1.0 BACKGROUND

1.1 INTRODUCTION

This Environmental Reference Document has been prepared by the United States Department of Energy (DOE) to provide an examination and review of the environmental considerations of carbon sequestration technologies that could be demonstrated or implemented under DOE's Carbon Sequestration Program. This document will help serve as a resource for DOE and its partners in determining the potential environmental aspects of future projects and will aid project proponents in site selection considerations and to institute Best Management Practices (BMPs) to avoid adverse environmental impacts. The National Energy Technology Laboratory (NETL) is a multi-purpose laboratory owned and operated by the DOE Office of Fossil Energy and is the primary DOE office implementing the Carbon Sequestration Program (hereafter referred to as "the Program"). NETL has a mission to implement a research, development, and demonstration program to resolve the environmental, supply, and reliability constraints of producing and using fossil energy resources.

In general, DOE will use this Environmental Reference Document to:

- Identify potential environmental issues and impacts associated with implementing Program technologies that should be addressed in future site-specific NEPA documents;
- Identify aspects of site-selection for future projects that must be considered (e.g., avoidance of sole-source aquifers);
- Identify general BMPs for planning, constructing and operating future projects;
- Provide an overview of general mitigation measures that could be applied to future projects.

1.2 U.S. GLOBAL CLIMATE CHANGE INITIATIVE

The U.S. Global Climate Change Initiative (GCCI) was signed on February 14, 2002, which calls for an 18 percent reduction in the carbon intensity [expressed in kilograms of carbon dioxide (CO_2) emitted per unit of economic activity] of the United States (U.S.) economy by 2012. By focusing on carbon intensity as the measure of success, this strategy promotes vital climate change R&D while minimizing the economic impact of greenhouse gas (GHG) stabilization in the U.S. Technology solutions that provide energy-based goods and services with reduced GHG emissions are the preferred approach to achieve the GCCI goal. The GCCI also calls for a progress review relative to the goals of the initiative in 2012, at which time decisions will be made about additional implementation of CO_2 reduction measures.

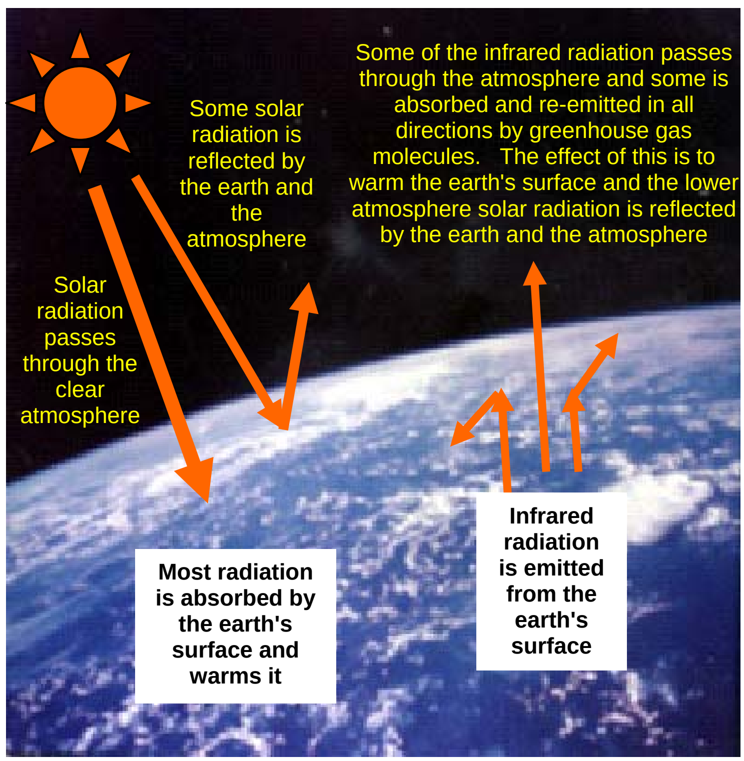


Figure 1-1. The Greenhouse Effect

The DOE established the Carbon Sequestration Program in 1997 with the focus of conducting research and development (R&D) activities to evaluate and develop carbon sequestration technologies. Carbon sequestration involves capturing and storing CO_2 emissions prior to release into the atmosphere, as well as enhancing natural carbon uptake and storage processes. CO_2, water vapor, and other gases exert a "greenhouse" effect that traps heat within the Earth's troposphere and which has, thus far, maintained the planet's temperate climate (Figure 1-1). Although CO_2 is a natural and important component of the atmosphere—animals and plants produce CO_2 during respiration, and plants need it for photosynthesis—global emissions of CO_2 from human activity have increased from an insignificant level two centuries ago to over twenty-one billion metric tons per year in 2003. The most notable human activity associated with the generation of CO_2 is the combustion of carbon-based fuels (including oil, natural gas, and coal). Many scientists, including the Intergovernmental Panel on Climate Change (IPCC), recognize a danger that even a modest increase in the Earth's temperature (called "global warming") could alter the global climate and cause significant adverse consequences for human health and welfare (NETL, 2004a).

CO_2, water vapor and other gases exert a "greenhouse" effect that traps heat within the Earth's troposphere. Strong evidence is emerging that increased GHG emissions are causing climate change impacts.

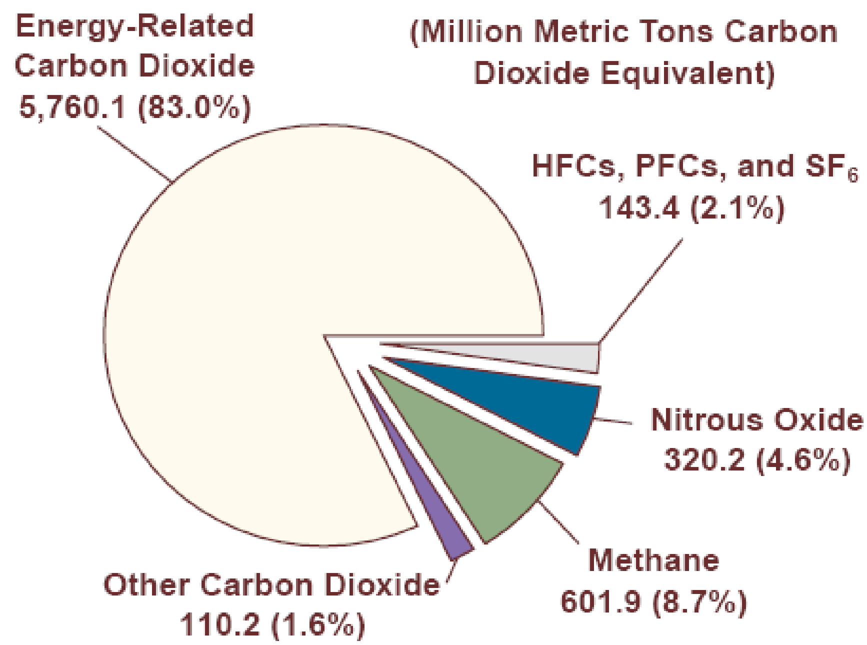
1.2.1 Current Status of Greenhouse Gas Emissions

