# Carbon Sequestration
## "The Path Forward"

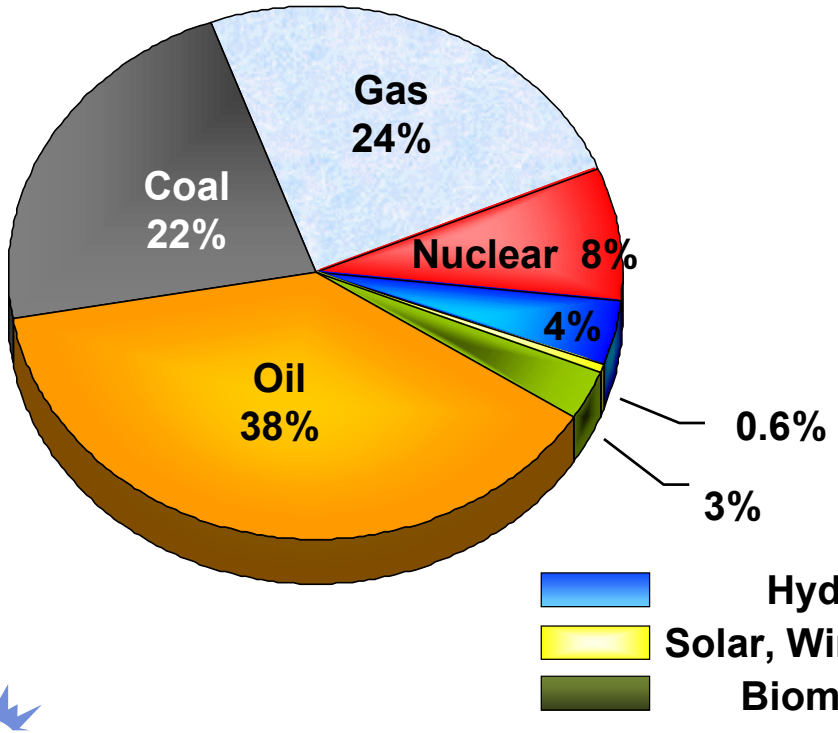
*"Pathways to Sustainable Use of Fossil Energy"*

**Charles E. Schmidt, Director**
**Clean Air Technology Division**

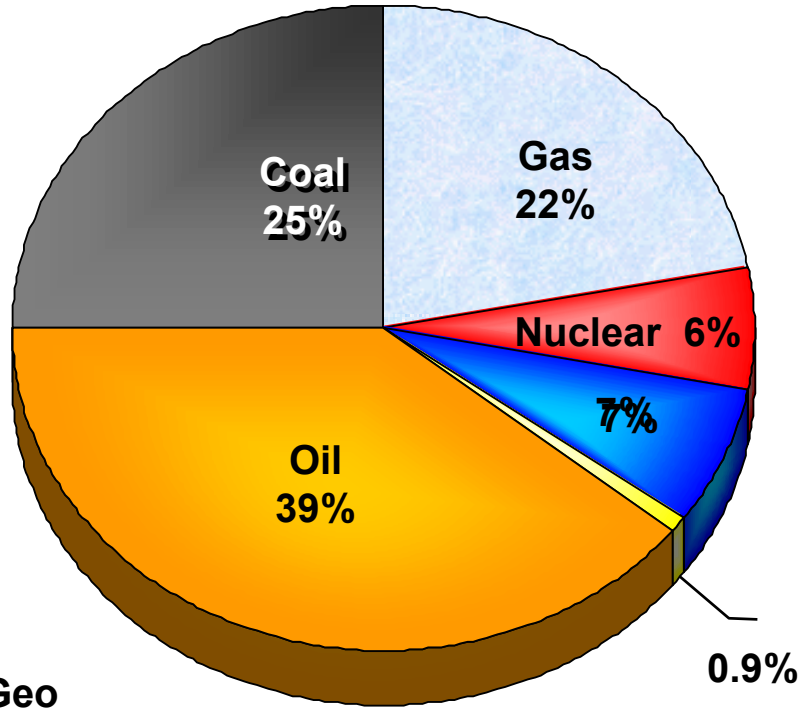
**Energy for the New Millennium**

# Fossil Fuels
## World's Dominant Energy Source

### United States
**99 QBtu/yr; 85% Fossil Energy**



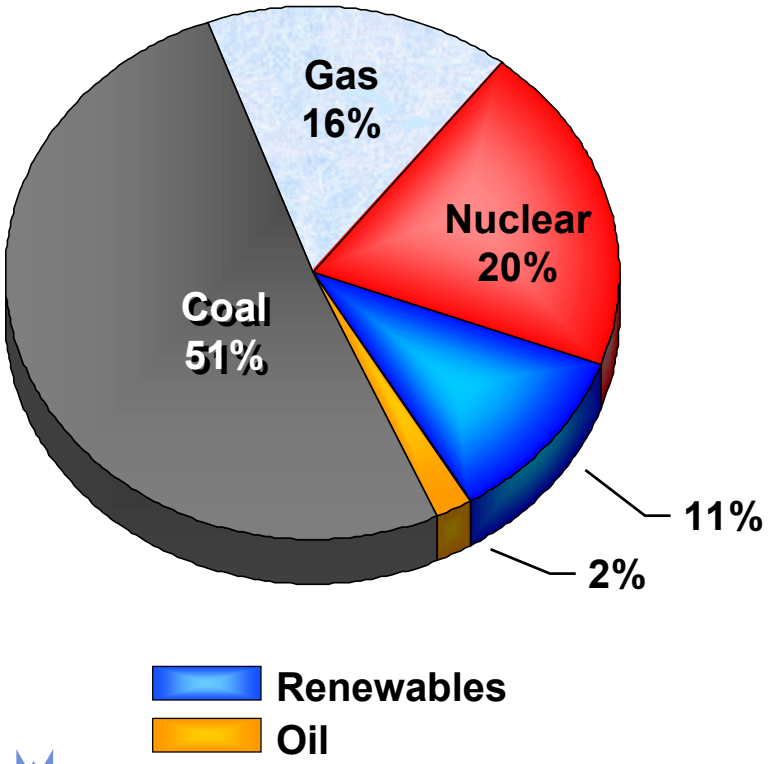

### World
**382 Quads/yr; 86% Fossil Energy**



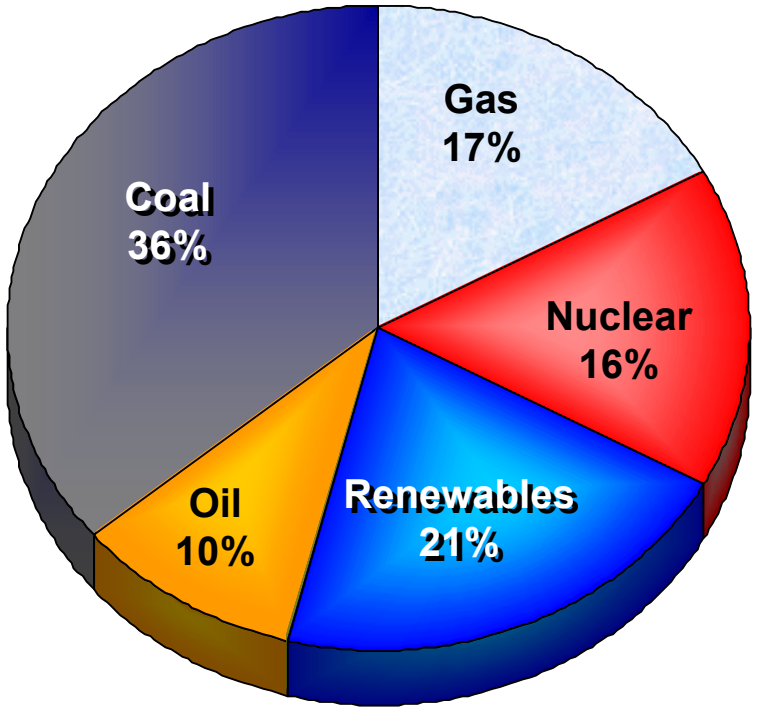

*Word Data from EIA96. Does not include non-grid-connected biomass.*
*U.S. Data from Table 2 of EIA REA 97 & AEO 2002 Table A2*

