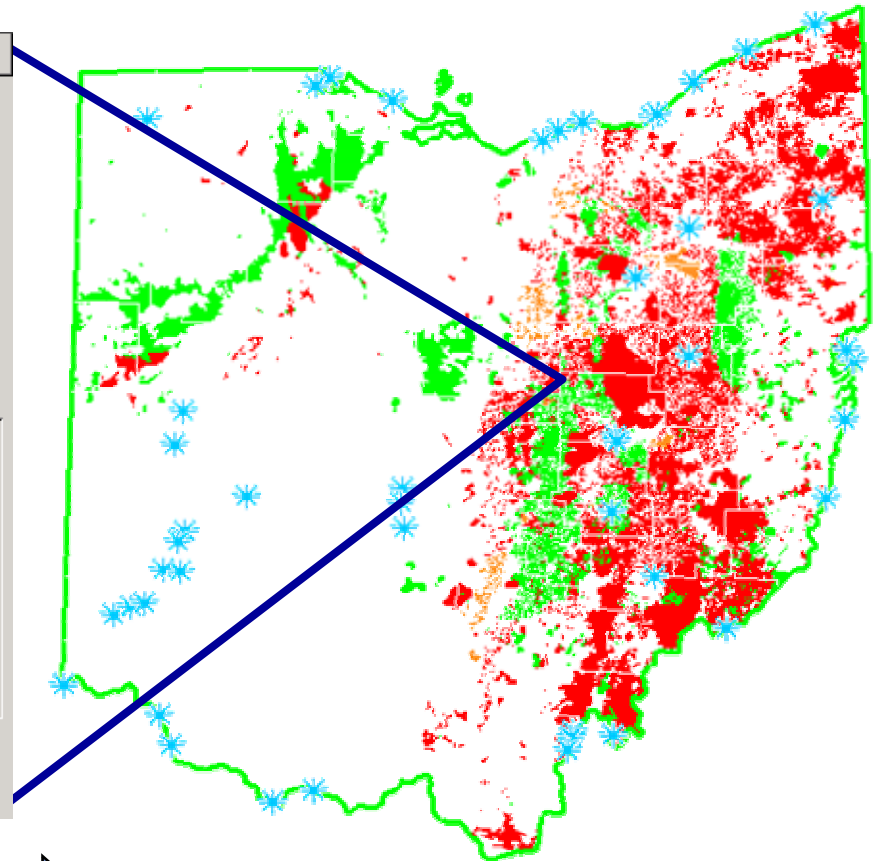
	GAS	OIL
IP Natural:	2000	10
IP After Treatment:	0	0

**PRESSURE**

Initial Pressure: 0  
 Last Pressure:     
 Year Last Pressure:   

**Cumulative Production for Well**

Oil (BBL):	Gas (MCF):	Water (BBL):
1070	769767	0



*Energy Production* ➔ *Geological Sinks*

Midcontinent Interactive Digital Carbon Atlas and Relational DataBase

[www.midcarb.org](http://www.midcarb.org)





# Geologic Sequestration Highlights

## *First U.S. Depleted Reservoir Storage Project*

- Inject CO<sub>2</sub> and monitor its movement
- Location
  - Oil reservoir near Roswell, New Mexico



*Participants: Pecos Petrol., Strata Prod., New Mexico Tech U., Sandia, LANL*

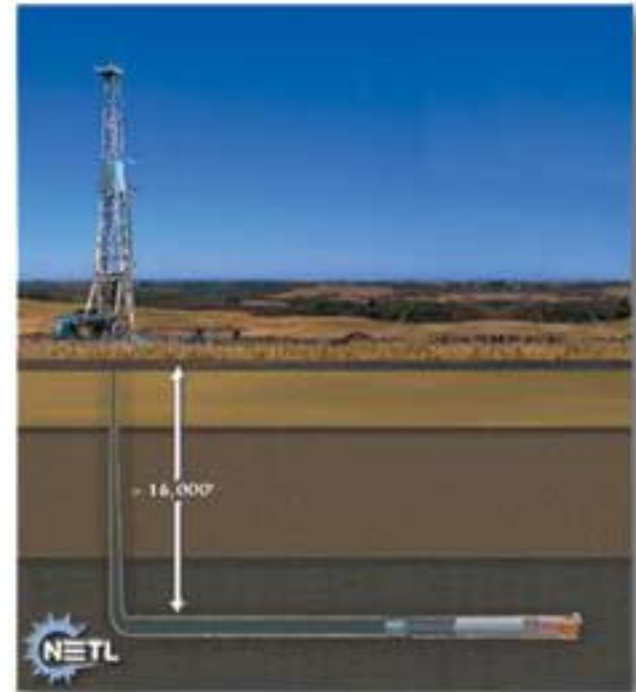




# Geologic Sequestration Highlights

## *Enhanced Coalbed Methane Recovery*

- Demonstrate CO<sub>2</sub> enhanced coal seam methane production using slant hole drilling
- Demonstrate permanence of CO<sub>2</sub> sequestration
- Value added methane to help offset sequestration cost
- Marshall County, WV