Six gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—have been identified as the primary contributors to the greenhouse effect. The individual emissions of these gases can be multiplied by the appropriate Global Warming Potential (GWP), which is an indexed ratio used to produce a CO_2 emissions equivalent. GWPs discussed in this document are those calculated over a 100 year time horizon. Because each gas has a different warming effect (e.g., a gram of CH_4 has roughly 23 times the warming effect of a gram of CO_2), the use of the GWP allows the warming effects of the different gases to be compared on an equal basis using CO_2 as the reference gas. On this basis, three gases (CO_2, CH_4, and N_2O) comprise 98 percent of GHG emissions (Energy Information Administration (EIA), 2004), and CO_2 far surpasses other GHGs both in quantity emitted and in its relative contribution to climate change effects (Figure 1-2). Thus, CO_2 is the primary focus of mitigation efforts for GHG emissions.

The combustion of fossil fuels by all energy sectors and sources contributes to CO_2 emissions (Figure 1-3). Electric power generation represents one of the largest CO_2 emitters in the U.S. The CO_2 emissions from electricity generation by power plants burning fossil fuels in the U.S. increased by 23.5 percent between 1990 and 2000 (EIA, 2001), and nearly two fifths of human-caused CO_2 emissions in the U.S. come from these plants (EIA, 2004). The geographic distribution of CO_2 emissions from U.S. power plants in million metric tons (MMT or million metric tons) is illustrated in Figure 1-4.

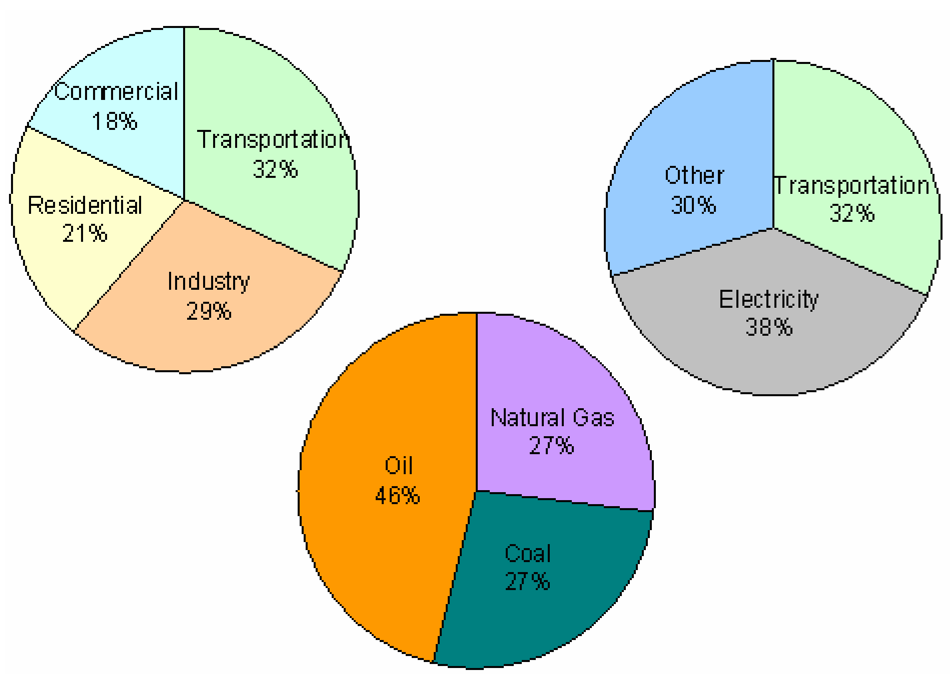
Low-cost reliable energy is one of the foundations of the U.S. economy. In 1999, the U.S. consumed 3 kilowatt-hours of energy for each dollar of economic activity, and 85 percent of that energy came from fossil fuel resources (coal, oil, and natural gas). In 2002, the U.S. generated 98 quadrillion British thermal units of energy, 86 percent of which was produced from fossil fuels. The EIA (2004) projects that U.S. consumption of coal, oil, and natural gas will increase by 40 percent over the next 20 years, while GHG emissions are projected to rise 33 percent over the same period. Because demand for electricity is expected to grow, and fossil fuels will continue to be the dominant fuel source, power generation can be expected to provide even greater contributions to GHG emissions in the future.

The Energy Information Administration (EIA) projects that U.S. consumption of coal, oil and natural gas will increase 40 percent over the next 20 years, while GHG emissions are projected to rise 33 percent over the same period.



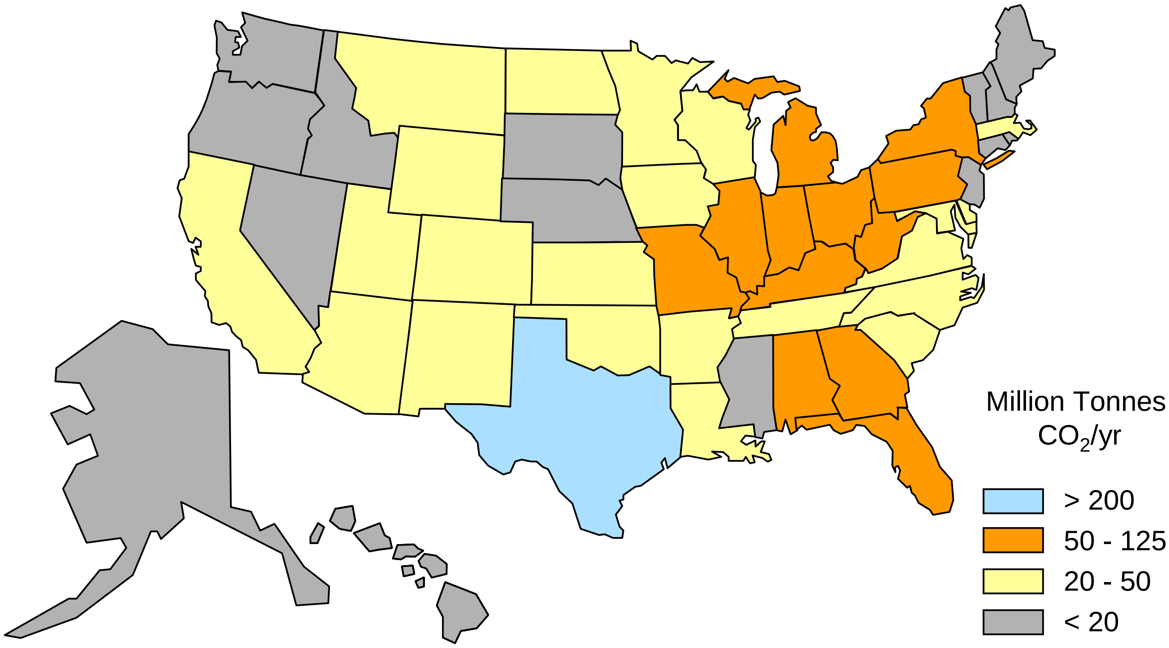
Source: EIA, 2004.