# Fossil Fuels
## World's Dominant Electricity Source

### United States - 1999
3.2 Trillion kWh - 69% Fossil Energy



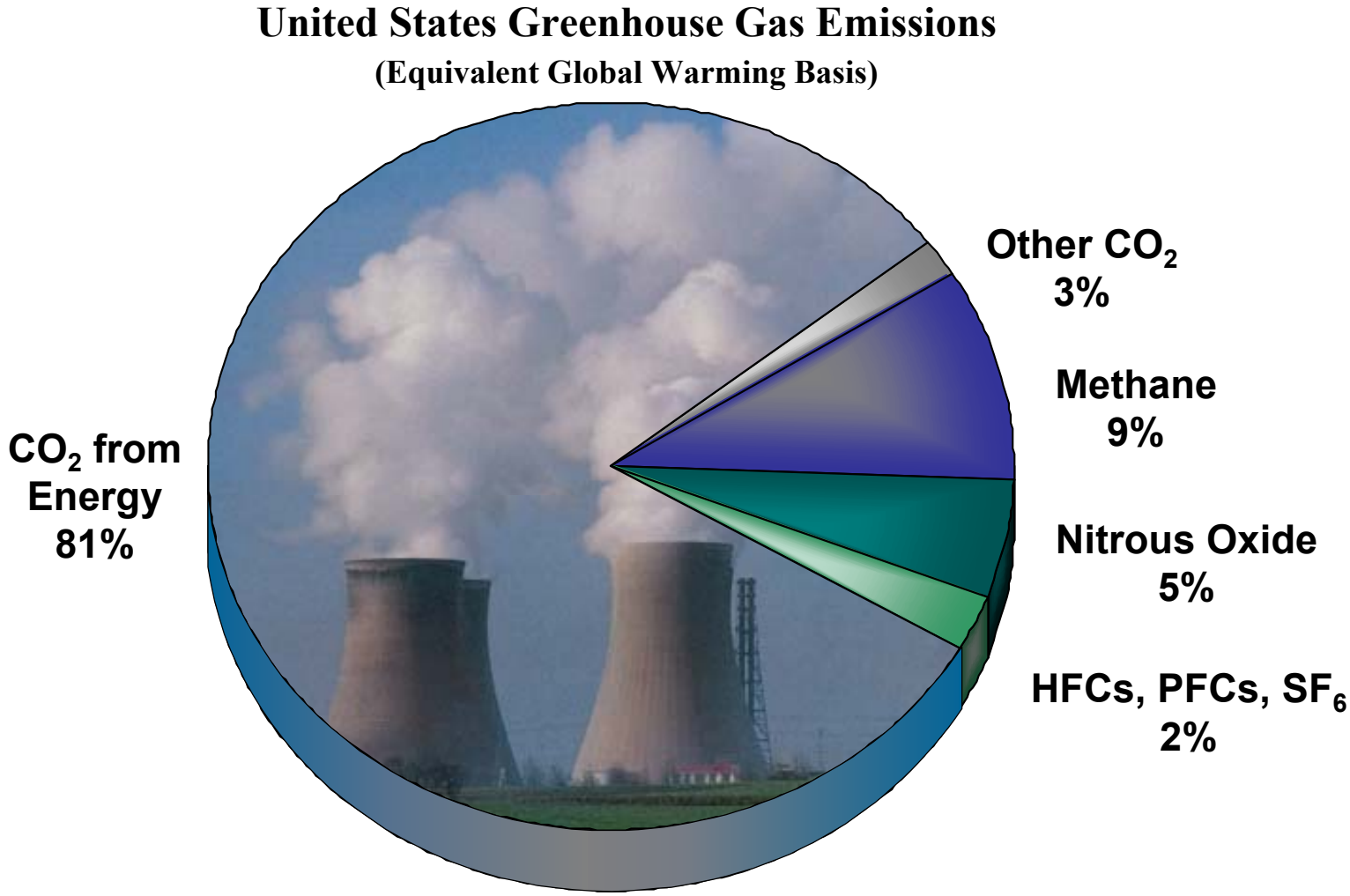

### World - 1999
12.8 Trillion kWh - 63% Fossil Energy




*Source: EIA International Energy Outlook 2001*
*Edison Electric Institute 2001*

# Greenhouse Gas Implications

# $CO_2$ & $CH_4$ - The Primary GHG Contributors




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

# Fugitive Methane Emissions Are Significant

## *Equivalent GWP* Compared to Emissions from 500 MW Plant*

### *Natural Gas Systems*

- **32 MMTCE methane emissions equivalent:**
  - **115 gas plants**
  - **40 coal plants**

### *Coal Mining*

- **17 MMTCE methane emissions equivalent:**
  - **60 gas plants**
  - **20 coal plants**

### *Landfills*

- **55 MMTCE methane emissions equivalent:**
  - **195 gas plants**
  - **70 coal plants**

***Global Warming Potential**

*Sources: EPA Inventory of U.S. GHG Emissions & Sinks - 2002 2000 emissions*

# Enter….

# Carbon Sequestration

# “Pathways to GHG Stabilization”

# 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

# Presidential Direction

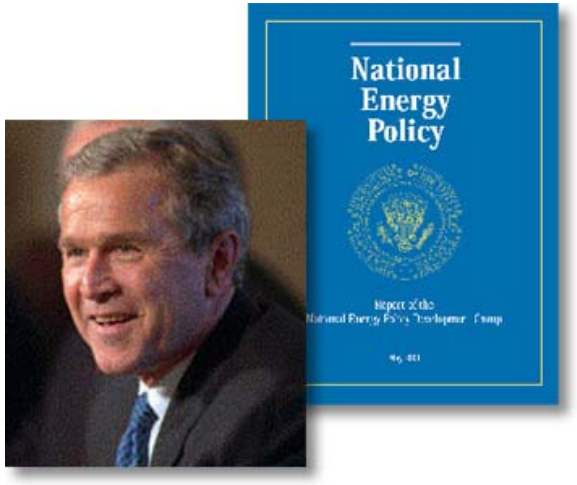
## *Drivers for Carbon Sequestration Program*