*Participants: CONSOL & Subsidiaries*



# Ocean Sequestration Research Priorities

- **Environmental Impacts**
- **Carbon Cycle Chemistry**
- **Long-Term Integrity**
- **Ocean Circulation**
- **Transport and Injection Technology**



# Ocean Sequestration Highlights

## *International Ocean Project*

- **Study environmental & technical feasibility of CO<sub>2</sub> storage in ocean**
- **U.S. territorial waters near Hawaii**
- **Funding organizations**
  - Japan (NEDO)
  - U.S. (NETL)
  - Australia (CSIRO)
  - Norway (NRC)
  - Canada (NRCAN)
  - ABB
  - CRIEPI (Japan)
- **U.S. research organizations**
  - MIT
  - U. of Hawaii
  - Naval Research Lab
  - PICHTR



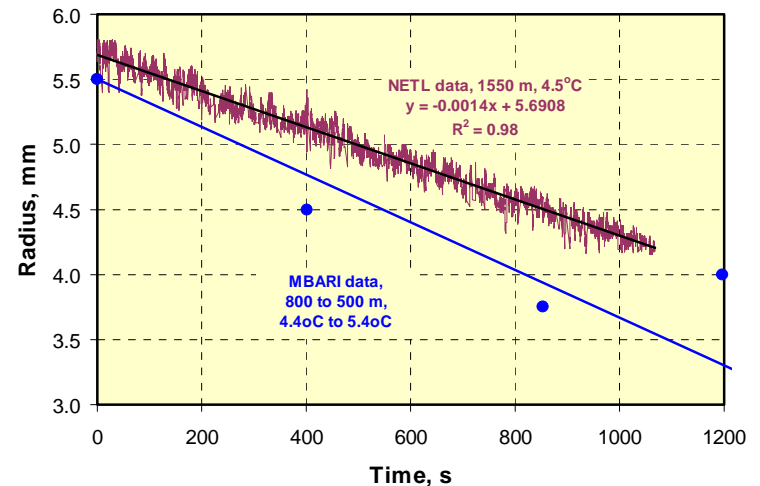
# Ocean Sequestration Highlights

## *Ocean Sequestration Research Facility*

- Study CO<sub>2</sub> behavior in laboratory environment
- Investigate phase and dissolution behavior
- Results correlates well to MBARI ocean experiments
- Potential to minimize expensive ocean experiments



*Participants: NETL & MBARI*



# Terrestrial Sequestration Highlights

## *The Nature Conservancy Project*

- Carbon inventories
- Advanced videography
- Land use trends models
- Domestic feasibility studies
- Project screening tool

## *Economic Modeling*

- Stephen F. Austin State University, TXU
- Reforesting AML in Appalachia



# Terrestrial Sequestration Highlights



## *Integrated Carbon Capture and Water Emissions Treatment System*

- TVA, EPRI
- Paradise Fossil Plant
- Life-cycle cost assessment of integrated electricity production and enhanced terrestrial sequestration

## *Larger-scale Demonstrations*

- University of Kentucky, Peabody Energy, USDA FS
- Virginia Tech, Mead-Westvaco, Plum Creek Timber, and Mountain Forest Products
- Reforesting mined lands for optimal sequestration





# Several Breakthrough Concepts in Program

- Recovery & sequestration of CO<sub>2</sub> by photosynthesis of microalgae - PSI
- Chemical fixation coal combustion products & recycling through algal biosystems - TVA
- Enhanced practical photosynthetic CO<sub>2</sub> mitigation - Ohio U.
- Enhanced practical photosynthesis - ORNL
- Photoreductive sequestration to form C1 products & fuel - SRI International
- Sequestration by mineral carbonation using a continuous flow reactor - Albany RC
- Chemical dissolution approaches to mineral sequestration - LANL



# Future Direction for Breakthrough Concepts

- **National Academy of Sciences “beating bushes” for ideas & participants**
  - Workshop targeting universities and small business around February 2003
- **Issuing solicitation early FY04**
  - Planned FY04 funding of \$1–2 M