Figure 1-2. Composition of Greenhouse Gas Emissions (CO_2-Equivalent Basis)



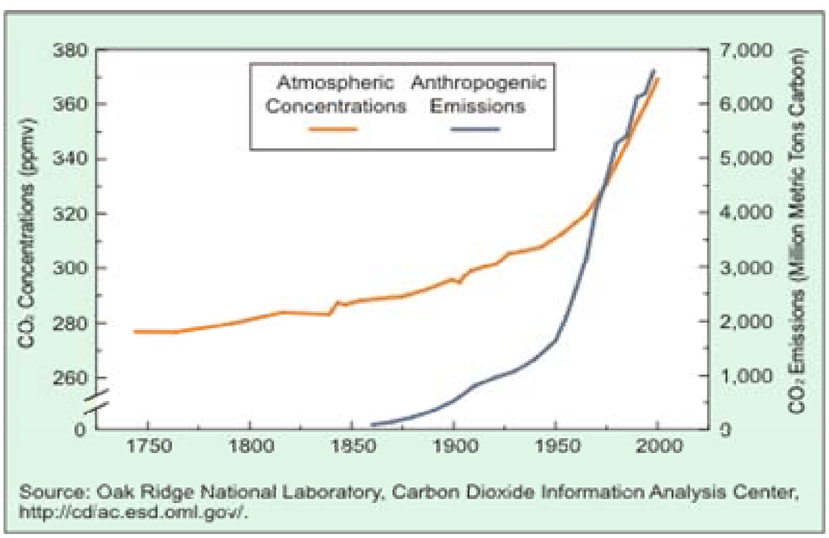
Source: EIA, 2005.

Figure 1-3. Contributions to CO_2 Emissions by Energy Sectors and Sources (2003)



Source: Utility Data Institute

Figure 1-4. Distribution of CO_2 Emissions by U.S. Power Plants



Source: ORNL, 2007.

Figure 1-5. Historical Comparison of Atmospheric CO_2 Concentrations and Anthropogenic Emissions

Strong evidence is emerging that GHG emissions are linked to potential climate-change impacts. As illustrated in Source: ORNL, 2007.

Figure 1-5, concentrations of CO_2 in the atmosphere correlate with anthropogenic emission increases over the last 150 years. Concentrations of CO_2 in the atmosphere have increased rapidly in recent decades, and the increase correlates with the rate of world industrialization, such that in the last 100 years, atmospheric CO_2 concentrations have increased from approximately 280 parts per million (ppm) to nearly 380 ppm (NETL, 2004a).

1.2.2 Future Projections of Greenhouse Gas (GHG) Emissions

Today, the atmosphere contains 33 percent more GHGs than it did prior to the industrial revolution, and the concentration is increasing steadily at a rate of more than 1 ppm per year (NETL, 2004a). It was reported in 2002 and 2003 that the annual increase was more than 2 ppm (Brown, 2004). It is generally recognized that anthropogenic GHG emissions are having a significant effect on global climate and that GHG emissions may need to be controlled to avoid future adverse impacts. Hence, in 1992 the U.S. and 160 other countries ratified the Rio Treaty, which calls for "…stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." What constitutes an appropriate level of GHG in the atmosphere remains open to debate, but even modest scenarios for stabilization would eventually require a reduction in worldwide GHG emissions of 50 to 90 percent below current levels (NETL, 2004a).

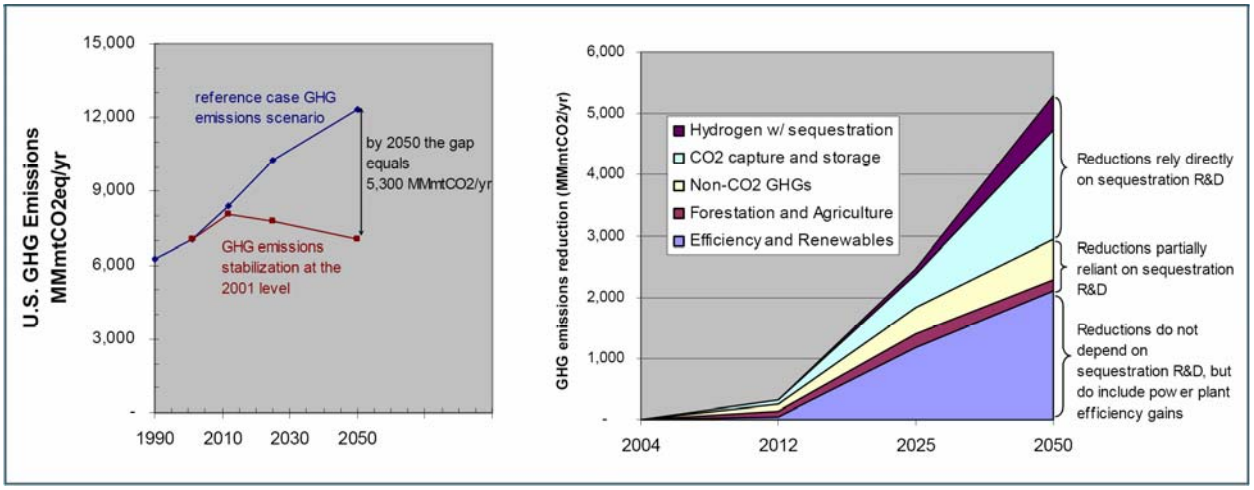
The Program has developed scenarios for domestic GHG emissions to the year 2050, which help to quantify the potential need for advanced carbon sequestration technologies that may stabilize GHG concentrations. In Figure 1-6, the upper curve in the graph on the left represents a reference-case GHG emissions scenario. It assumes significant development and implementation of technologies for low- or no-carbon fuels and improved efficiency, but it does not include direct incentives for GHG emissions reduction. The lower curve in the left graph represents an emissions-stabilization scenario. It assumes accelerated reductions in GHG intensity through 2012 with gradually reduced emissions thereafter. The goal is to stabilize emissions at the 2001 level. The required emissions reduction, which equals the gap between the two scenarios, grows to 5,300 MMT of CO_2 per year by 2050. Emissions stabilization is a first step toward atmospheric concentration stabilization. This would require emissions to be reduced by 80 to 90 percent below current levels (NETL, 2004a).