### 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."

### February 14, 2002

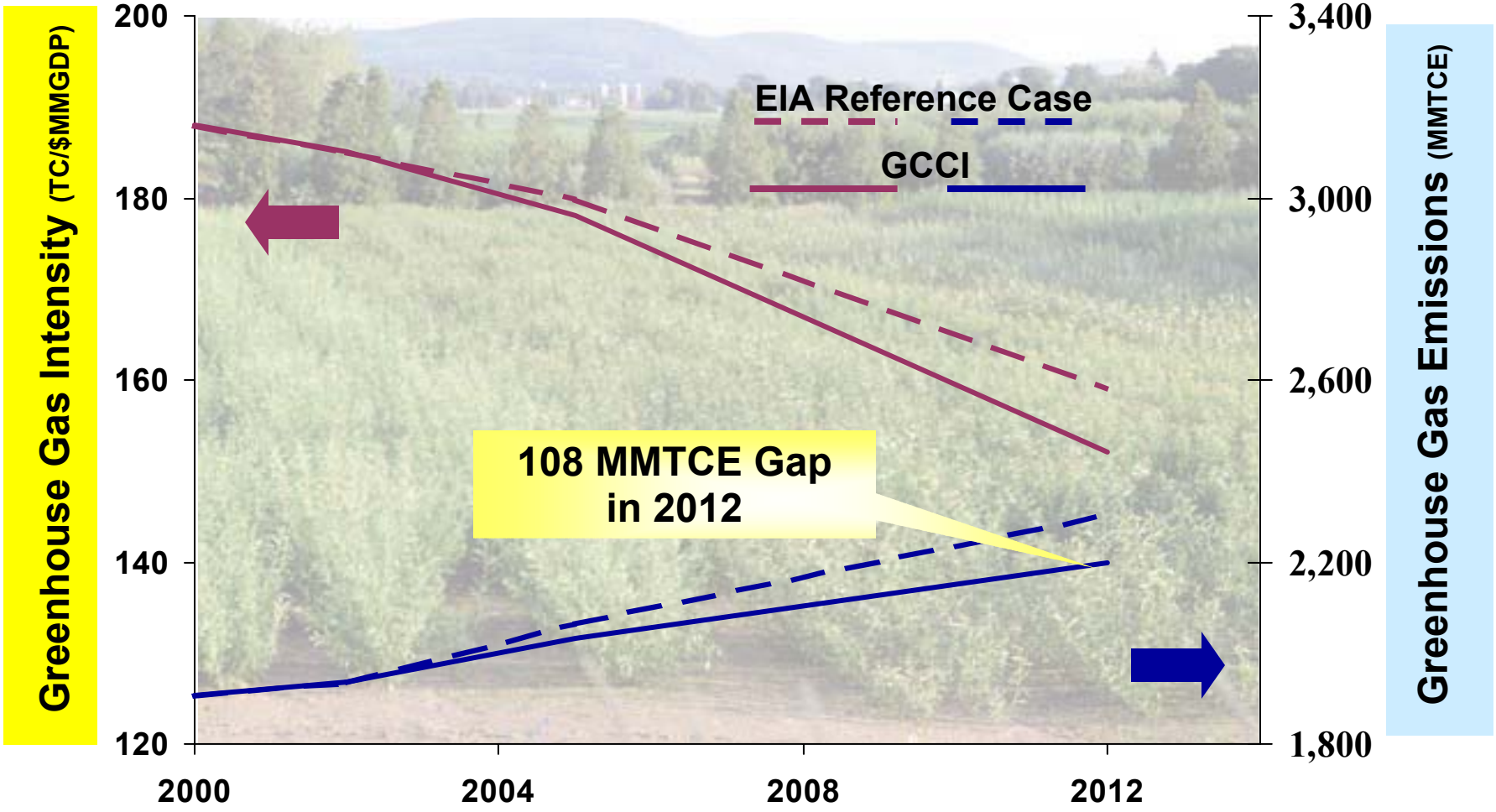
- Sustain economic growth
- Reduce GHG intensity by 18% in next 10 years




*White House photo: Paul Morse*

# GCCI Pathway to 2012

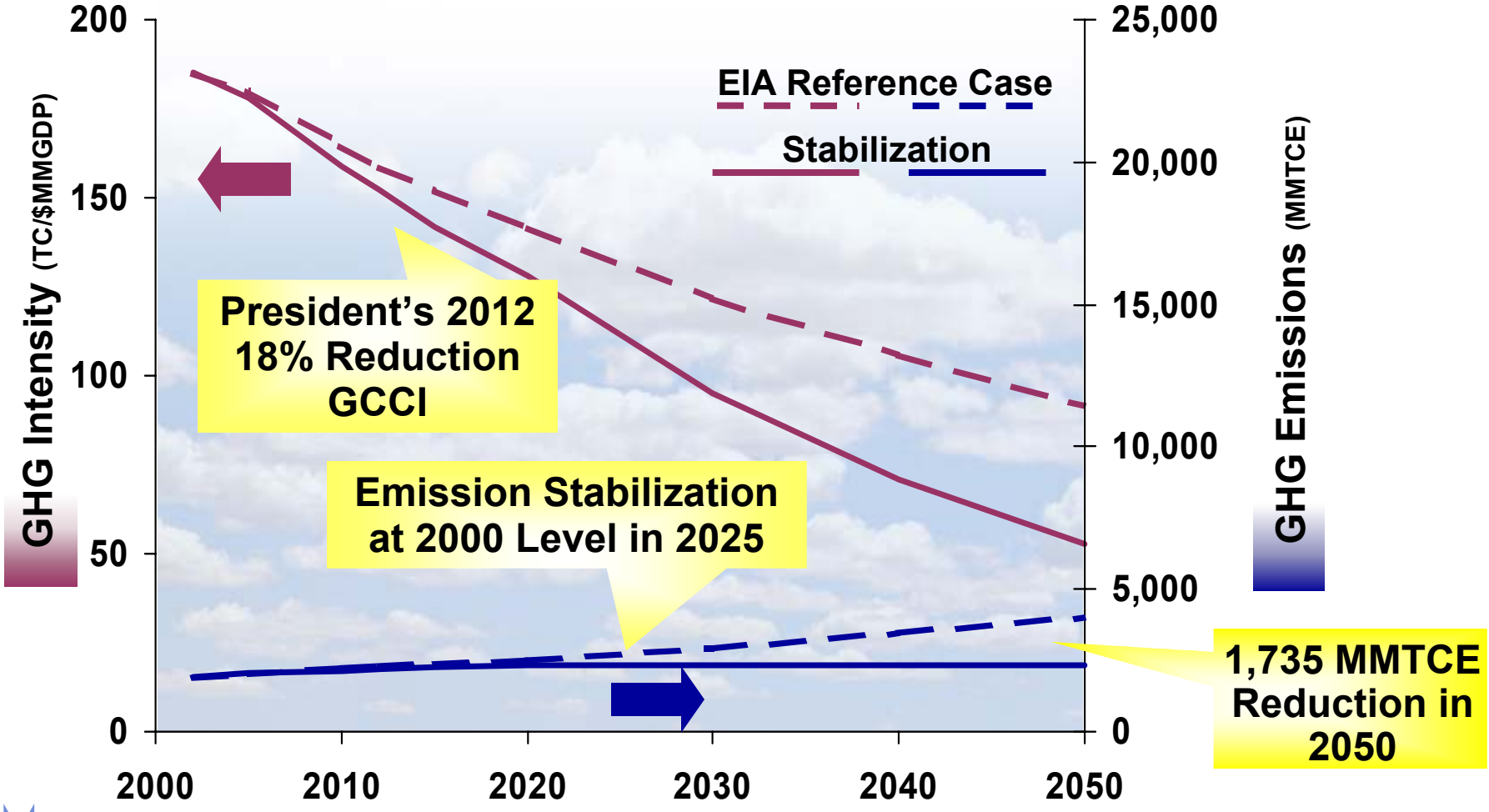
## *18% Reduction in Greenhouse Gas Intensity*




