

U.S. DOE Carbon Sequestration Program



*IBC's Carbon Sequestration
Conference*

*October 24-25, 2002
Houston, Texas*

Sarah M. Forbes - National Energy Technology Laboratory



National Energy Technology Laboratory



- One of DOE's 17 national labs
- Government owned/operated
- Sites in Pennsylvania, West Virginia, Oklahoma, Alaska
- More than 1,100 federal and support contractor employees
- FY 02 budget of \$750 million



Presidential Direction

Current Drivers for Carbon Sequestration Program

NCCTI
June 11, 2001

- Third option for global climate change
- Enables continued use of domestic energy resources and infrastructure
- Geologic formations have potential for essentially unlimited storage capacity
- Demonstrated industry interest, participation, and cost-sharing in public/private partnerships
- “We all believe technology offer great promise to significantly reduce emissions -- especially carbon capture, storage and sequestration technologies.”

GCCI
February 14, 2002

- Sustain economic growth
- Reduce GHG intensity by 18% in next 10 years
- Reevaluate science & path in 2012

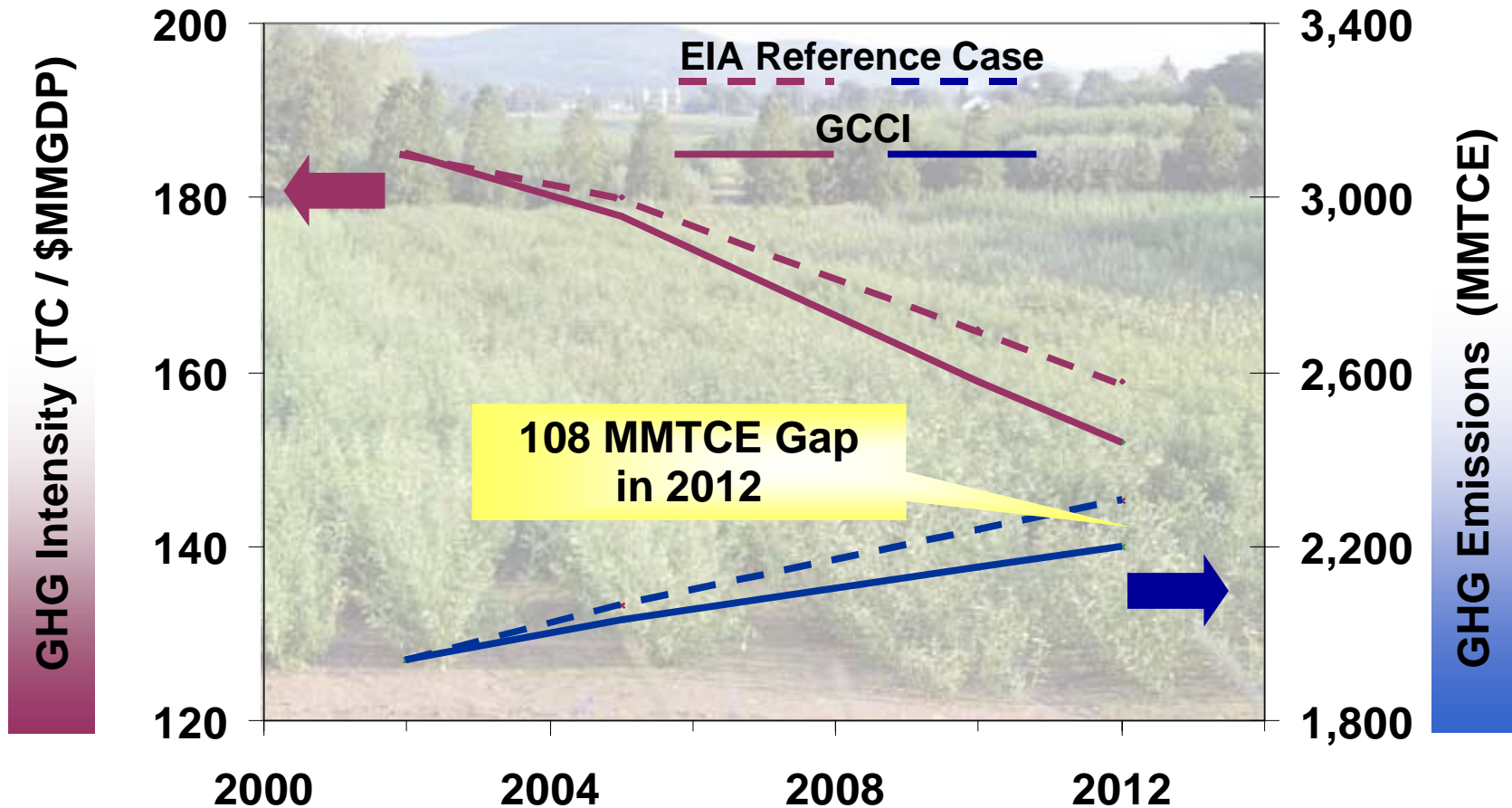


White House photo: Paul Morse



GCCI Goal

18% Reduction in Greenhouse Gas Intensity

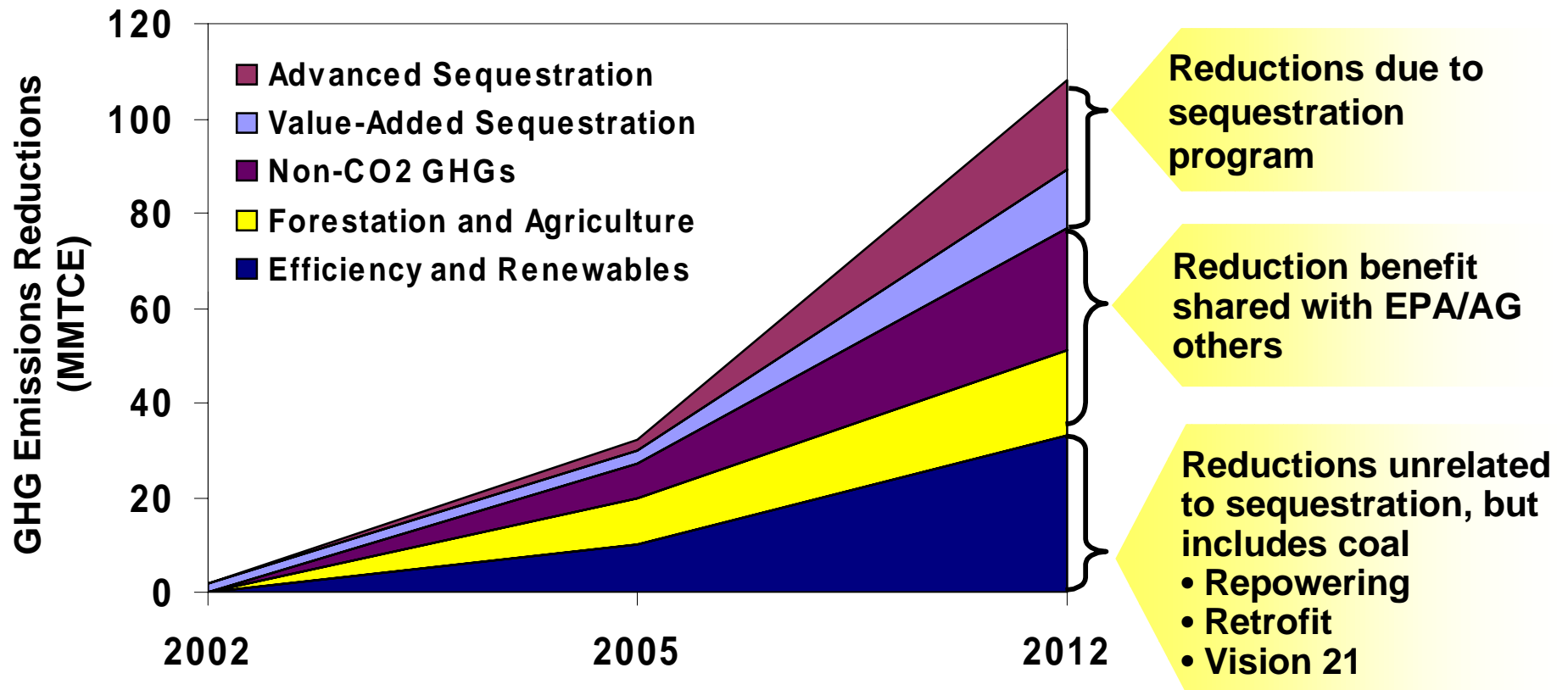


EIA Annual Energy Outlook 2002
EPA Special Studies
DOE/FE/NETL Sequestration Benefits Model

SMK - LERDWG - 10/9/02

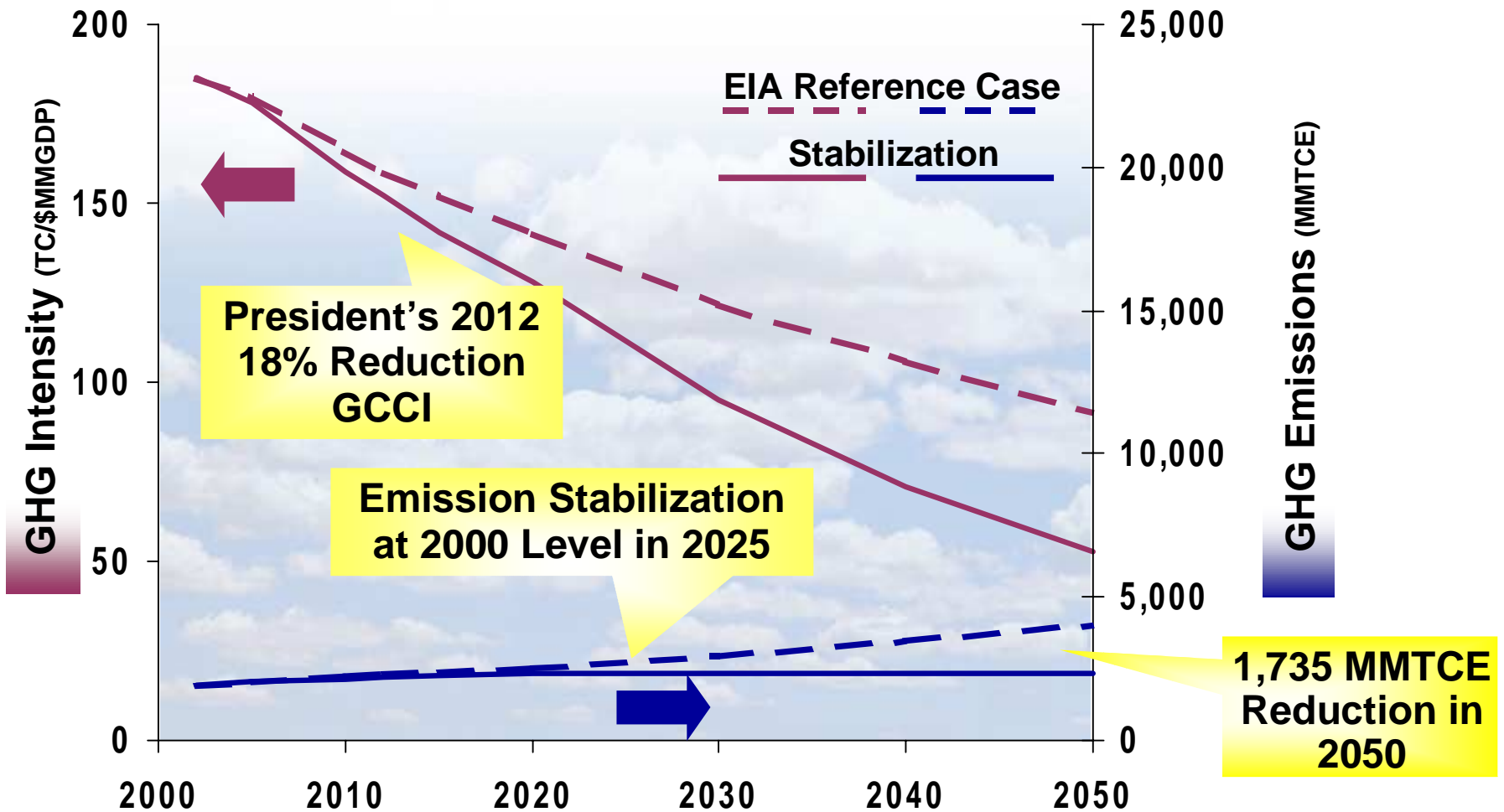
Carbon Sequestration Contributes to GCCI Goal