The graph in Figure 1-6 shows the contributions of various mitigation options needed to meet the gap under the emissions stabilization scenario. The DOE has estimated the contribution of each option by using an internal planning model that is based on cost/supply curves. Although "Efficiency and Renewable" sources are generally less expensive to implement and will be important components, they cannot alone meet the total reduction goals indicated by the gap. Two options, "CO_2 capture and storage" and "Hydrogen with Sequestration", are directly dependent on research conducted by the Program. Together, the two options account for 45 percent of total emissions reduction in 2050 under the emissions stabilization scenario. Two other options, "Forestation and Agriculture" and "Non-CO_2 GHGs" control, which are being pursued by the Program in concert with other public and private partners, contribute another 15 percent. Clearly, carbon sequestration technology will play a pivotal role should GHG stabilization be deemed necessary (NETL, 2004a).

By working with market growth and capital stock turnover, the stabilization strategy allows time for new technology and low-cost options to evolve. It also prevents a rapid increase in GHG emissions during the next 50 years, thus reducing the potential need for steep, economically disruptive reductions in the future. Over the next 20 to 30 years, "value-added" sequestration applications, such as enhanced oil recovery (EOR), can provide a cost-effective means for reducing CO_2 emissions and offer collateral benefits through increased domestic production of oil and natural gas. In the mid- and long-term, even more advanced CO_2 capture technology and integrated CO_2 capture, storage, and conversion systems can provide cost-effective options for deep reductions in GHG emissions. The premise of the analysis is that

> "Value-added" sequestration applications, such as enhanced oil recovery, can provide a cost-effective means for reducing CO_2 emissions and offer collateral benefits through increased domestic production of oil and natural gas.

the sequestration options would not be available without an aggressive R&D effort. Thus, the economic benefits result from a reduced cost of GHG emissions mitigation.



Source: NETL, 2004a.

Figure 1-6. Pathway to Stabilization Strategy

1.2.2.1 The Stabilization Triangle

To understand the relative degree to which carbon sequestration and other carbon mitigation approaches can contribute to solving the greenhouse gas problem, researchers with the Carbon Mitigation Initiative (CMI) developed a tool called the "stabilization triangle". Through CMI, over 60 researchers in science, engineering, and policy are developing strategies to reduce global carbon emissions safely, effectively, and affordably (CMI, 2004).

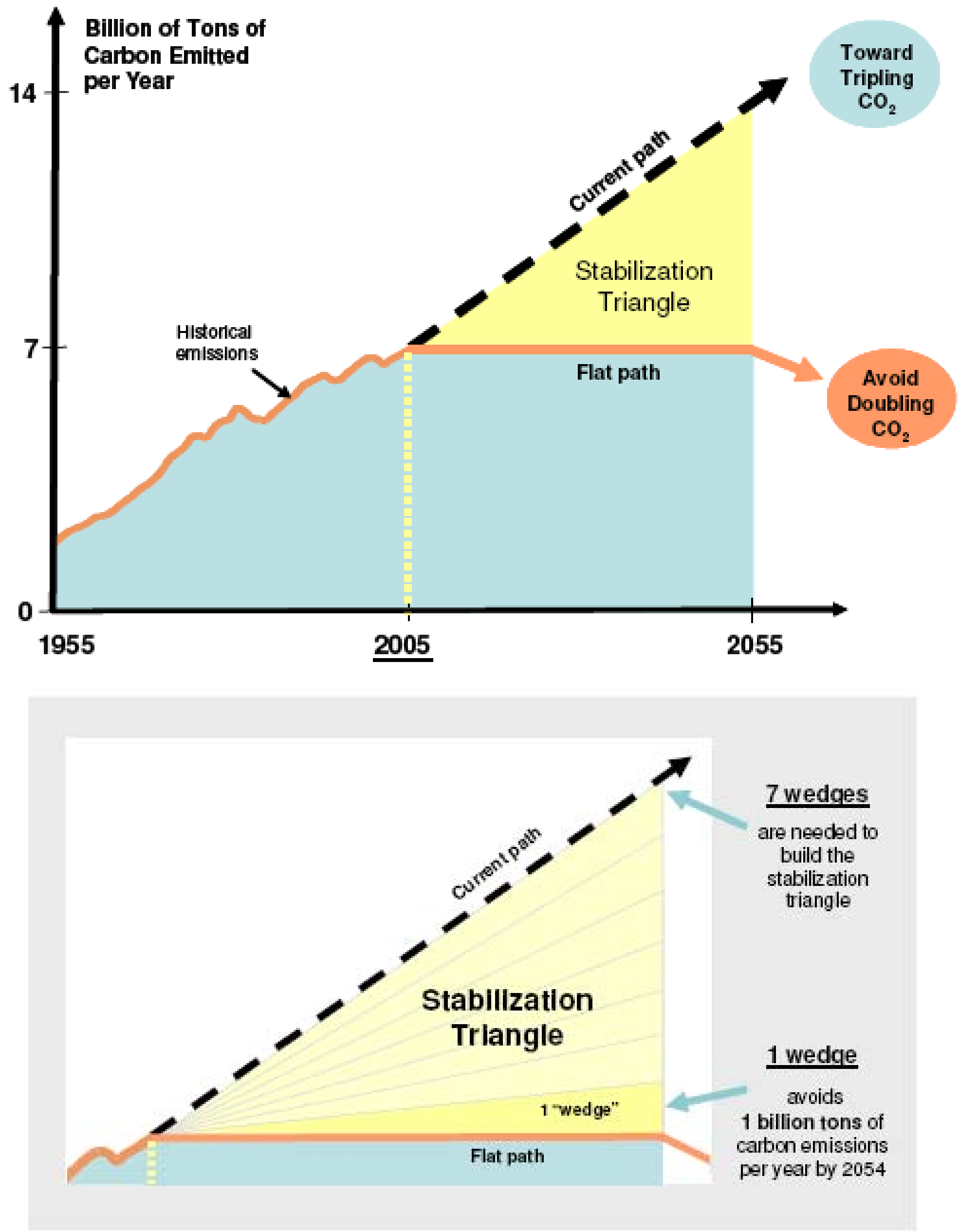
CMI predicts that to keep emissions of CO_2 flat for 50 years, CO_2 output must be reduced by approximately 7 billion tons per year by 2054. These reductions are depicted as the "stabilization triangle". Within this triangle, strategies for meeting this reduction goal are referred to as "wedges" of the triangle. If each wedge reduced carbon by at least 1 billion tons per year by 2054, seven wedges would be required to stabilize emissions (CMI, 2004) (Figure 1-7).

The CMI identified 8 strategic areas and 15 specific goals or "wedges" that could achieve this rate of carbon reduction. The 8 strategic areas are:

- Efficiency
- Fuel Switching
- Carbon Capture and Storage
- Nuclear Power
- Wind Power
- Solar Power
- Biomass Fuels
- Natural Sinks (terrestrial sequestration)

Specific goals comprising the 15 wedges are shown in Figure 1-8.