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

# Possible Pathway to Stabilization

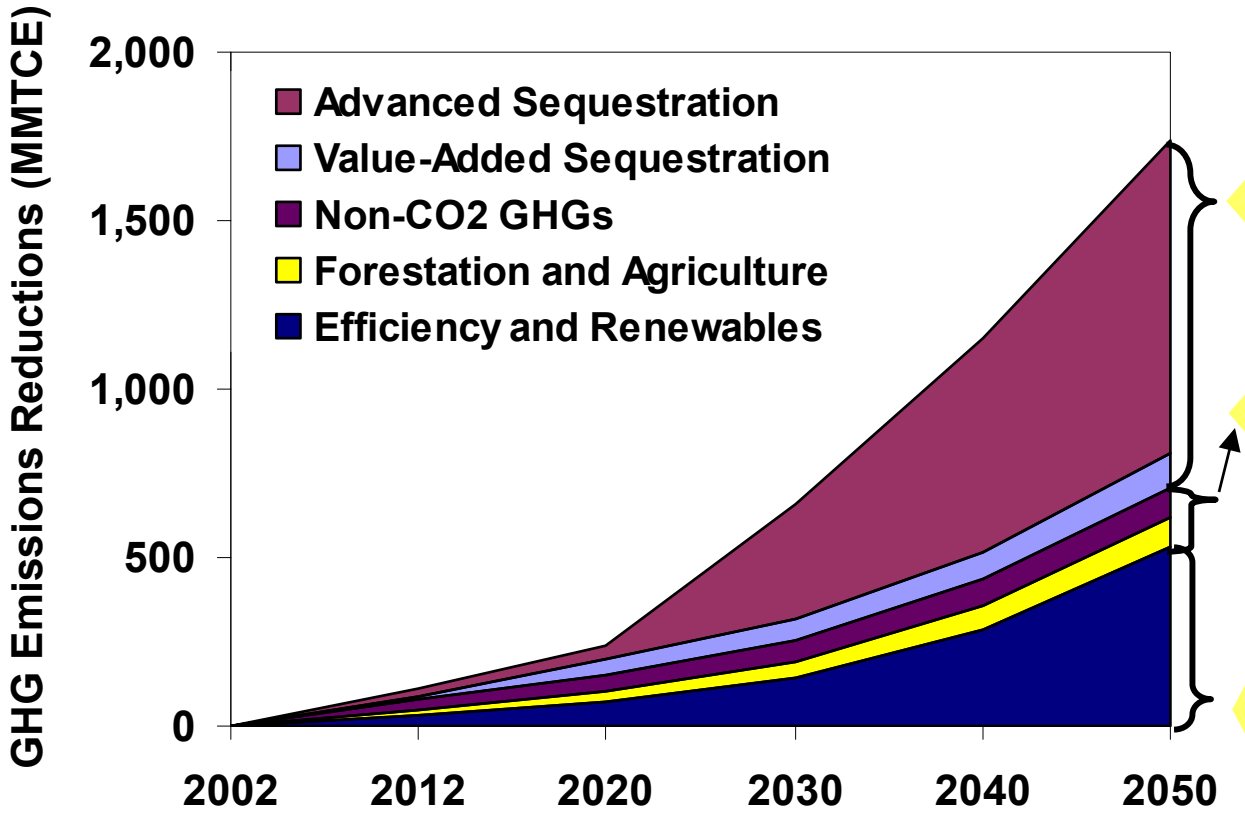
## *A Significant Undertaking*




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

# Stabilization = Sequestration

## *Must Account For > 60% of Reduction Gap*




**Reductions rely on carbon management program**

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

**Reductions unrelated to sequestration, but includes coal**
- **Repowering**
- **Retrofit**
- **Vision 21**

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

# Coal & Electricity Are Major Contributors

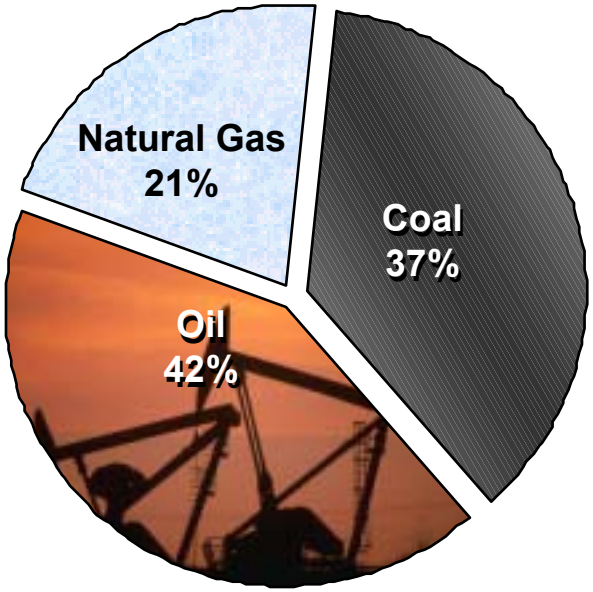
## *Account for ~ 40% of $CO_2$ Emissions*

### 1998 United States CO2 Emissions

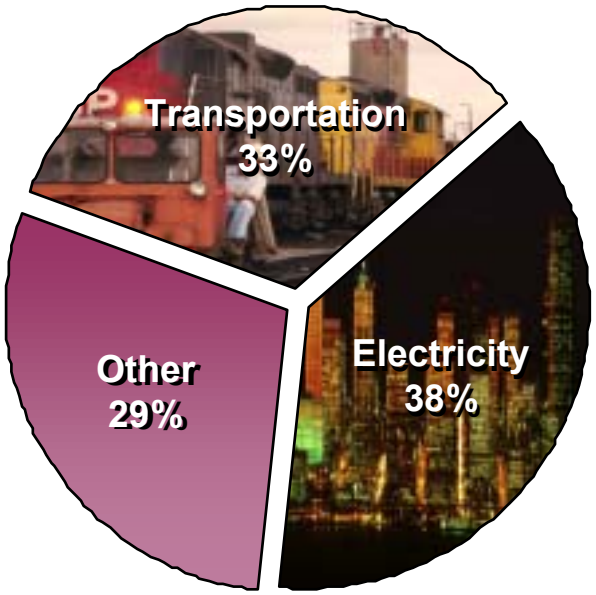
**(Million Metric Tons Per Year Carbon Equivalent)**