Plausible Scenario to Meet GCCI Goal



Possible Pathway to Stabilization

A Significant Undertaking

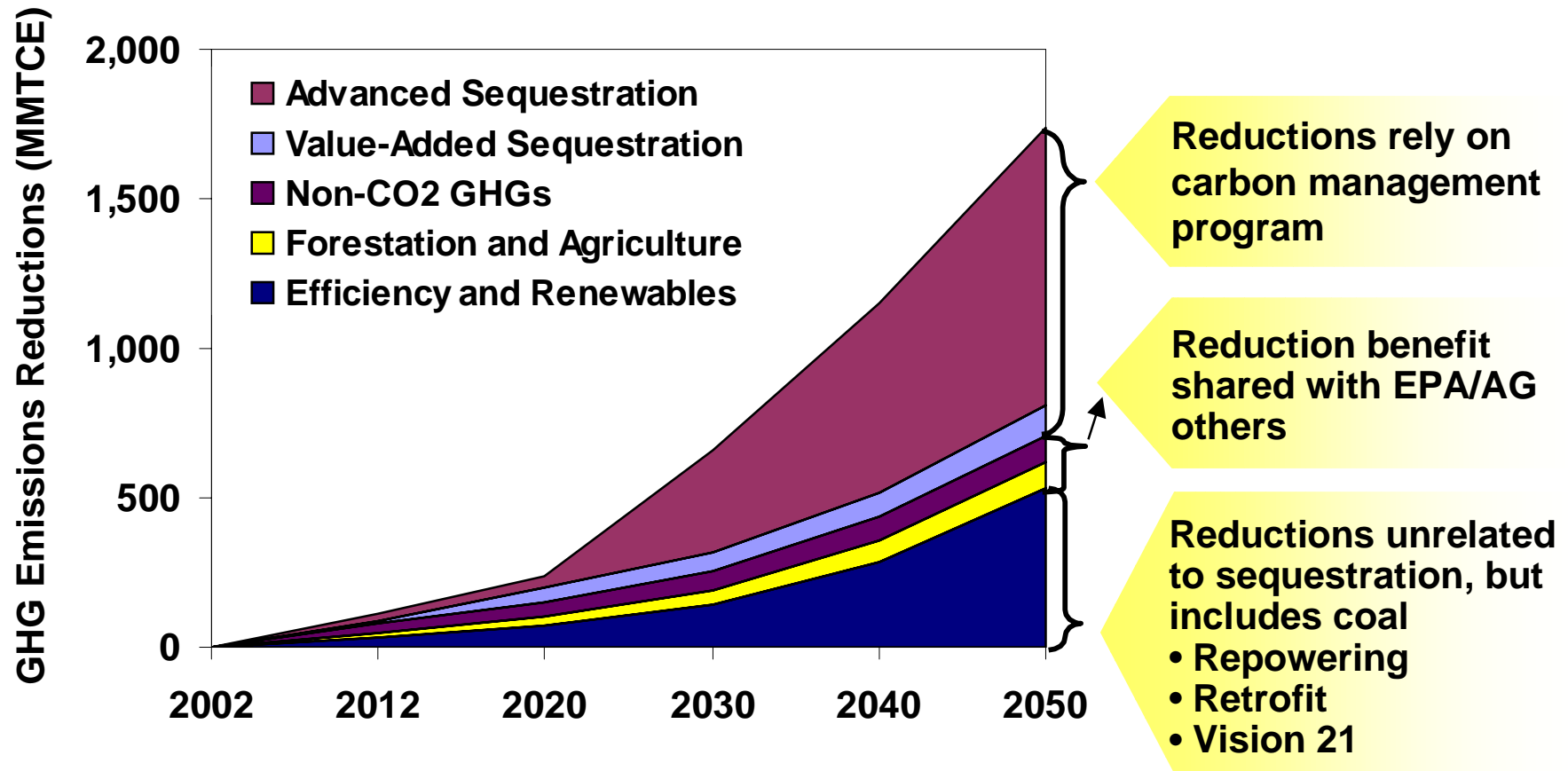


Sources: EIA Annual Energy Outlook 2002 to 2020
 EPA special studies
 DOE/FE/NETL Sequestration Benefits Model