While many strategies will be needed to stabilize carbon emissions over the next few decades, this document focuses on DOE's program related to Carbon Capture and Storage and Natural Sinks. Other federal programs that focus on other GHG reduction strategies are discussed in Appendix A.



Source: CMI, 2004.

Figure 1-7. The Carbon Stabilization Triangle

Source: CMI, 2007.

Figure 1-8. Strategies to Build the Stabilization Triangle

1.3 PROGRAM OVERVIEW

The Program encompasses all areas of carbon sequestration (Figure 1-9) including the following principal components: Core R&D; Infrastructure Development; Integration; and Program Management. Summary level information on each of these components is presented in the following sections.

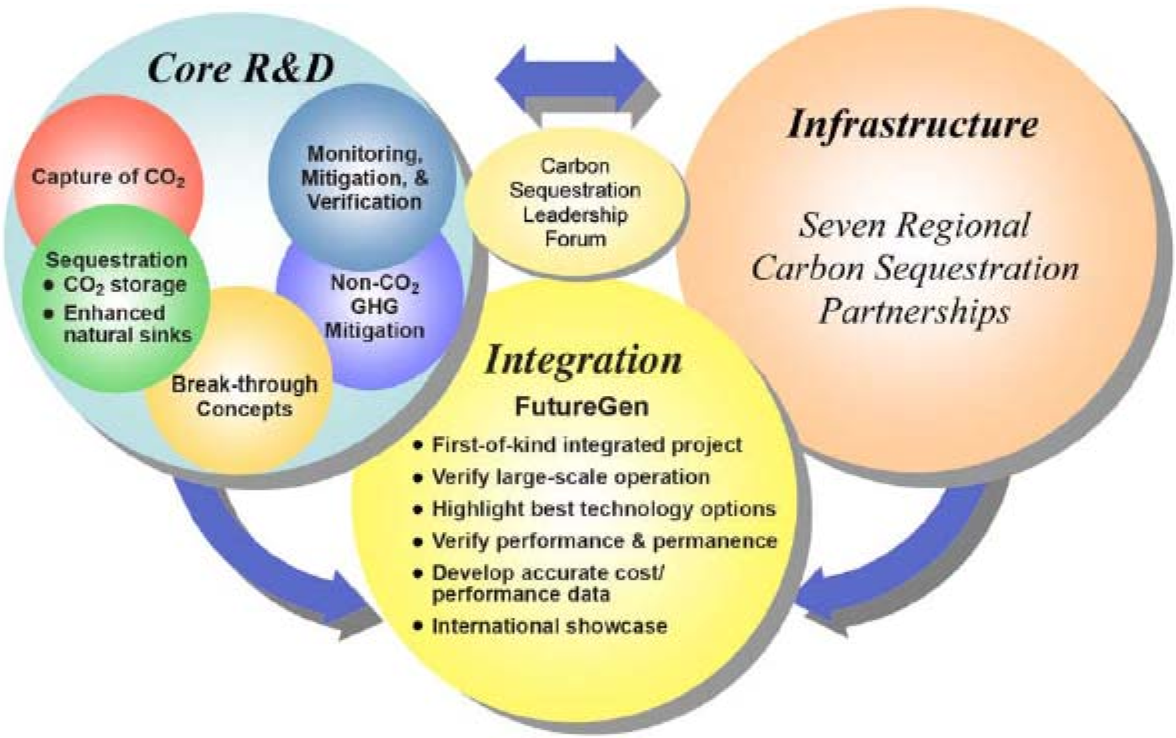


Figure 1-9. Carbon Sequestration Program Structure

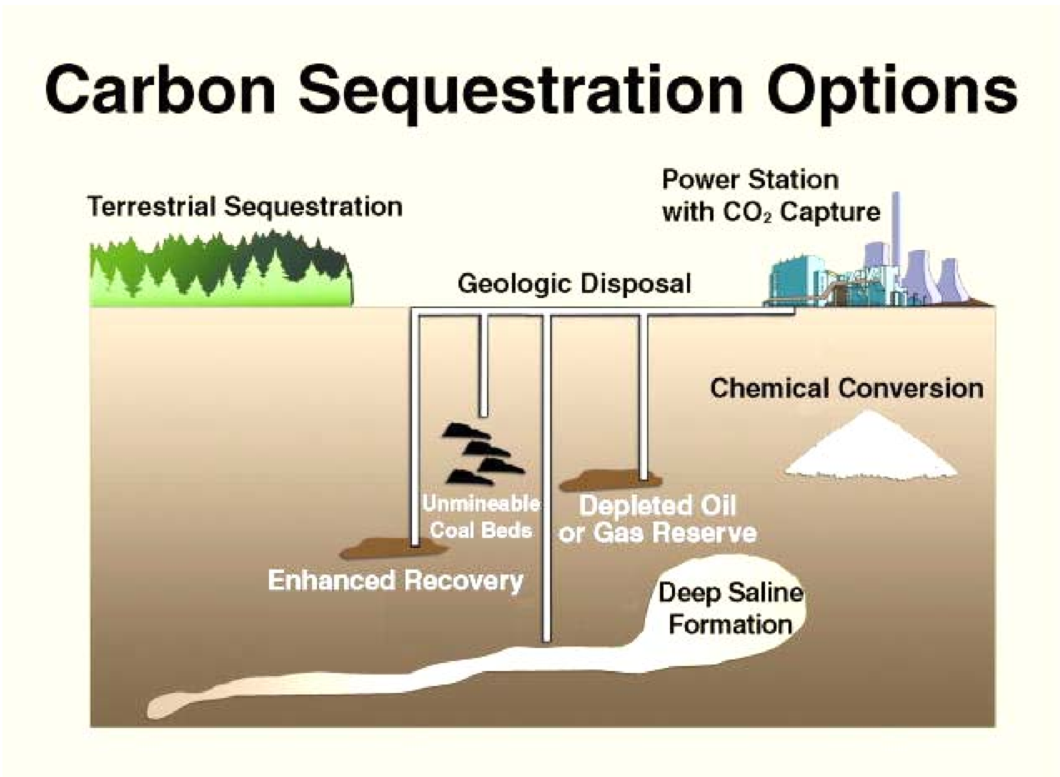
1.3.1 Core R&D

Core R&D includes the laboratory, pilot plant, and field efforts necessary to develop new technologies and new systems for GHG mitigation. As depicted in Figure 1-9, the Core R&D component of the Program consists of the following five major elements.

- CO_2 Separation and Capture – Development and demonstration of technologies to efficiently separate CO_2 from emissions sources or the atmosphere, and recovering of a concentrated stream of CO_2 that is amenable to sequestration or conversion.
- Sequestration – Development and demonstration of technologies for the placement of CO_2 into a repository so it can be stored for long periods of time (hundreds to thousands of years). The potential pathways for storage are geologic sequestration and terrestrial sequestration.
- Monitoring, Mitigation, and Verification (MM&V) – Development and demonstration of technologies to measure the amount of CO_2 stored at a specific sequestration site, monitoring the integrity of the storage site over time and mitigating against the potential for leakage. This includes verifying that the CO_2 is remaining stored as predicted and is not harming the host system or presenting risks to human health or the environment.