**(Total Emissions = 1450)**

### By Fossil Fuel Type

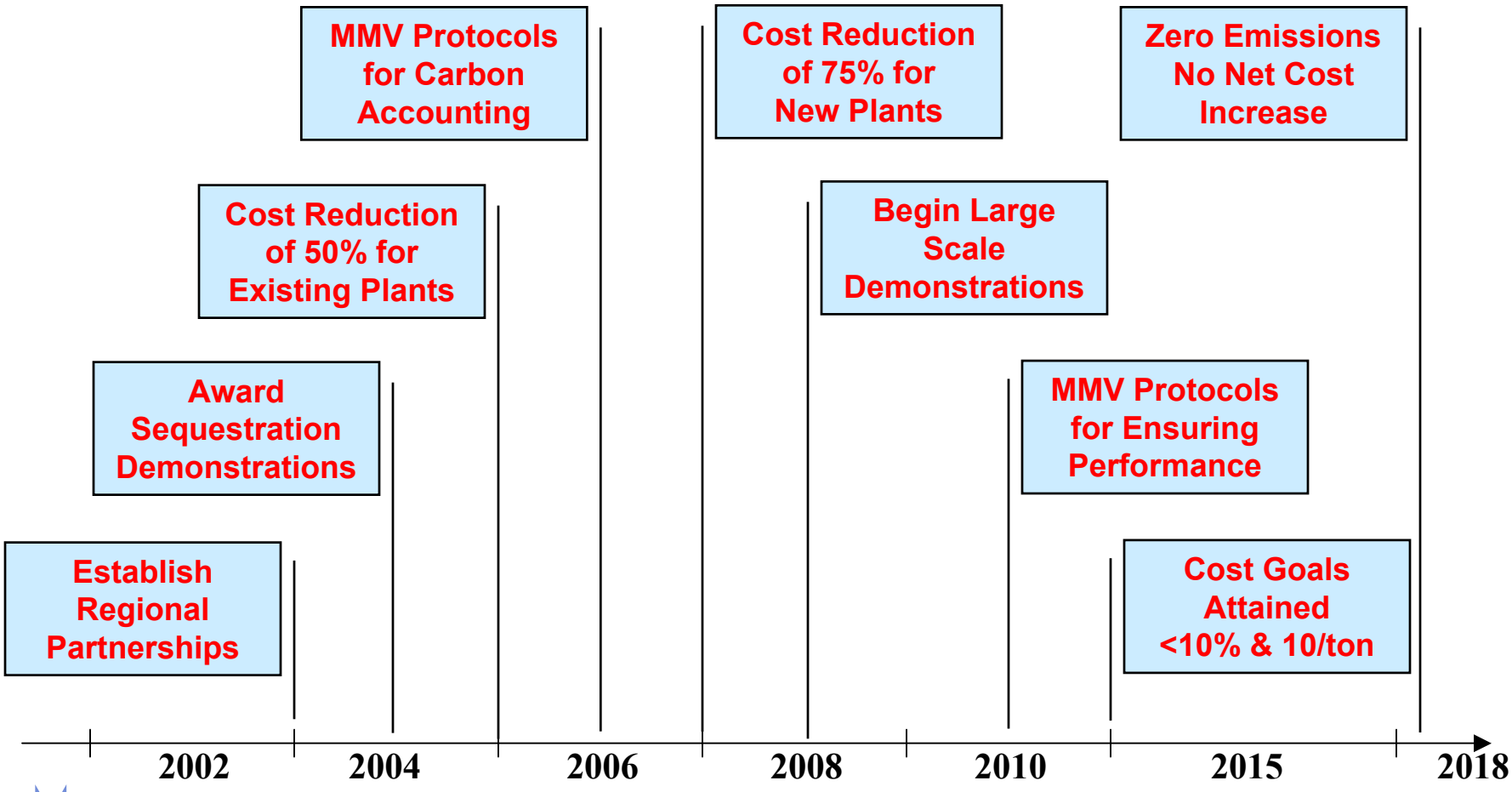



### By Sector




*Source: EPA, Inventory of Greenhouse Gas Emissions, 2000*

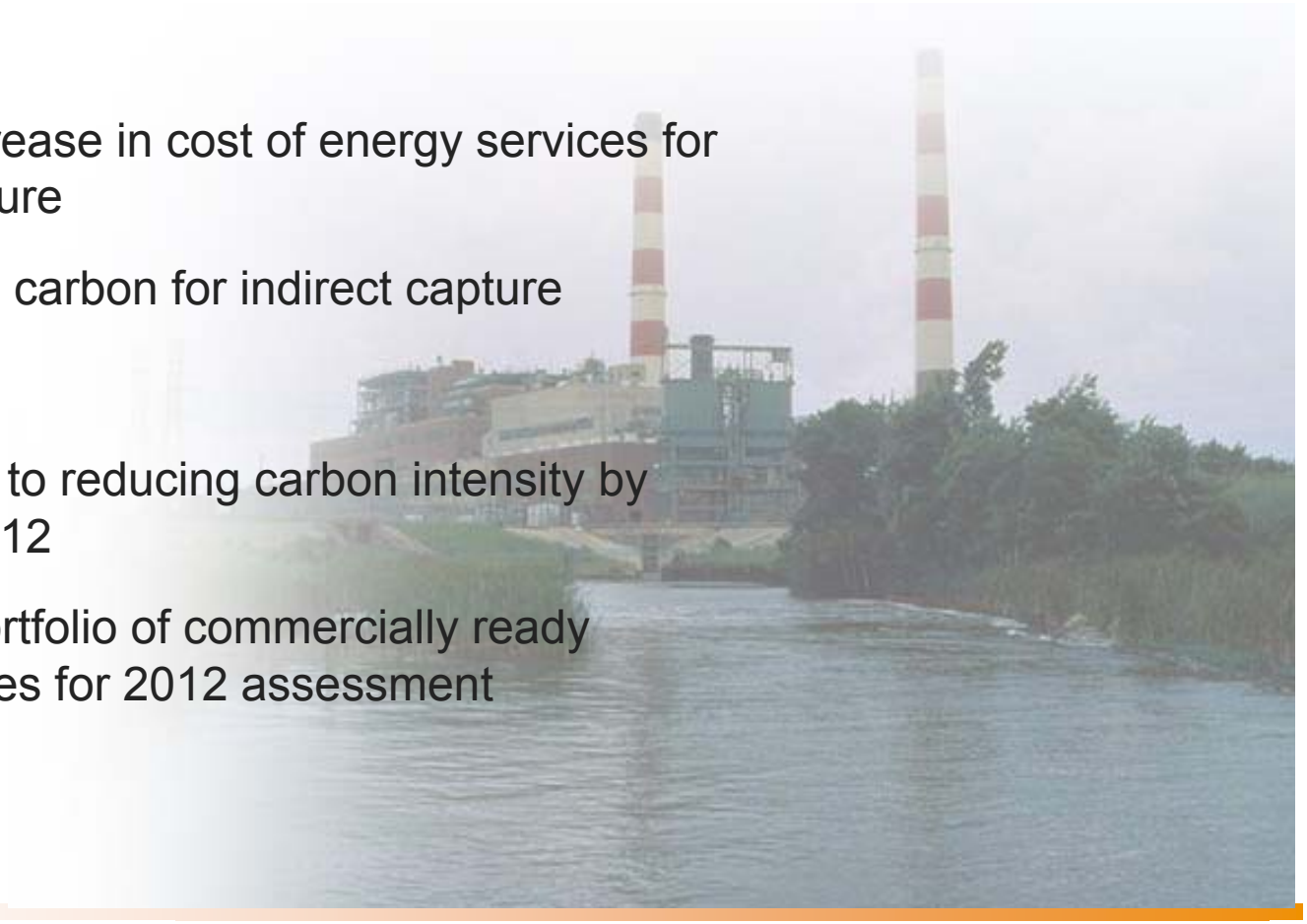
# Carbon Sequestration Roadmap



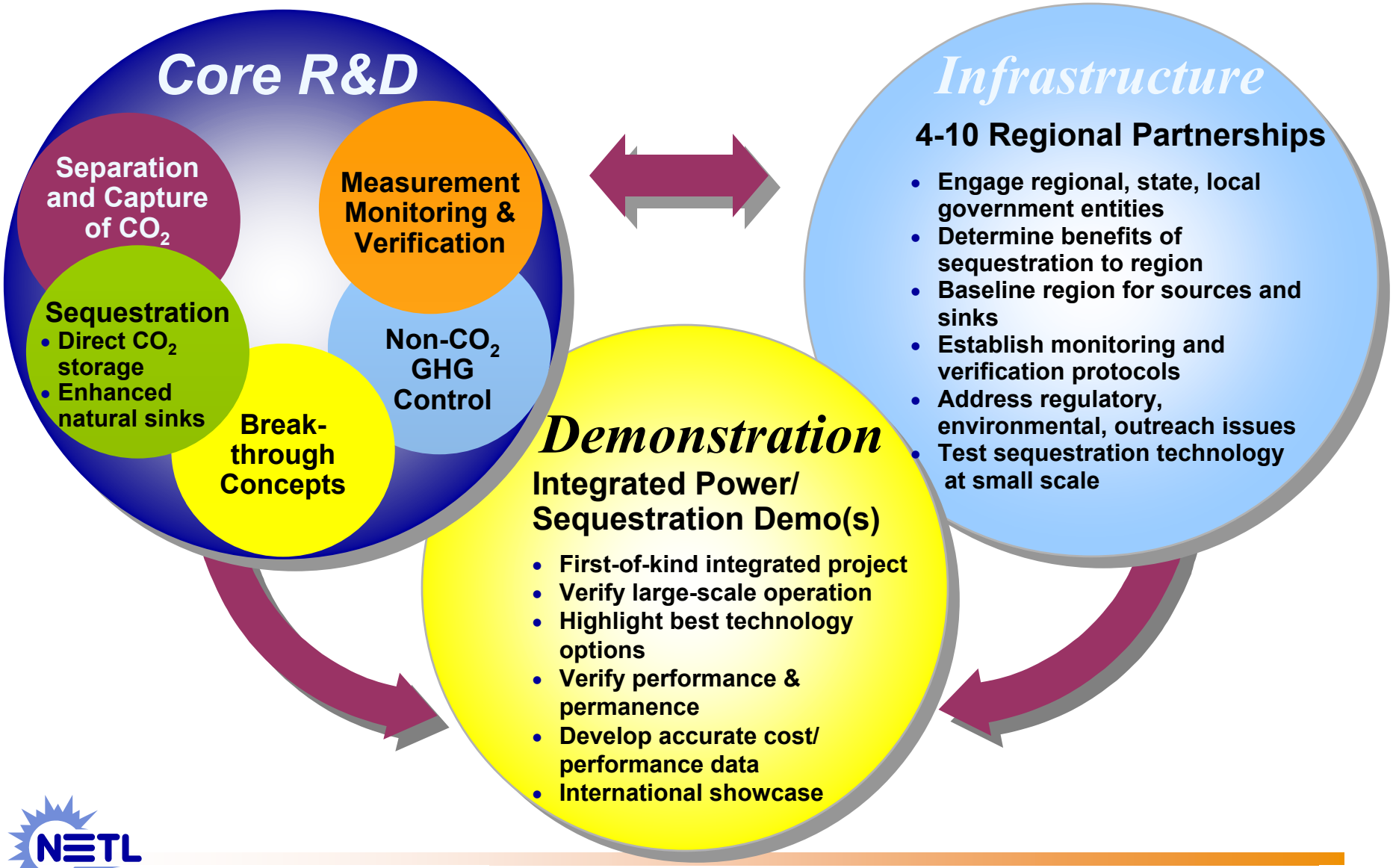
# Program Goals

## *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



# Carbon Management Program Structure



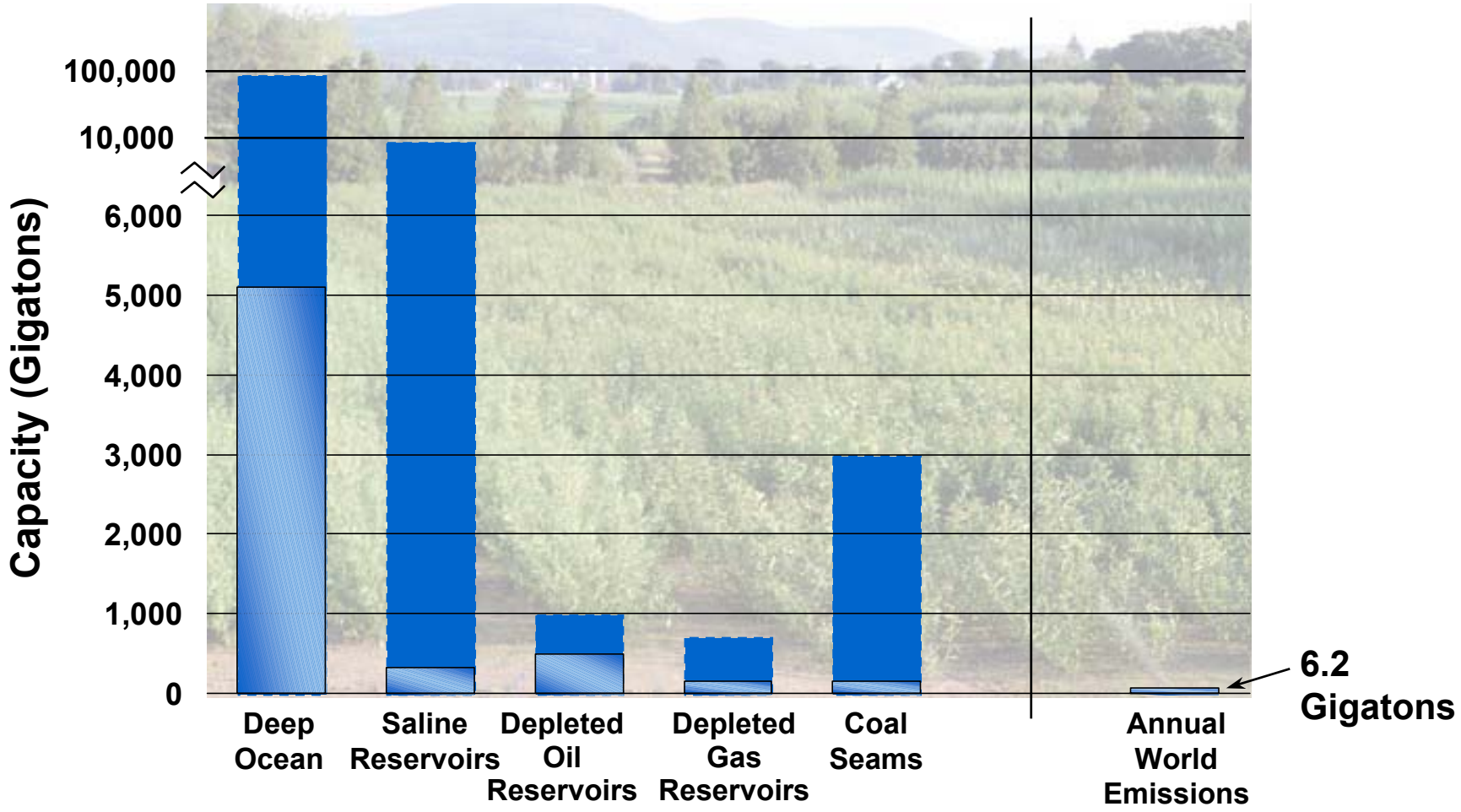
# Technology R&D Pathways

| | |
|---|---|
| • Separation and Capture | • Pre-combustion Decarbonization<br>• Oxygen-Fired Combustion<br>• Post-combustion Capture<br>• Advanced Integrated Capture Systems<br>• Crosscutting Science and Technology |
| • Geologic Sequestration | • Monitoring, Verification, and Remediation Technology<br>• Health, Safety, and Environmental Risk Assessment<br>• Knowledge Base and Technology for Storage Reservoirs |
| • Terrestrial Sequestration | • Productivity Enhancement<br>• Ecosystem Dynamics<br>• Monitoring and Verification |
| • Ocean Sequestration | • Ecosystem Dynamics<br>• Measurement and Prediction<br>• Direct Injection of $CO_2$<br>• Ocean Fertilization |