Carbon Sequestration Must Play Key Role

Plausible Scenario to Stop GHG Emissions Growth



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



Capture and Sequestration Options

Direct Sequestration

< 10% Increase in Cost of Energy



Capture and storage

Oil & Gas Reservoirs

Unmineable Coal Seams

Saline Formations

Oceans

Indirect Sequestration

< \$10/ton Carbon Sequestered



Remove CO₂ from atmosphere

Forestation

Mineralization

Agricultural Practices

Ocean Fertilization

Advanced Concepts

Convert CO₂

Stable Solids

Useful Products

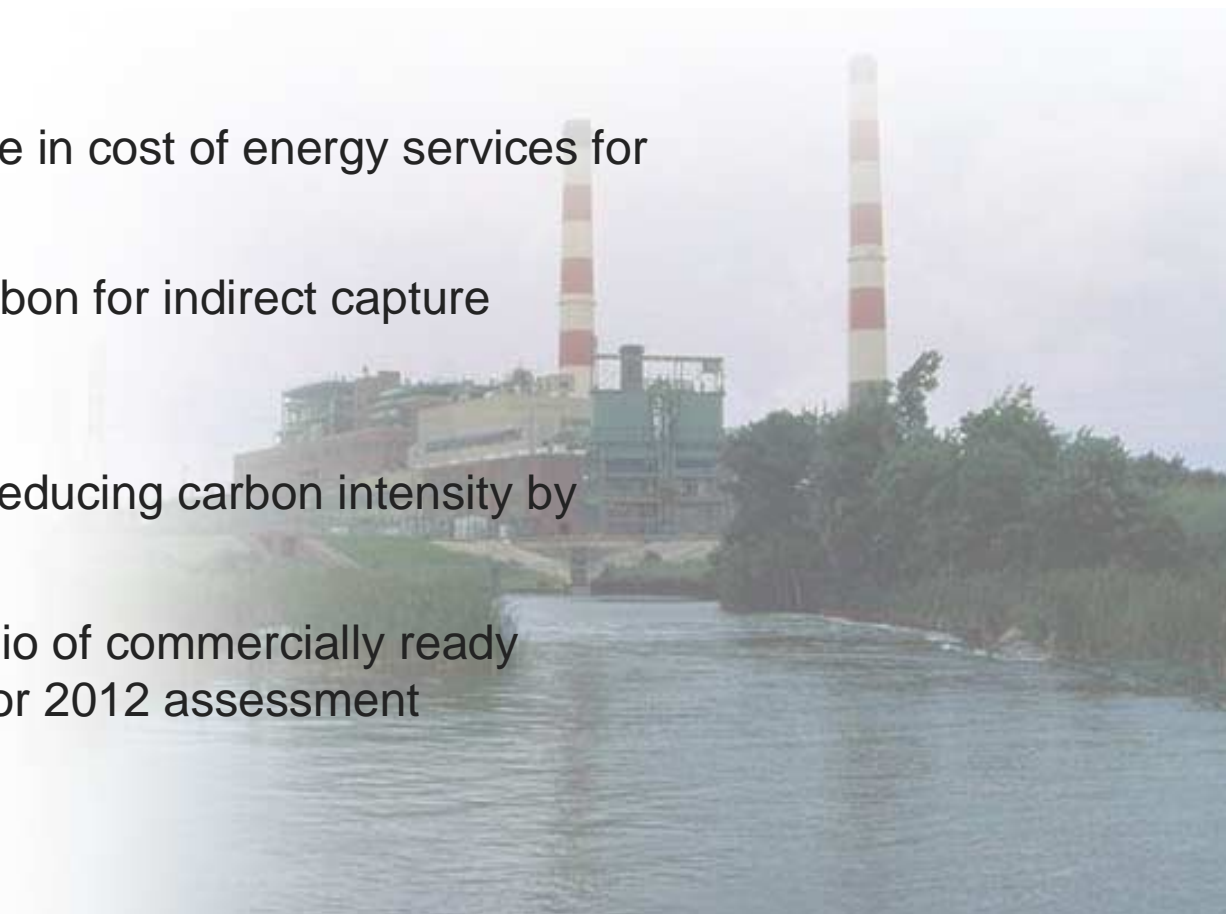
Fuels



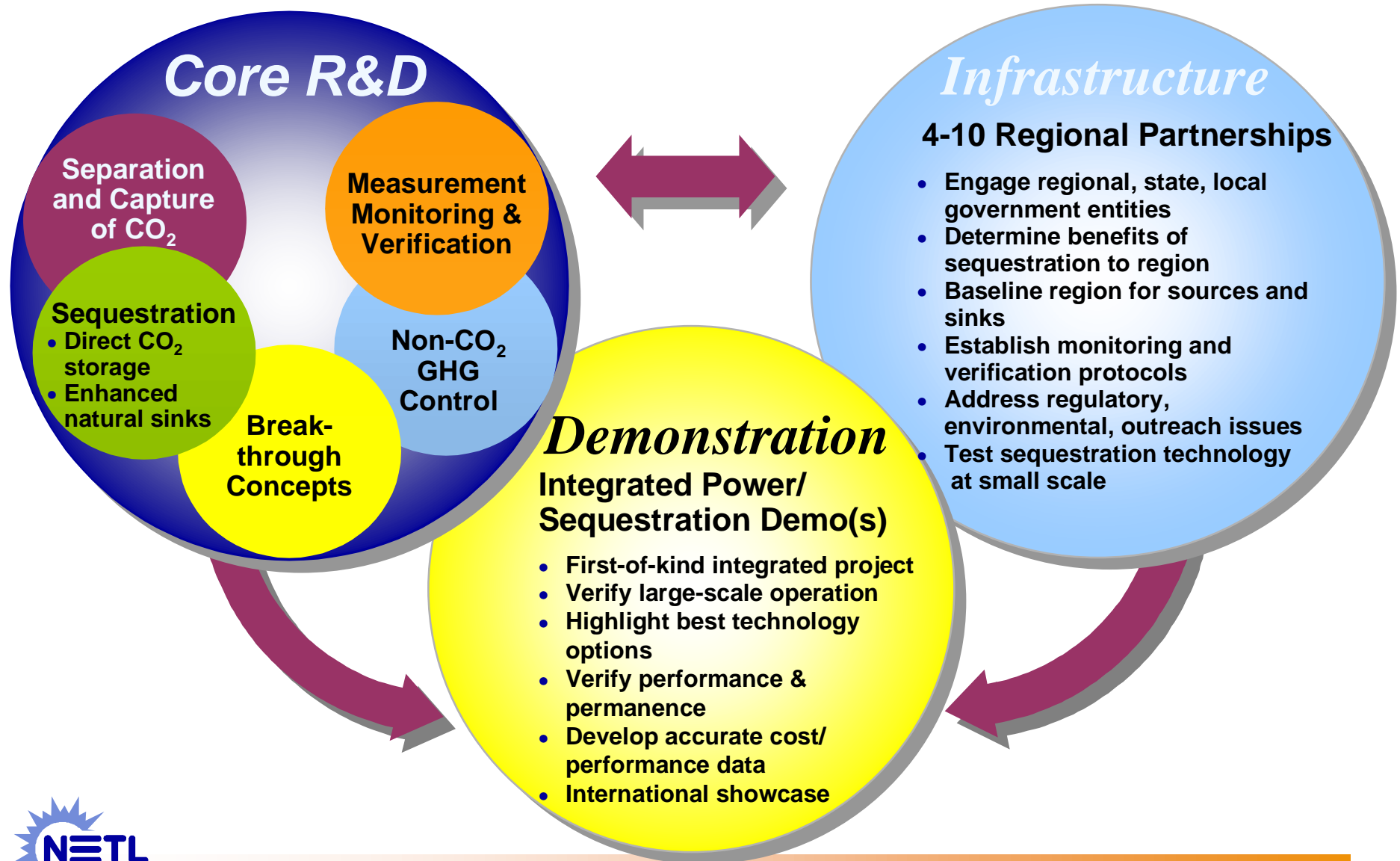
Program Goals

Technology Options for GHG Management That...

- **Are safe and environmentally acceptable**
- **Result in**
 - < 10% increase in cost of energy services for direct capture
 - < \$10 / ton carbon for indirect capture
- **GCCI**
 - Contribute to reducing carbon intensity by 18% by 2012
 - Provide portfolio of commercially ready technologies for 2012 assessment

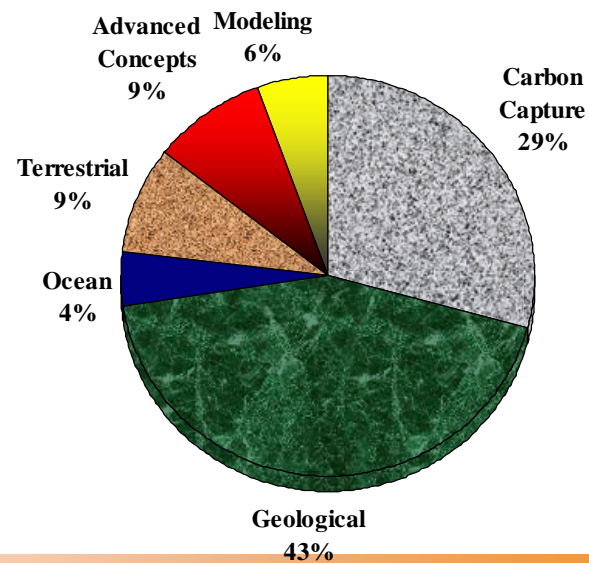
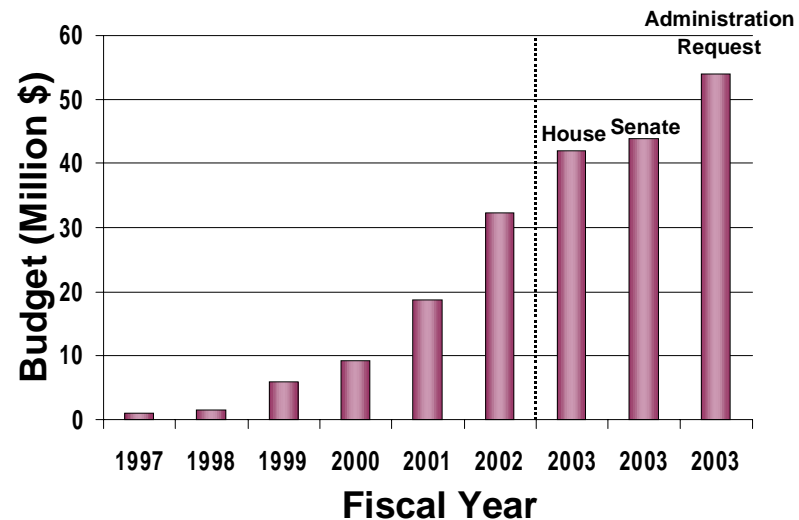