- Breakthrough Concepts – The pursuit of unique, revolutionary, and transformational approaches to CO_2 sequestration that offer the potential for low cost, permanence, and global capacity.
- Non-CO_2 GHG Mitigation – The pursuit of methods to reduce or avoid methane emissions by integrating abatement with energy production, conversion, and use. The U.S. Environmental Protection Agency (EPA) is the lead agency for this effort to assess the role that non-CO_2 emissions abatement can play in a nationwide strategy for reducing GHG emissions intensity. DOE's Carbon Sequestration Program will coordinate with EPA on this initiative, however, as this document focuses on carbon sequestration only, non-CO_2 GHG mitigation is not be addressed.

The Program places a strong focus on direct capture of CO_2 emissions from large-point sources with subsequent storage in geologic formations (see Figure 1-10). These large-point sources, such as power plants, oil refineries, and industrial facilities, are the foundations of the U.S. economy. Reducing net CO_2 emissions from these facilities complements efforts to reduce emissions of particulate matter, sulfur dioxide, and nitrogen oxides. It also represents a progression toward fossil fuel production, conversion, and use with little or no detrimental environmental impact. Through its core R&D efforts, the Program also has engaged federal and private sector partners that have expertise in certain technology areas such as the U.S. Department of Agriculture (USDA) and electric utilities in terrestrial sequestration, the U.S. Geologic Survey (USGS) and the oil industry in geologic sequestration, the National Academies of Science (NAS) in breakthrough concepts, the EPA and Non-Governmental Organizations (NGOs).



Source: The White House, 2006.

Figure 1-10. Primary Carbon Sequestration Options

1.3.2 Infrastructure Development – Regional Partnerships

DOE selected seven Regional Partnerships in 2003 with the goal of evaluating and pursuing opportunities for carbon sequestration deployment (see Figure 1-11). For the purposes of this reference document, the affected environment focuses on the regions defined by the Regional Partnership effort. This approach is justified by the regional diversity of carbon sequestration opportunities as well as the regional and local differences in natural resources and the potential impacts of sequestration technologies.

The Regional Partnerships include more than 300 state agencies, universities, non-governmental organizations, and private companies. Each Partnership is focused on a specific region of the country, taking into consideration the local ecosystem, the local geology, and the types of CO_2 emissions sources and sinks found in the region. Together the seven Partnerships provide a network of capability, knowledge, and infrastructure to enable carbon sequestration technology to play a major role in a national strategy to mitigate GHG emissions. These Partnerships are screening their respective regions for significant CO_2 sources and sinks, and they will establish necessary MM&V protocols. The Partnerships will support the development of infrastructure needed to validate and deploy sequestration technologies, and they will address the regulatory, environmental, and outreach issues associated with priority sequestration opportunities in the region.

> Regional Carbon Sequestration Partnerships are generally comprised of state agencies, universities, non-governmental organizations and private companies. Together, the 7 Regional Partnerships provide a network of capability, knowledge and infrastructure to further the goals of the Program.

The Partnerships that will implement carbon sequestration projects include:

- West Coast Regional Carbon Sequestration Partnership (WESTCARB)
- Big Sky Carbon Sequestration Partnership
- Southwest Regional Partnership on Carbon Sequestration
- The Plains CO_2 Reduction Partnership (PCO_2R)
- Midwest Geologic Sequestration Consortium (Illinois Basin)
- Midwest Regional Carbon Sequestration Partnership (MRCSP); and
- Southeast Regional Carbon Sequestration Partnership (SECARB)

These Partnerships were selected after a competitive process, which motivated the awardees to assemble teams of highly qualified experts and to offer an average 39 percent cost share for project implementation. The partnership approach is partitioned into three phases:

- Characterization (Phase I) – This phase was structured to be a scoping, assessment, screening, and outreach/education effort and was completed in June 2005. During this Phase, the Partnerships characterized their opportunities for sequestration, the sources in their region, infrastructure for transportation of CO_2, ad the regulatory requirements to implement future tests.
- Validation (Phase II) - The Partnerships are validating the storage opportunities identified previously through a series of field validation tests.
- Deployment (Phase III) – The Partnerships will develop large volume sequestration tests where up to 1 million metric tons of CO_2 will be stored in different geologies of North America.

More information regarding the Regional Partnerships can be found at http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html.

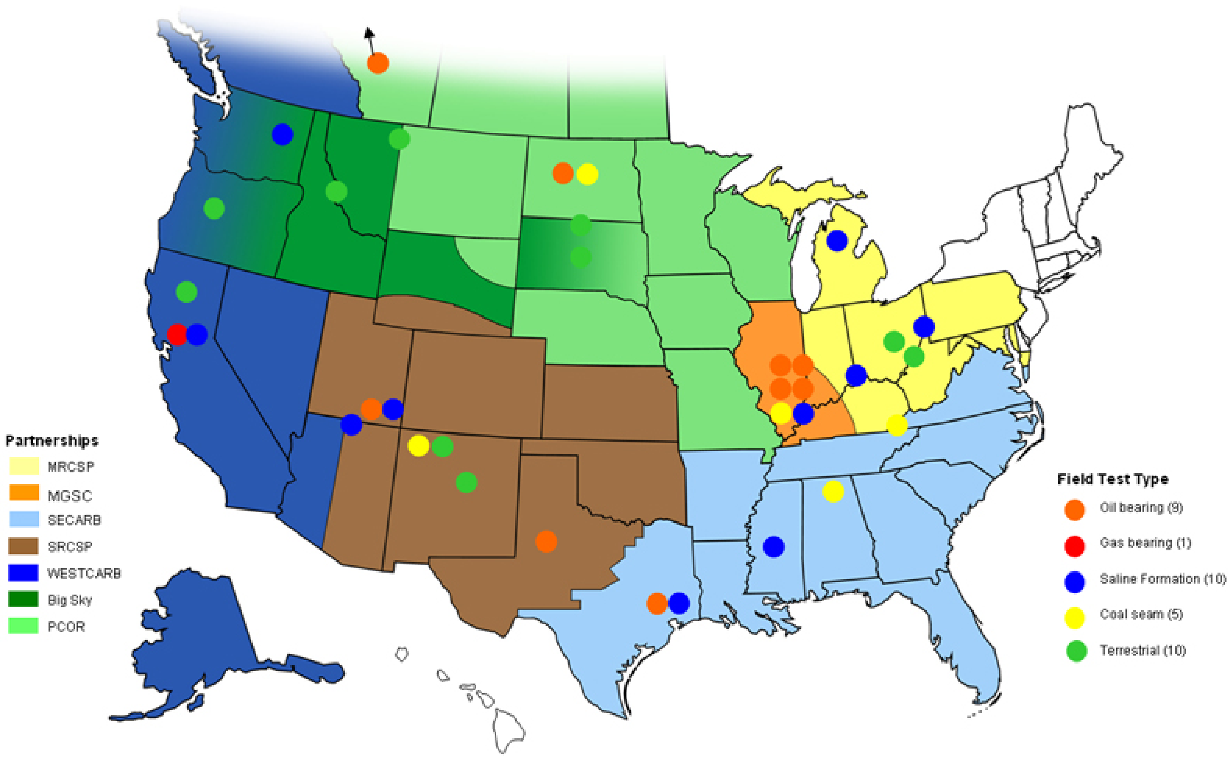


Figure 1-11. Regional Partnerships

The Partnerships are producing materials and data relating to the following information within their respective regions:

- Carbon sequestration atlases illustrating and describing the point sources of CO_2 emissions, geologic formations that have potential for CO_2 storage, and opportunities for terrestrial sequestration.
- Project implementation plans identifying the most promising terrestrial and/or geologic sequestration projects in each region.
- Action plans for regulatory compliance identifying the areas of increased understanding, sequestration technology performance metrics, MM&V capability, and risk assessment requirements needed to address and comply with environmental regulations.
- Action plans for public outreach and education setting forth methods for public engagement and tools for stakeholder education.

1.3.3 Regional Partnerships' Validation Phase Projects

The seven Regional Partnerships projects were selected by DOE in 2005 to implement field tests and validate carbon sequestration technologies that are best suited to their respective regions. They will also evaluate the most promising regional repositories for CO_2. As part of this effort, the Partnerships will also conduct public outreach, satisfy permitting requirements, and identify best-management practices for future deployment activities. The Partnerships are led by public-private sector consortiums of businesses, state agencies, and universities (DOE, 2005).

The selected Regional Partnerships and a summary of their projects follow:

- **Big Sky Regional Carbon Sequestration Partnership** will demonstrate geologic storage in mafic/basalt rock formations, which hold significant potential for long-term storage of CO_2. For example, the Big Sky region's Columbia River Basalt area could store an estimated 30 years of CO_2 emissions from all U.S. coal-fired power plants. The Partnership, headed by Montana State University, is evaluating opportunities to design cropland and forestland field test sites. The covered states include Montana, Wyoming, South Dakota, Idaho, and eastern Washington and Oregon. For more information, visit http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase2/pdf/bigsky.pdf.
- **Midwest Geological Sequestration Consortium-Illinois Basin** will determine the ability, safety, and capacity of geological formations to store CO_2 in deep coal seams, mature oil fields, deep saline formations, and organic-rich shales of the Illinois Basin. The consortium is conducting six small-scale sequestration field tests in depleted oil and gas fields, a saline formation, and unmineable coal seams to assess the ability of the formations to sequester a portion of the 276 million tons of CO_2 emitted annually from fixed sources in the Illinois Basin. The Partnership is led by the University of Illinois-Illinois State Geological Survey. For more information, visit http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase2/pdf/mgsc.pdf.
- **Midwest Regional Carbon Sequestration Partnership** is conducting at least three small-scale CO_2 injection field tests in the region's deep geologic saline formations, which have more than 200 years of storage capacity, to demonstrate the safety and effectiveness of geologic sequestration systems. The Partnership will also conduct small-scale terrestrial sequestration field tests to demonstrate measurement techniques associated with carbon storage and will monitor how carbon credits can be traded in voluntary greenhouse gas markets. Battelle Memorial Institute located in Columbus, Ohio, heads the Midwest Partnership, which covers Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia. For more information, visit http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase2/pdf/mrcsp.pdf.
- **Southeast Regional Carbon Sequestration Partnership** is defining the potential for storing CO_2 in three field sequestration validation tests in four target geologic formations. The field tests include: enhanced oil recovery and saline stacked formations, unmineable coal seams, and saline formations. The region covers Georgia, Florida, South Carolina, North Carolina, Virginia, Tennessee, Alabama, Tennessee, Mississippi, Arkansas, Louisiana, and southeast Texas. The Partnership is led by Southern States Energy Board, Norcross, Ga. For more information, visit http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase2/pdf/southeast.pdf.
- **Southwest Regional Partnership for Carbon Sequestration** is conducting five field tests (three geologic, two terrestrial) to validate the most promising carbon sequestration technologies and infrastructure concepts. The Partnership geologic sequestration tests are located in Utah, New Mexico, and Texas, as well as region-wide terrestrial analysis. The tests represent a variety of carbon sink targets, including deep saline sequestration, enhanced oil recovery and sequestration, enhanced coalbed methane production, and geologic sequestration tests combined with terrestrial tests. The Southwest Partnership includes the states of New Mexico, Oklahoma, Kansas, Colorado, Utah, and portions of Texas, Wyoming, and Arizona. The Partnership is coordinated by the New Mexico Institute of Mining and Technology. For more information, visit http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase2/pdf/southwest.pdf.
- **Plains CO_2 Reduction Partnership** is conducting four technology validation field trials and two investigations of carbon sequestration concepts. The field trials will involve storage of CO_2, comprehensive monitoring, and mitigation in depleted oil and gas formations, unmineable coal seams and restoration of wetlands. The Plains Partnership includes North Dakota, South Dakota, Minnesota, Montana, Wyoming, Nebraska, Iowa, Missouri, and Wisconsin, along with the Canadian provinces of Alberta, Saskatchewan, and Manitoba. The Partnership is led by the

Energy & Environmental Research Center at the University of North Dakota, Grand Forks. For more information, visit http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase2/pdf/pcor.pdf.

- **West Coast Regional Carbon Sequestration Partnership** will conduct two CO_2 storage tests in California and one in Arizona related to CO_2 storage in depleting gas formations and saline formations; assess the storage potential for two additional geologic formations; conduct terrestrial sequestration pilot projects in Lake County, Oregon, and Shasta County, California; and convey results through a variety of means such as public meetings, conference papers, and the web. States involved include California, Oregon, Washington, Alaska, Nevada, the western portion of Arizona, and British Columbia. The project is led by the California Energy Commission. For more information, visit http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase2/pdf/westcarb.pdf.

1.3.4 Regional Partnerships Deployment Phase Activities

The DOE is working with the Regional Partnerships to conduct large volume (between 100,000 and 1,000,000 tons per year of CO_2) sequestration tests. A large volume of CO_2 would be injected during several years of injection operations into a geologic formation which is representative of a relatively large storage capacity for the region. The amount of CO_2 injected would depend on the cost and availability of CO_2 in the region. These large volume sequestration test activities would last for 10 years and be divided into three budget periods. The following is an example of the activities that will occur during these budget periods. The duration of these budget periods may vary.