| • Novel Sequestration Systems | • Biogeochemical Processes<br>• Mineral Conversion<br>• Novel Integrated Systems<br>• Crosscutting Science and Technology |

# Requirements for Sequestration

- Environmentally acceptable
- Safe
- Verifiable
- Economically viable

# Large Potential Worldwide Storage Capacity




*Storage Options: IEA Greenhouse Gas R&D Program;*
*Advanced Resources International estimates for coal seams*
*World Emissions: International Energy Outlook 2000, Table A10*

# Sequestration: A Dynamic Program

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

## *Example Projects*

- **Sandia/Strata**
  - Tracking $CO_2$ in depleted oil reservoir
- **Consol**
  - Sequestration in unmineable coal seams
- **U. of Kentucky**
  - Terrestrial sequestration in mined lands
- **MIDCARB, State Geologic Consortia**
  - Storage potential of geologic formation in five states

# Separation & Capture
## Engineered Sequestration Feasible

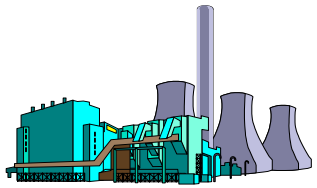
- 70 $CO_2$ enhanced oil recovery sites in U.S.
- Weyburn EOR project in Saskatchewan
- Numerous reforestation projects underway
- Sleipner gas production in North Sea