Program Structure



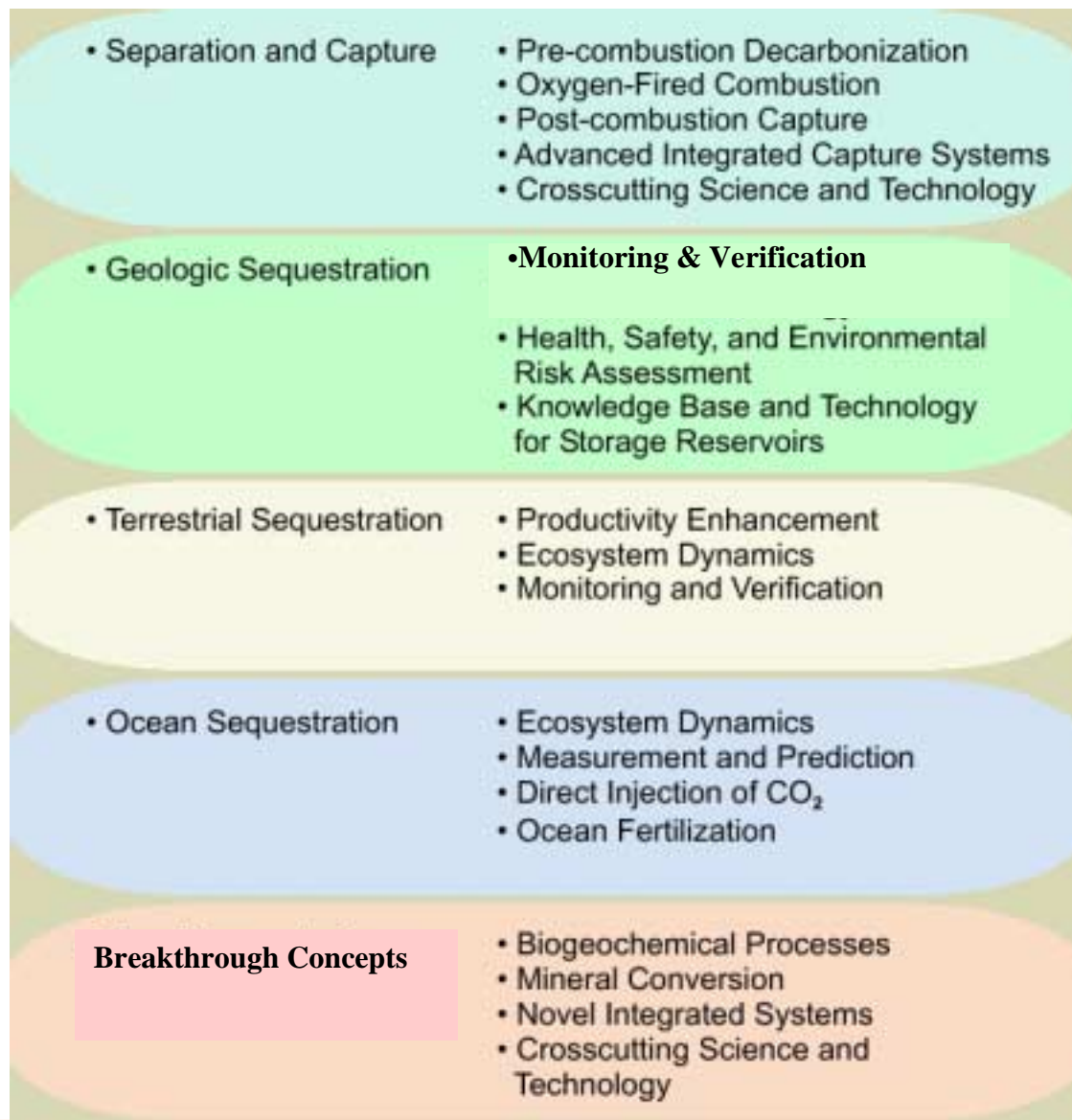
Portfolio Overview

- **Diverse research portfolio**
 - 60 external projects
 - Onsite focus area
- **Strong industry support**
 - 40% cost share
- **Portfolio funding \$100M**