- Budget Period 1 – Site selection, characterization, NEPA compliance, permitting and infrastructure development.
- Budget Period 2 – Injection and monitoring activities.
- Budget Period 3 – Site closure, post injection monitoring and analysis.

1.3.5 Integration - FutureGen

FutureGen, the Integrated Sequestration and Hydrogen Research Initiative, is a $1 billion government/industry partnership to design, build, and operate a nearly emission-free, coal-fired electric and hydrogen production plant. The prototype plant will serve as a large-scale engineering laboratory for testing new clean power, carbon capture, and coal-to-hydrogen technologies. It is intended to be the cleanest fossil fuel-fired power plant in the world. Virtually every aspect of the prototype plant will employ cutting-edge technology. With respect to sequestration technologies, captured CO_2 will be separated from the hydrogen perhaps by novel membranes currently under development. It would then be permanently sequestered in a deep saline formation. A Draft EIS for the FutureGen Project was published in May 2007.

1.3.6 Program Goals

The principal goal of the Carbon Sequestration Program is to gain a scientific understanding of carbon sequestration options and to provide cost-effective, environmentally-sound technology options that ultimately may lead to a reduction in GHG intensity and stabilization of atmospheric concentrations of CO_2. The Program is at the forefront of the Nation's efforts to address the problem of GHG emissions and is an integral part of plans to develop large-scale fossil fuel conversion processes with near-zero GHG emissions. Overarching goals of the Program are presented in Table 1-1 with component-specific goals being presented in Table 1-2. The primary Carbon Sequestration Program Goal is to develop fossil fuel conversion systems that offer 90 percent CO_2 capture with 99 percent storage permanence at less than 10 percent increase in the cost of energy services.

Table 1-1. Overarching Program Goals

Year	Goal
2007	Identify capture technologies that increase the cost of energy services by less than 20 percent for pre-combustion systems and less than 45 percent for post-combustion systems and oxy-combustion systems.
2008	Develop Monitoring, Mitigation and Verification (MM&V) protocols that enable 95 percent of stored CO_2 to be credited as net emissions reduction.
2009	Complete validation phase of Regional Carbon Sequestration Partnership Program.
2011	Initiate at least one large-scale demonstration of CO_2 storage (1 million tons CO_2/year) in a geologic formation.
2012	Develop MM&V protocols that enable 99 percent of CO_2 to be credited as net emissions reduction.
2014	Initiate at least two slipstream tests of novel CO_2 capture technologies that offer significant cost reductions.
2015	Develop terrestrial sequestration technologies to the point of commercialization at a cost not exceeding $5/metric ton of carbon sequestered.
2016	Begin at least one demonstration in which CO_2 is stored in a saline formation and brine water from the saline formation is recovered for beneficial use.

Source: NETL, 2007.

In addition to the component-specific goals and through the Regional Partnerships, DOE established the several objectives. These objectives are consistent with the overarching goals of the Program and include initiating seven cost-share projects that were to be completed in 2004, issuing awards for Phase II technology validation (awarded 2006), and conducting numerous small-scale field validation tests to be completed between 2006 and 2013. Lastly, in the pursuit of breakthrough concepts, DOE collaborated with the National Academy of Science (NAS) in 2003, which conducted a workshop to identify R&D opportunities for breakthrough concepts advancing carbon sequestration. DOE used the results of the workshop to develop a solicitation for R&D projects that were selected by the Program. When proposals were received, a NAS committee evaluated the scientific, technical, engineering, and environmental merits of each. Through this collaborative effort, DOE established the following objectives:

- Award multiple R&D projects (completed in 2004);
- Demonstrate, potentially, 2 projects at the laboratory scale (by 2007); and
- Assess at least one GCCI technology breakthrough concept (by 2012).

Table 1-2. Component-Specific Goals

Program Component	Goals	Pathways	Metrics for Success	
			2007	**2012**
CO_2 Capture	Lower the capital cost and energy penalty associated with capturing CO_2 from large point sources.	Membranes Advanced Scrubbers CO_2 Hydrates Oxy-fuel Combustion	50% reduction in cost of avoided CO_2 emissions from power plants compared to 2002 technology (based on pilot-scale performance)	Develop at least two capture technologies that each result in less than a 10% increase in cost of energy services.
Sequestration /Storage	Improve understanding of factors affecting CO_2 storage performance and capacity in geologic formations, terrestrial ecosystems and possibly the deep oceans. Develop field practices to optimize CO_2 storage.	Hydrocarbon bearing geologic formations Saline formations Tree plantings, silvicultural practices and soil reclamation Increased ocean uptake	Field tests provide improved understanding of the factors affecting permanence and capacity in a broad range of CO_2 storage formations.	Demonstrate ability to predict CO_2 storage capacity with +/- 30% accuracy. Demonstrate enhanced CO_2 trapping at pre-commercial scale.
Monitoring, Mitigation & Verification	Develop technologies and methodologies to accurately measure the amount of CO_2 stored in terrestrial ecosystems and geologic formations. Develop the capability to address any leaks of the stored CO_2 from various repositories.	Advanced soil carbon measurement Remote sensing of above-ground CO_2 storage and leaks Detection and measurement of CO_2 in geologic formations Fate and transport models for CO_2 in geologic formations	Demonstrate advanced CO_2 measurement and detection technologies at sequestration field tests and commercial deployments.	MM&V protocols that enable 95% of stored CO_2 to be credited as net emissions reduction. MM&V represents no more than 10% of the total sequestration system cost.
Breakthrough Concepts	Develop revolutionary approaches to CO_2 capture and storage that have the potential to address the level of reductions in greenhouse gas emissions consistent with long term atmospheric stabilization.	Advanced CO_2 capture Advanced subsurface technologies Advanced geochemical sequestration Novel niches	Laboratory scale results from 1-2 of the current breakthrough concepts show promise to reach the goal of a 10% or less increase in the cost of energy, and are advanced to the pilot scale.	Technology from the program's portfolio revolutionaized the possibilities for CO_2 capture, storage, or conversion.
Non-CO_2 GHGs	Develop technologies to mitigate fugitive methane from energy systems.	Minemouth ventilation Landfill gas recovery	Effective deployment of cost-effective methane capture systems.	Commercial deployment of at least two technologies from the R&D program.
Infrastructure Development	Develop the infrastructure required for wide scale deployment of sequestration concepts that are tailored to opportunities within specific regions of the U.S. and involve citizens, companies, and governments from those areas.	Sequestration atlases Project implementation plans Regulatory compliance Outreach and education	Regional Partnerships have developed action plans and completed regional atlases. Partnerships begin pursuing action plans and validation of sequestration concepts.	Regional Partnerships start to become self-sustaining and begin to actively pursue sequestration deployments.