*Statoil's Sleipner production platform, with $CO_2$ injection*

# Separation and Capture

## Improve Performance, Reduce Costs, Establish Protocols

**Current Technologies**



**Future Technologies**

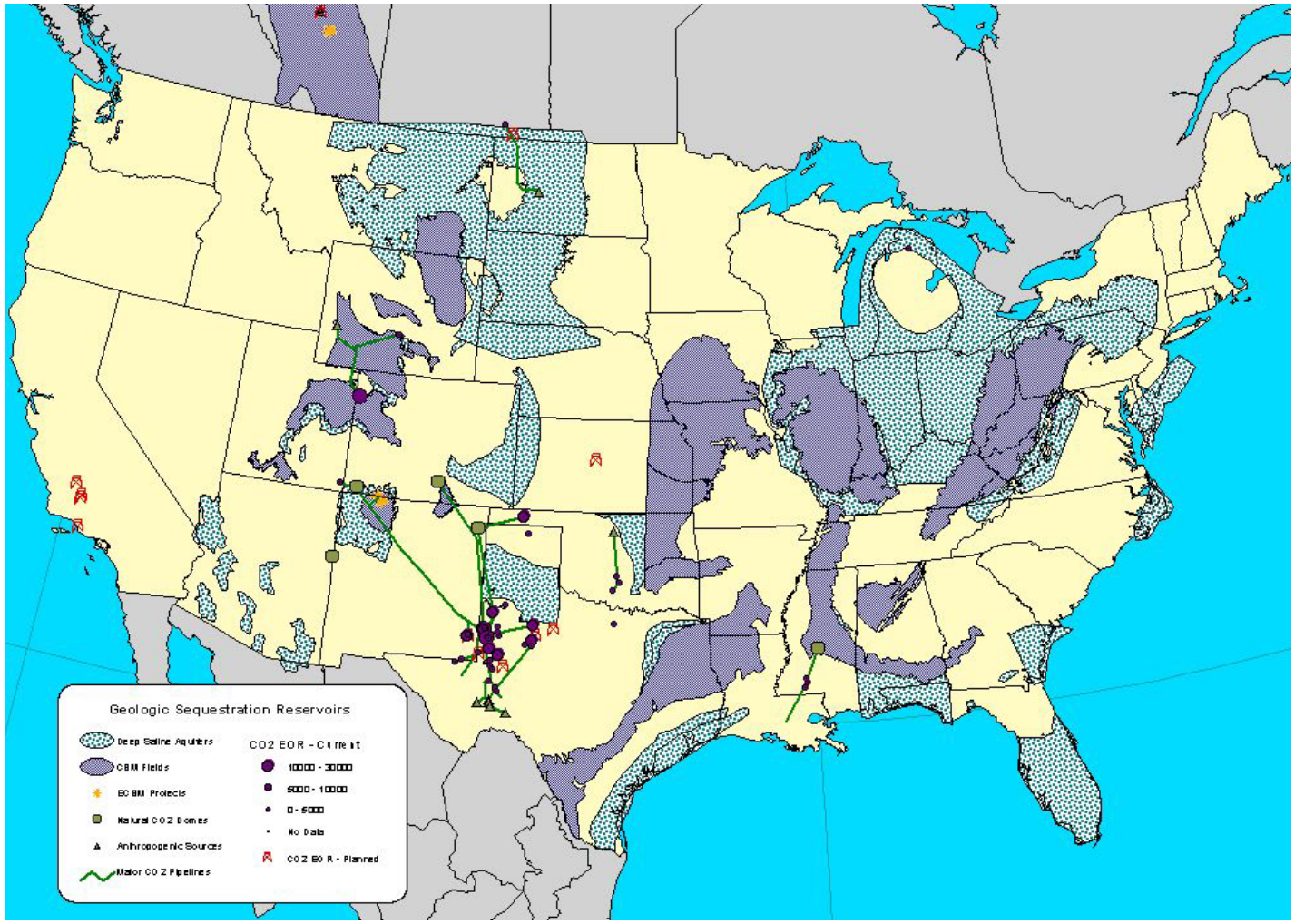
- Amine Scrubbing Systems
- Oxygen Based Combustion

- Advanced Sorbents
- Advanced Membranes
- Solid Sorbents
- $CO_2$ Hydrates

# Geological Sequestration Research Priorities

- Monitoring & Verification Methods/Protocols
- Capacity Evaluations
- Sequestration Mechanisms
- Long-Term Integrity & Permanence
- Environmental Impacts
- Safety
- Major Sequestration R&D Focus

# Geologic Sequestration Options




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

# Terrestrial Sequestration
## Establish Methods and Protocols

- **Improve Soil Carbon Measurement**
  - Decrease sample time and cost
  - Develop measurement protocols
- **Improve Regional Measurement and Verification**
  - Remote sensing opportunities
  - Vegetation carbon databases for calibration
- **Enhance Carbon Uptake**
  - Amendments, soil management, bio waste ventures
- **Partner with USDA and other Organizations**

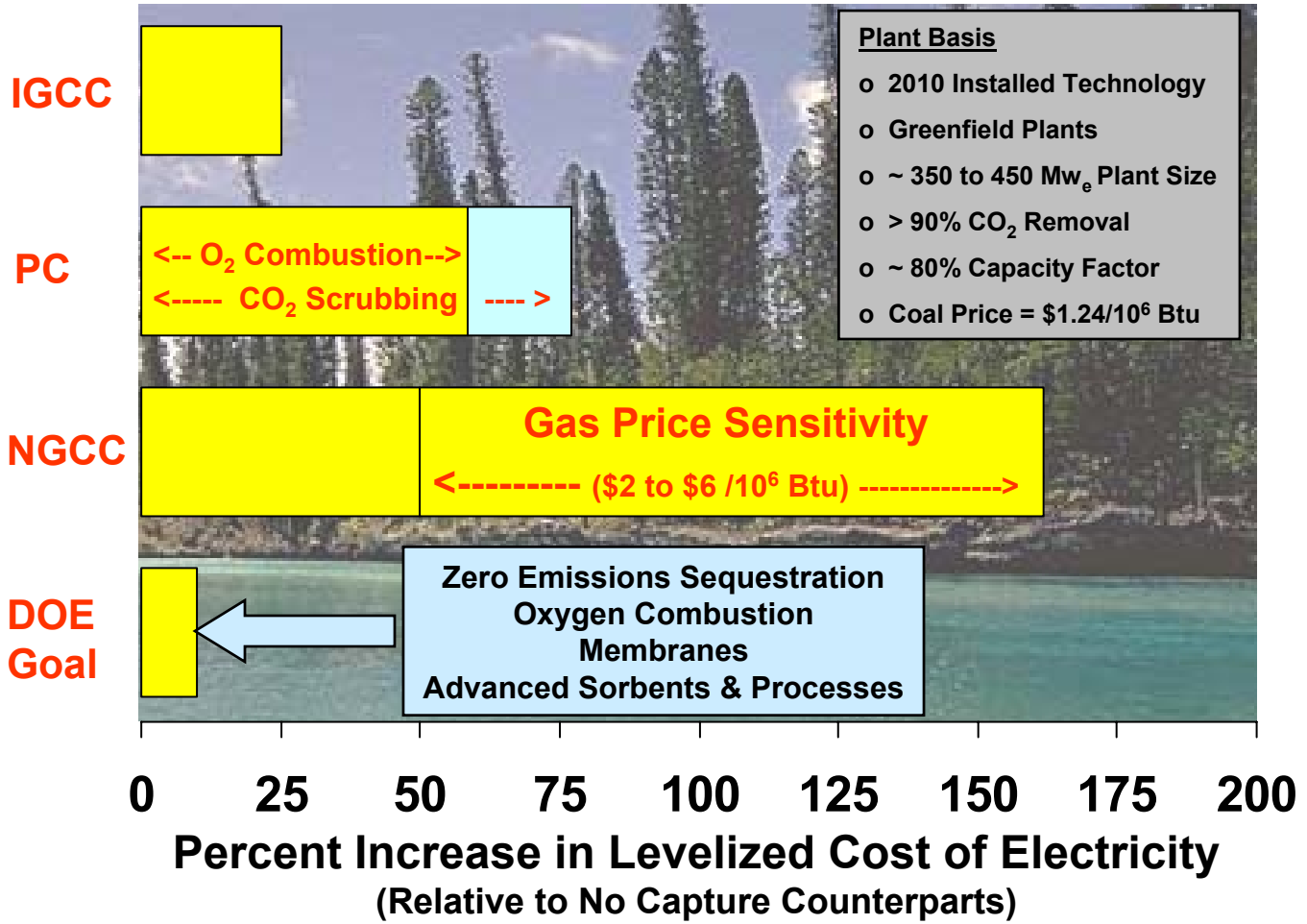
# Terrestrial Sequestration
## Project Portfolio

- **Soil Carbon Measuring and Monitoring**
  - Los Alamos National Laboratory - LIBS
- **Regional Measuring, Monitoring and Verification**
  - The Nature Conservancy - Advanced Videography
- **Enhance Plant Growth on Degraded Lands**
  - Oak Ridge/Pacific Northwest National Laboratories (CSiTE) - Industrial By-products Amendments
  - Tennessee Valley Authority - FGD Amendments
- **Economic Modeling**
  - Stephen F. Austin State University - Appalachia

# Several Novel Systems in Program

- Recovery & sequestration of $CO_2$ by photosynthesis of microalgae - PSI
- Chemical fixation coal combustion products & recycling through algal biosystems - TVA
- Enhanced practical photosynthetic $CO_2$ 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