# Measurement, Monitoring and Verification

## *Establish Protocols for Terrestrial Sequestration*



- **Improve soil carbon measurement**
  - Decrease sample time and cost
  - Develop measurement protocols
- **Improve regional MM&V**
  - Remote sensing opportunities
  - Vegetation carbon databases for calibration
- **Partner with USDA and other organizations**

# Measurement, Monitoring and Verification

## *Establish Protocols for Geologic Sequestration*



- **Improve measurement accuracy**
  - Develop tools for surface-level measurements
  - Improve existing tools for in-reservoir MM&V
  - Ensure protection of human and ecosystem health
- **Create infrastructure**
  - Develop universal MM&V protocols
  - Assist regulators in developing guidelines
- **Reduce cost of MM&V**

# Measurement, Monitoring and Verification

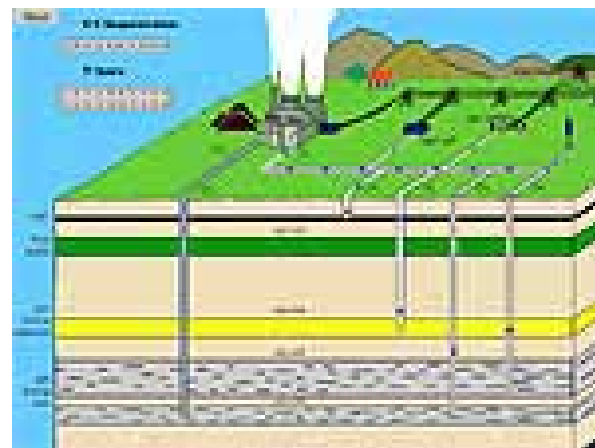
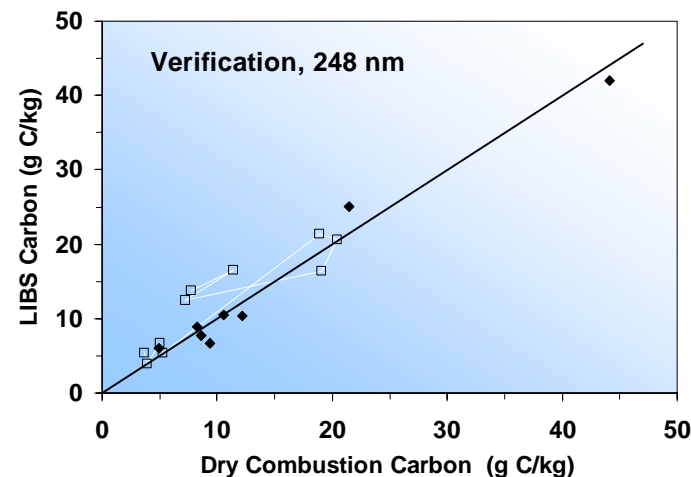
## *Highlights*

### *Terrestrial*

- LIBS Soil carbon measurement (LANL)
- Aerial Videography for above-ground carbon (TNC)

### *Geologic*

- Advanced imaging technology (LBNL)
- Measure CO<sub>2</sub> migration in active field tests (Dakota Gasification, SNL, LLNL)
- Field test tracer chemicals at injection sites (CSSFA, LBNL)





# Visit the NETL Sequestration Website

[www.netl.doe.gov/coalpower/sequestration/](http://www.netl.doe.gov/coalpower/sequestration/)

**NATIONAL ENERGY TECHNOLOGY LABORATORY**  
**CARBON SEQUESTRATION WEBSITE**

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January 13, 2003

## Carbon Sequestration

*Pathways to Sustainable Use of Fossil Fuels--  
enabling the removal and permanent storage  
of carbon dioxide from fossil-energy systems*

Welcome to NETL's **Carbon Sequestration Product** webpage. We seek to define carbon sequestration's role in stabilizing atmospheric carbon dioxide levels by developing a scientific understanding and environmentally acceptable technologies. Our research areas include capture & storage, geologic, ocean, and terrestrial sequestration, advanced CO<sub>2</sub> conversion & reuse, and modeling & analysis.