Technology R&D Pathways

Measurement,
Monitoring &
Verification

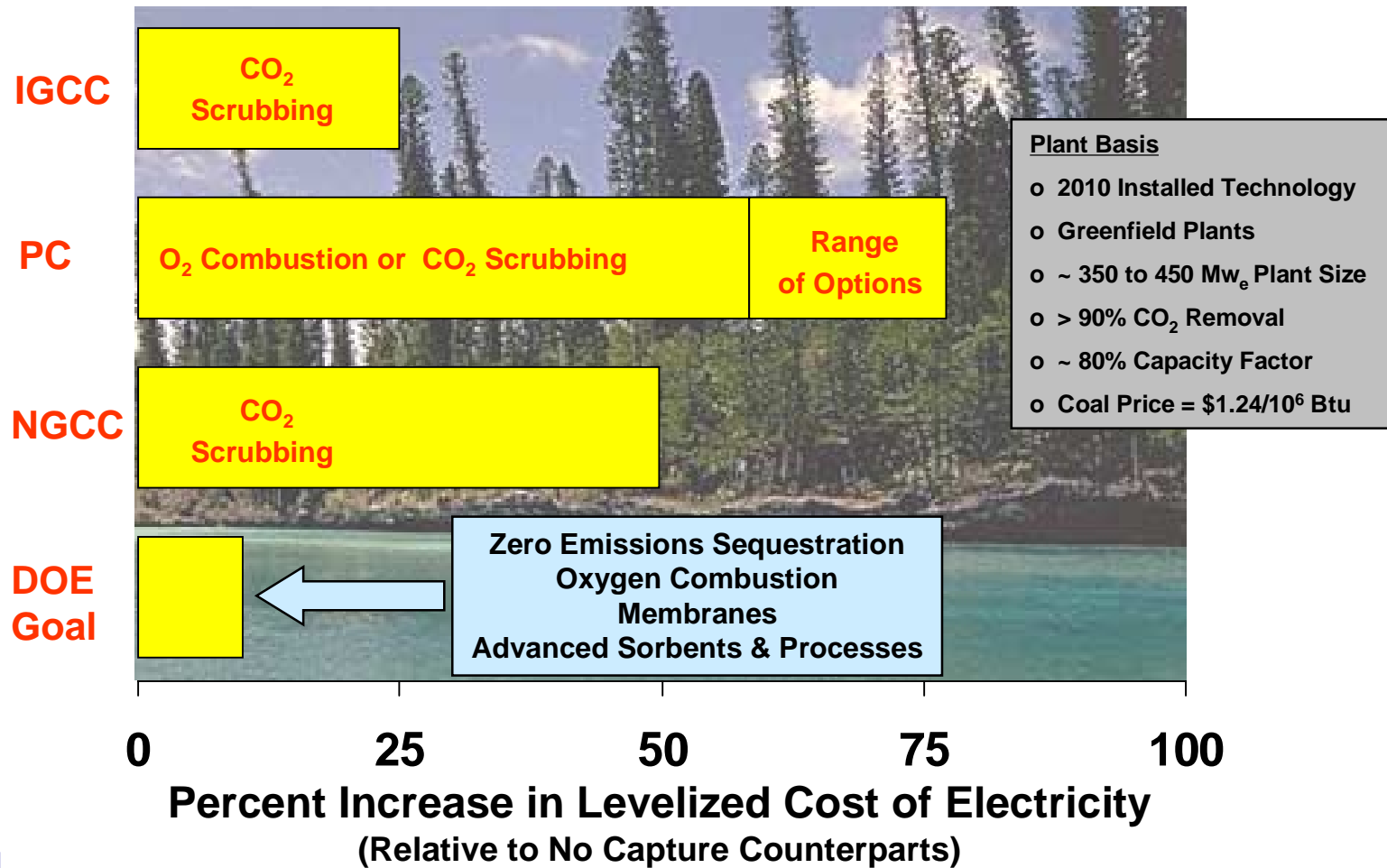


Measurement,
Monitoring &
Verification



Separation and Capture

A Challenging Task Ahead



Separation and Capture Highlights

Many Advanced Integrated Schemes Emerging

Coal Gasification

CO₂ 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 CO₂ at High Pressure

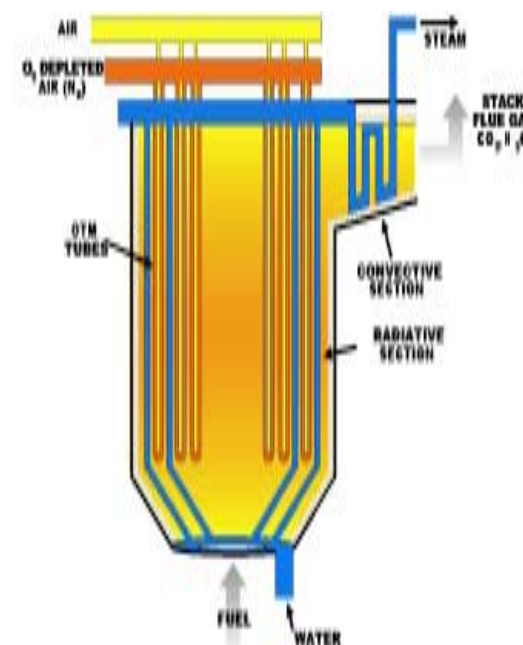
- *Improves Sequestration Economics*
- *Reduces Energy Penalty*



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 O₂
- Integrates air separation using oxygen transport membrane & O₂ combustion
- Combustion in an oxygen environment resulting in a flue gas with a high CO₂
- Materials and system integration barriers

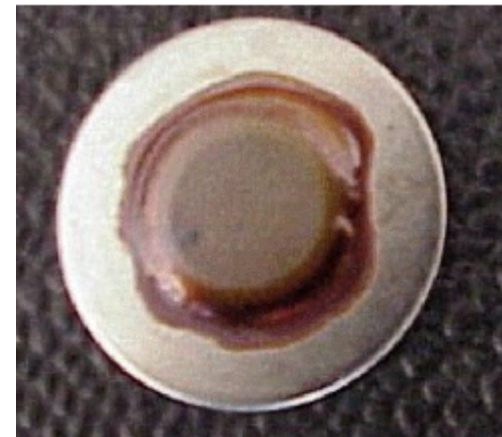


Participants: Praxair and Alstom Power

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 (polybenzimidazole sintered metal support)
- Potential application in many gas separation processes