# Technology Today / Technology Tomorrow
## How Will Goals Be Achieved

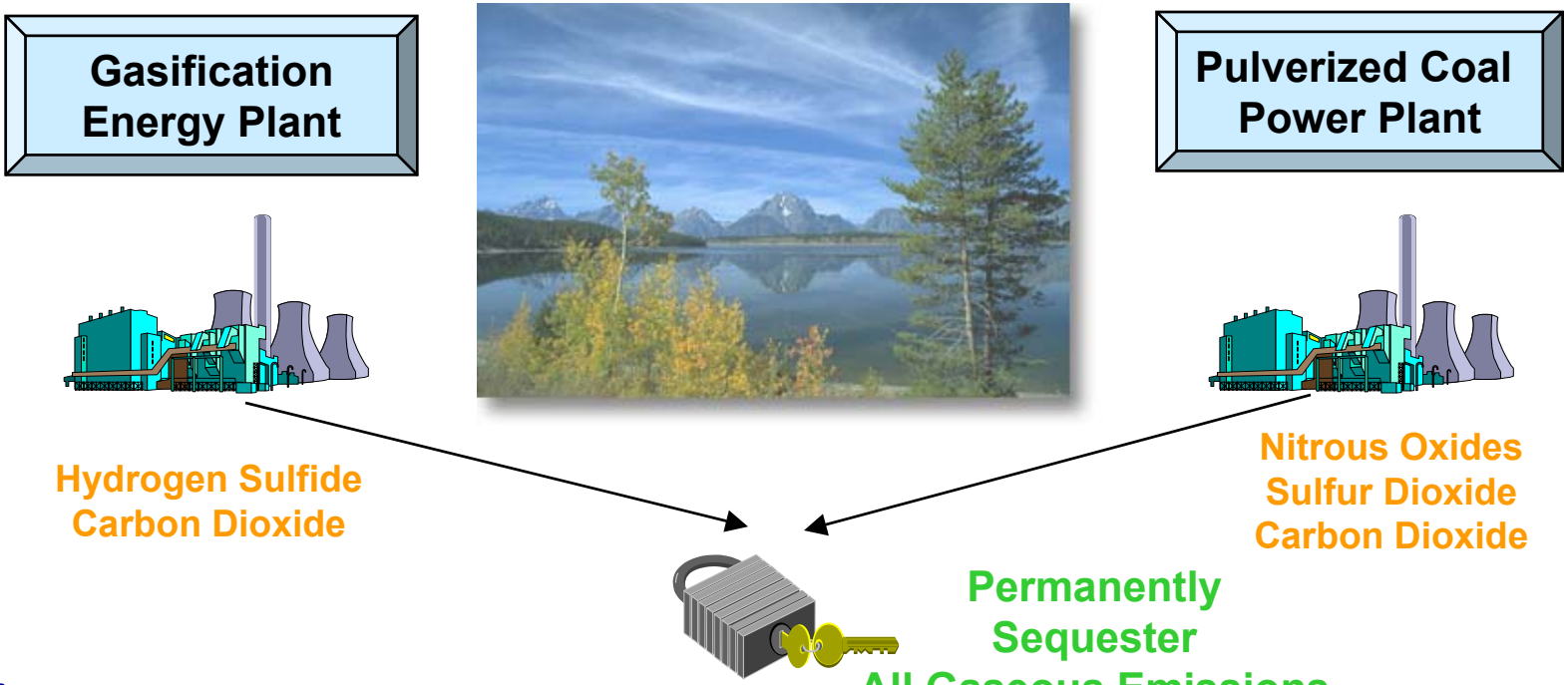


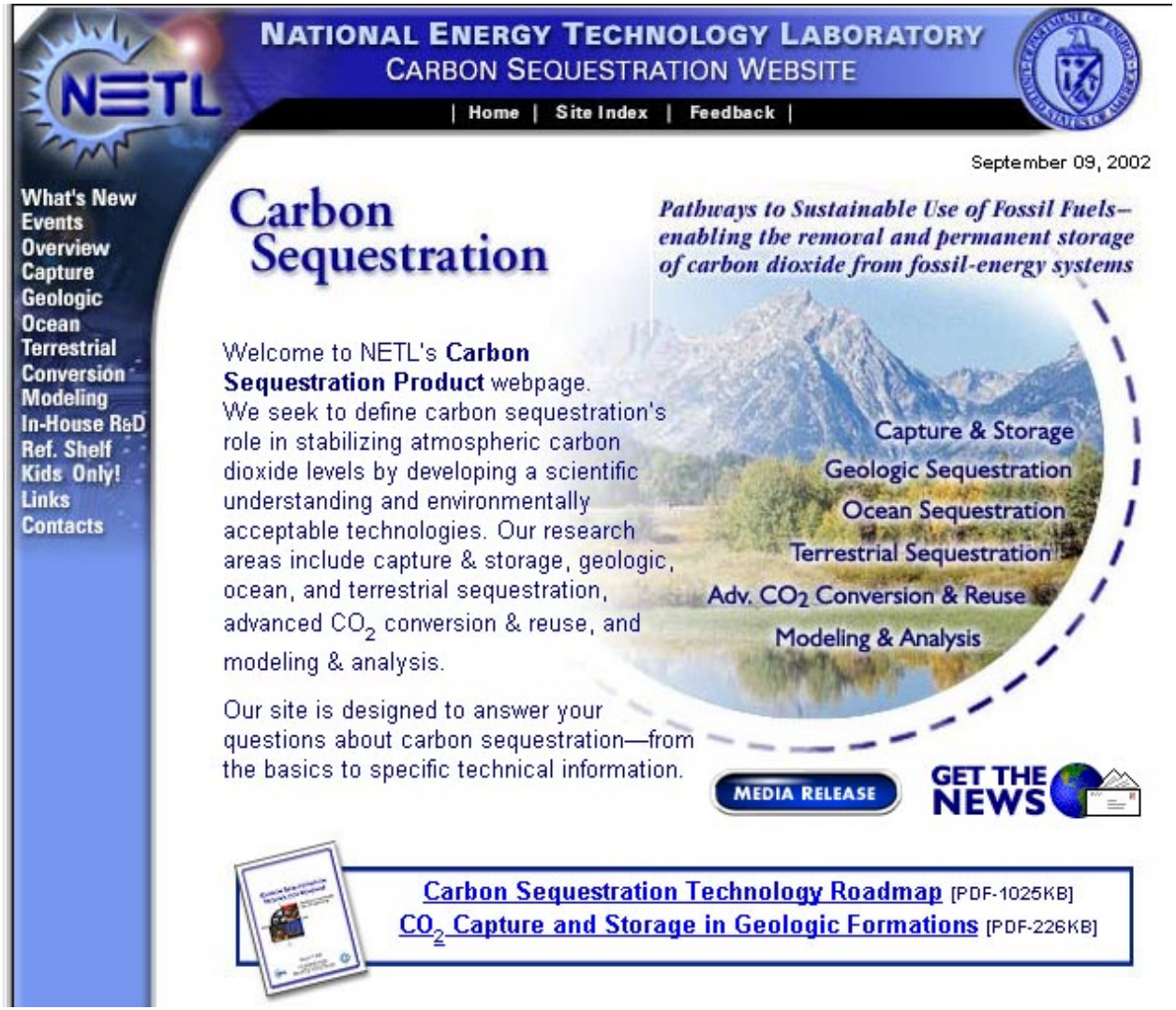

*Sources: Derived From NETL, EPRI, Alstom*

# Sequestration - Not Just About $CO_2$

## *(Near Zero Emissions Concept)*

- Sequester traditional pollutants & $CO_2$ from IGCC Energy Plants
- Sequester traditional pollutants & $CO_2$ from Pulverized Coal Power Plants
- Avoid costs, energy & complexity of controlling traditional pollutants
- Provide major cost & energy offsets for $CO_2$ capture & sequestration
- Substantially reduce footprint and complexity of plants



# Visit Our NETL Sequestration Website

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