Our site is designed to answer your questions about carbon sequestration—

- Regional Partnerships
- Capture & Storage
- Geologic Sequestration
- Ocean Sequestration
- Terrestrial Sequestration
- Adv. CO<sub>2</sub> Conversion & Reuse
- Modeling & Analysis

**What's New**  
Events  
Overview  
Capture  
Geologic  
Ocean  
Terrestrial  
Conversion  
Modeling  
In-House R&D  
Ref. Shelf  
Kids Only!  
Links  
Contacts  
GHG Facts





# Carbon Sequestration E-mail Newsletter

## Subscribe for The Carbon Sequestration Newsletter

Each month, NETL publishes a short newsletter describing significant events related to carbon sequestration that have taken place over the past month. This newsletter is posted here on our website's [Reference Shelf](#) and distributed by e-mail. If you'd like to join the e-mail distribution list, please refer to the [Subscription Directions](#) page for more information as to "Subscribing" and "Unsubscribing" to our mailing list.



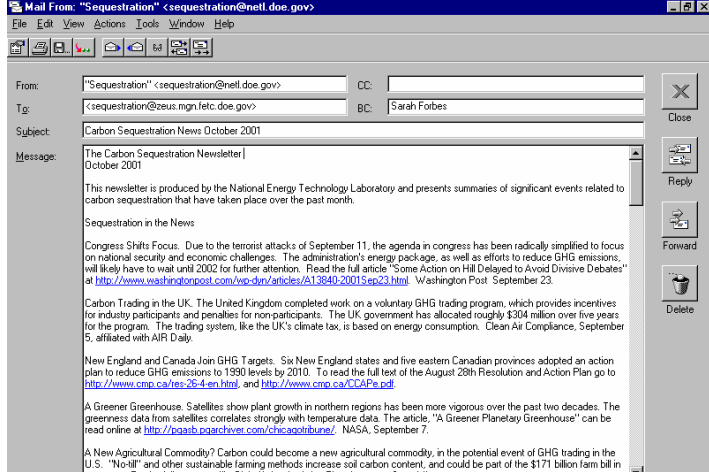
## The Carbon Sequestration Newsletter

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- Sequestration in the News
- Events/ Announcements from NETL's Carbon Sequestration Program
- Publications
- Legislative Activity [www.netl.doe.gov/products/sequestration/refshelf.html](http://www.netl.doe.gov/products/sequestration/refshelf.html)

Sequestration in the News

<b>Congress Shifts Focus</b> Due to the terrorist attacks of September 11, the agenda in congress has been radically simplified to focus on national	<b>A Greener Greenhouse</b> NASA Satellites show plant growth in northern regions has been more vigorous over the past two decades. The
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Mail From: "Sequestration" <sequestration@netl.doe.gov>

From: "Sequestration" <sequestration@netl.doe.gov> CC:   
To: <sequestration@zeus.mgn.tlc.doe.gov> BC: Sarah Forbes  
Subject: Carbon Sequestration News October 2001

Message: [The Carbon Sequestration Newsletter] October 2001

This newsletter is produced by the National Energy Technology Laboratory and presents summaries of significant events related to carbon sequestration that have taken place over the past month.

Sequestration in the News

Congress Shifts Focus. Due to the terrorist attacks of September 11, the agenda in congress has been radically simplified to focus on national security and economic challenges. The administration's energy package, as well as efforts to reduce GHG emissions, will likely have to wait until 2002 for further attention. Read the full article "Some Action on Hill Delayed to Avoid Divisive Debates" at <http://www.washingtonpost.com/wp-dyn/articles/A13640-20010923.html> Washington Post, September 23

Carbon Trading in the UK. The United Kingdom completed work on a voluntary GHG trading program, which provides incentives for industry participants and penalties for non-participants. The UK government has allocated roughly \$304 million over five years for the program. The trading system, like the UK's climate tax, is based on energy consumption. Clean Air Compliance, September 5, affiliated with AIR Daily.

New England and Canada Join GHG Targets. Six New England states and five eastern Canadian provinces adopted an action plan to reduce GHG emissions to 1990 levels by 2010. To read the full text of the August 28th Resolution and Action Plan go to <http://www.cmp.ca/res/26-4-en.html> and <http://www.cmp.ca/CCAPs.pdf>.

A Greener Greenhouse. Satellites show plant growth in northern regions has been more vigorous over the past two decades. The greenness data from satellites correlates strongly with temperature data. The article, "A Greener Planetary Greenhouse" can be read online at <http://jqaib.pqarchiver.com/chc-aq01buns/> NASA, September 7.

A New Agricultural Commodity? Carbon could become a new agricultural commodity, in the potential event of GHG trading in the U.S. "No-till" and other sustainable farming methods increase soil carbon content, and could be part of the \$171 billion farm bill in congress. For the full story, see "In Global Warming War, Plowshares are Swords" at