PBI coated metal

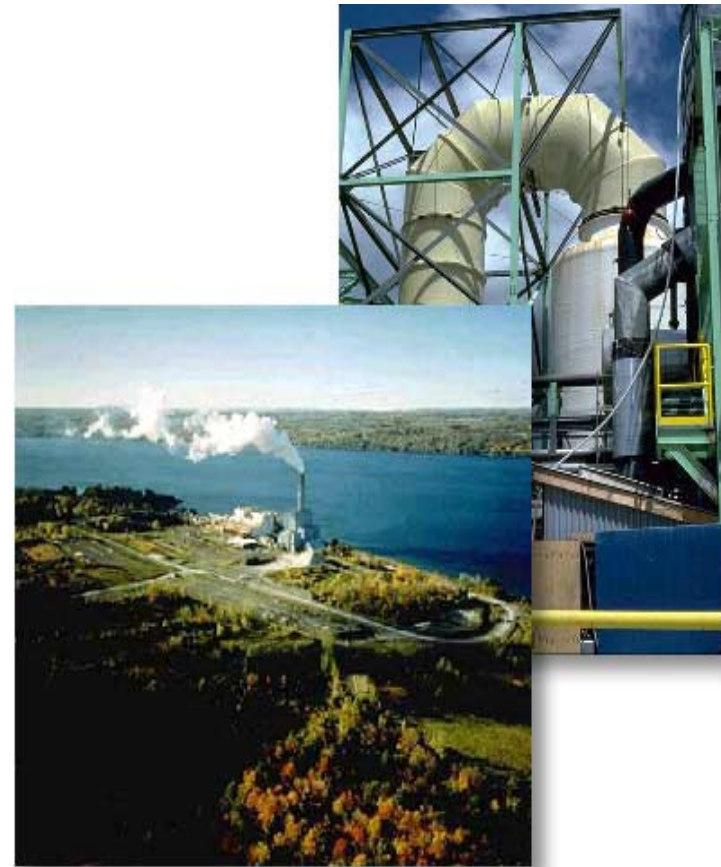


Participants: LANL, INEEL, Univ. Colorado, Pall, Shell

Separation and Capture Highlights

Dry Regenerable Sorbents

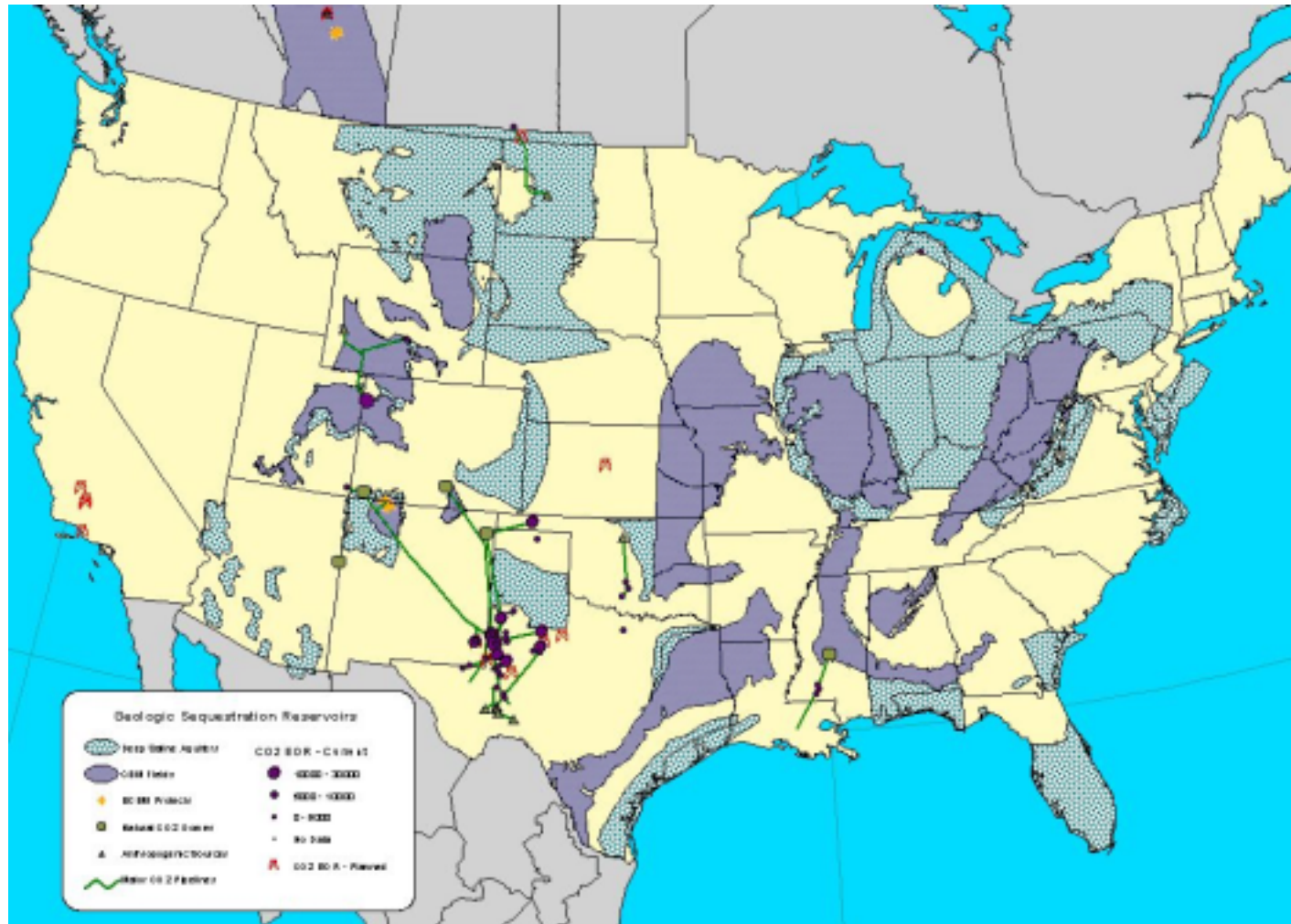
- Sorbent characterized & kinetics understood
- Optimizing process and headed to pilot testing
- Use sodium carbonate, a dry regenerable sorbent
- Little power requirement



Participants: RTI, LSU, Church & Dwight



Geologic Sequestration Options



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



Geologic Sequestration Highlights

(1 Million TPY CO₂, ~ 100 MW Coal Power Plant)

Weyburn CO₂ EOR Project

- Pan Canadian Resources
- 200-mile CO₂ pipeline from Dakota Gasification Plant
- 130M barrels oil over 20-year project
- \$28M

Sleipner North Sea Project

- Statoil
- Currently monitoring CO₂ migration
- \$80M “incremental cost”
- \$36–50 / ton CO₂ tax



Geologic Sequestration Highlights

Baselining Source & 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: IJSHN 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

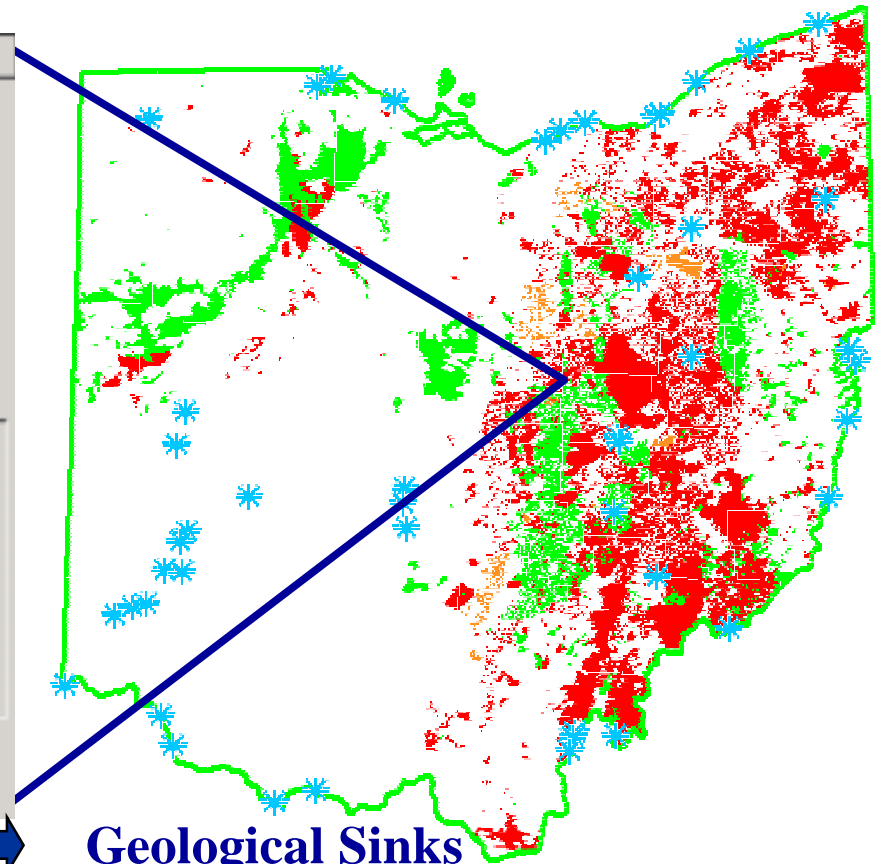
	GAS	OIL
IP Natural	2000	10
IP After Treatment	0	0

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



Geologic Sequestration Highlights

First U.S. Depleted Reservoir Storage Project

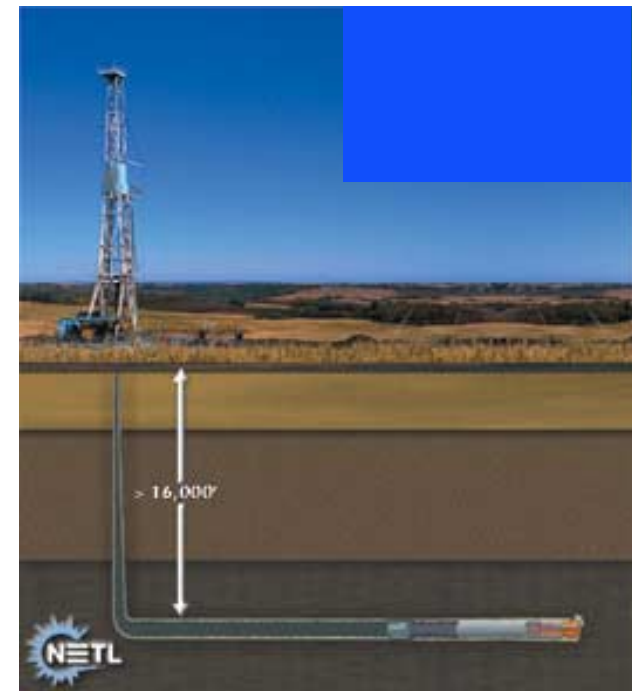
- **Inject CO₂ and monitor its movement**
- **Location**
 - Oil reservoir near Roswell, New Mexico
- **Partners**
 - Pecos Petroleum
 - Strata Production
 - New Mexico Tech U.
 - Sandia
 - LANL
 - NETL



Geologic Sequestration Highlights

Enhanced Coalbed Methane Recovery

- Demonstrate CO₂ enhanced coal seam methane production using slant hole drilling
- Demonstrate permanence of CO₂ sequestration
- Value added methane to help offset sequestration cost
- Marshall County, WV



Participants: CONSOL & Subsidiaries



Terrestrial Sequestration

Establish Methods and Protocols



Improve Soil Carbon Measurement

- Decrease sample time and cost
- Develop measurement protocols

Improve Regional MMV

- Remote sensing opportunities
- Vegetation carbon databases for calibration

Enhance Carbon Uptake

- Amendments
- Soil management

Partner with USDA and other Organizations



Terrestrial Sequestration Highlights



- **Soil Carbon Measuring and Monitoring**
 - LANL - LIBS
- **Regional Measuring, Monitoring and Verification**
 - The Nature Conservancy - Advanced Videography
- **Enhance Plant Growth on Degraded Lands**
 - TVA - FGD Amendments
- **Economic Modeling**
 - Stephen F. Austin State U. - Appalachia

Ocean Sequestration Research Priorities

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



Ocean Sequestration Highlights

International Ocean Project

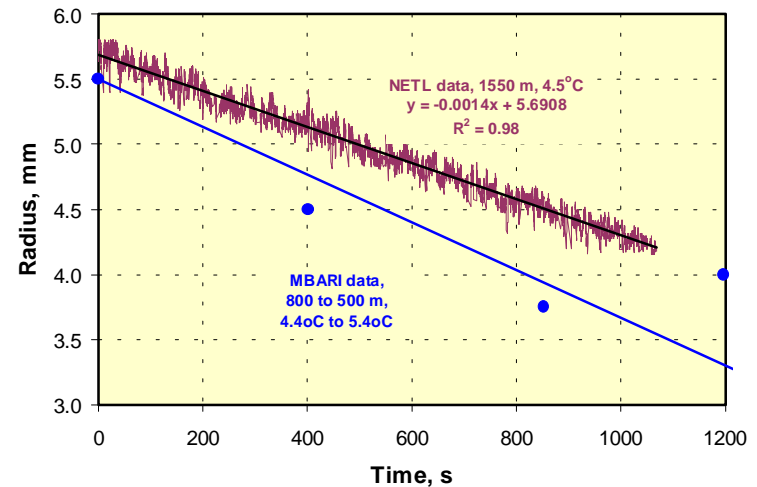
- **Study environmental & technical feasibility of CO₂ storage in ocean**
- **U.S. territorial waters near Hawaii**
- **Funding organizations**
 - Japan (NEDO)
 - U.S. (NETL)
 - Australia (CSIRO)
 - Norway (NRC)
 - Canada (NRCAN)
 - ABB
 - CRIEPI (Japan)
- **U.S. research organizations**
 - MIT
 - U. of Hawaii
 - Naval Research Lab
 - PICHTR



Ocean Sequestration Highlights

Oceanic Sequestration Research Facility

- Study CO₂ 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

Several Novel Systems in Program

- Recovery & sequestration of CO₂ by photosynthesis of microalgae - PSI
- Chemical fixation coal combustion products & recycling through algal biosystems - TVA
- Enhanced practical photosynthetic CO₂ 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 Novel Systems

- **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



Visit Our NETL Sequestration Website

www.netl.doe.gov/coalpower/sequestration/

The screenshot shows the homepage of the National Energy Technology Laboratory's Carbon Sequestration Website. At the top, the NETL logo is on the left, and the text "NATIONAL ENERGY TECHNOLOGY LABORATORY CARBON SEQUESTRATION WEBSITE" is in the center. A navigation bar includes links for "Home", "Site Index", and "Feedback". The date "September 09, 2002" is displayed on the right. A vertical sidebar on the left lists categories: "What's New", "Events", "Overview", "Capture", "Geologic", "Ocean", "Terrestrial", "Conversion", "Modeling", "In-House R&D", "Ref. Shelf", "Kids Only!", "Links", and "Contacts". The main content area features a large circular image of a mountain landscape. Overlaid on this image is the text "Carbon Sequestration" and a list of research areas: "Capture & Storage", "Geologic Sequestration", "Ocean Sequestration", "Terrestrial Sequestration", "Adv. CO₂ Conversion & Reuse", and "Modeling & Analysis". A sub-header reads "Pathways to Sustainable Use of Fossil Fuels—enabling the removal and permanent storage of carbon dioxide from fossil-energy systems". Below the image, a welcome message states: "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 CO₂ conversion & reuse, and modeling & analysis." A second paragraph says: "Our site is designed to answer your questions about carbon sequestration—from the basics to specific technical information." At the bottom of the main area, there are buttons for "MEDIA RELEASE" and "GET THE NEWS" (with a globe icon). A box at the bottom right contains two PDF links: "Carbon Sequestration Technology Roadmap [PDF-1025KB]" and "CO₂ Capture and Storage in Geologic Formations [PDF-226KB]". A small image of a document is shown to the left of these links.



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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- Publications
- Legislative Activity

www.netl.doe.gov/products/sequestration/refshelf.html

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	A Greener Greenhouse NASA Satellites show plant growth in northern regions has been more vigorous over the past two decades. The

Mail From: "Sequestration" <sequestration@netl.doe.gov>

File Edit View Actions Tools Window Help

From: "Sequestration" <sequestration@netl.doe.gov> CC: [Redacted]
To: <sequestration@zeus.mgr.tet.c.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/A138402001Sep23.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/CCAPe.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://jcasas.esa.int/river.com/zhc-aqdt/burne/>. 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

