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Climate Change Research Analysis

An Interactive Qualifying Project Report
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By

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1. Climate
2. Technology
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Abstract

The Environmental Protection Agency (EPA) is responsible for monitoring climate change in the U.S., and setting and enforcing regulations. National Center for Environmental Research (NCER), a branch of the EPA, funds technological projects that will mitigate global warming. The aim of this project was to research the developmental status of existing climate change technologies through literature reviews and interviews. Assessing what other organizations such as the Department of Energy are funding was another vital step. Using knowledge gained from the literature review, interviews, and assessment, recommendations were made to what technologies NCER should fund to have the greatest impact based on a limited budget.

Executive Summary

Since the Industrial Revolution, humans have been emitting greenhouse gases (GHGs) into the atmosphere from various sources such as energy production and transportation. Because of these emissions, the average surface temperature of the planet is increasing, causing changes in the Earth's natural systems. GHGs warm the earth in a way similar to how greenhouses trap sunlight for heat energy. The average surface temperature of the planet has increased 1.2 to 1.4 º F since 1900 and the temperature could increase by 2.5 to 10.4 º F above the levels of 1900 by the year 2100 (UNFCCC, 2007). Observed changes to the Earth due to this temperature increase are glacial retreat and decrease in the depth of snow cover in the northern hemisphere. This temperature increase and the problems it's causing have motivated countries to implement policies to mitigate this problem.

In 1997 the Kyoto Protocol was accepted by all the members of the United Nations Framework Convention on Climate Change (UNFCCC). Today, with 175 parties who have signed, the Kyoto Protocol binds the committed countries to reducing their emissions by individual, predetermined amounts. All industrialized nations except the United States have signed the Kyoto Protocol. China and India are not considered industrialized countries by the IPCC, so they have not signed the protocol. This has caused controversy because China is on pace to exceed the U.S. in emissions.

This project was completed in collaboration with the National Center for Environmental Research (NCER), a branch of the Environmental Protection Agency's (EPA) Office of Research and Development (ORD). The objectives for this project were to first assess a broad spectrum of technologies proposed to this date to mitigate climate change, secondly to analyze the climate change technologies that have been funded by NCER's programs such as People, Prosperity, and the Planet (P3), and the Small Business Innovation Research (SBIR) program, third to analyze agencies such as the Department of Energy (DOE), Department of Transportation (DOT), and United States Department of Agriculture (USDA) to determine which climate change technologies they are working on and to what extent, and fourth to give recommendations to NCER on which climate change technologies they could fund.

To complete the assigned project, the objectives were accomplished. First, a broad range of technologies that have been proposed to reduce or eliminate greenhouse gas emissions was assessed. The second objective was to assess the status of the climate change technologies that have been promoted by the EPA through various programs such as the Small Business Innovation Research (SBIR) program, and People, Prosperity, and the Planet (P3) program. Finally, a broad scope of environmental research and funding currently being pursued in the U.S. was analyzed and presented to NCER.

A literature review was used to gain an understanding of the basic science behind climate change, policies and legislation due to climate change, and mitigation technologies. Climate change in general was researched so that the basic science behind the idea was understood, which aided in the assessment of proposed climate change technologies. Technologies were examined and categorized into GHG monitoring, efficiency and conservation, low carbon fuels, carbon capture and sequestration and renewable energy sources and biofuels. These categories were then used to create a matrix of all the technologies researched. This matrix placed the technologies into the appropriate categories and rated them on several characteristics including: where the research funding is coming from, who is conducting the research, level of development, potential sector for implementation, level of relevancy to NCER research, presence of existing NCER focus, and presence of existing DOE focus.

In addition, databases from Small Business Innovation Research (SBIR) and People, Prosperity and the Planet programs were analyzed to gain an understanding of the existing portfolio of climate change technologies within NCER. This portfolio included number of projects, funding amounts and the number of projects involving climate change technologies.

An analysis of U.S. agencies that are funding climate change technologies was completed in order to determine which technologies are being heavily researched, and which ones receive little funding. The analysis included the funding landscape of the main contributors to the Climate Change Technology Program (CCTP). This program released a strategic plan in 2006 that showed what areas of technology the major contributors worked with. A write up was completed on these major contributors that showed what areas of technology were funded and to what level. The agencies analyzed are as follows: EPA, DOE (Department of Energy), DOT (Department of Transportation), NASA (National Aeronautics and Space Administration), USAID (U.S. Agency for International Development) and USDA (U.S. Department of Agriculture). Areas of climate change technology that have received funding from government agencies were analyzed. The analysis concluded that the DOE was the only significant agency within the U.S. government funding climate change technology research. Their research included almost every technology research in the technology matrix.

Once technologies that are being funded by other agencies were identified, the technologies were analyzed. A set of criteria developed to judge technologies for NCER was created so that a proper analysis could take place. The criteria that were considered when analyzing the technology were: the level of development of the technology, the attention by other agencies and departments on this area of technology, the amount of GHG avoidance, how the technology fits into the EPA's mission and goals, and how well the technology fits in the existing NCER climate change funding profile. These criteria were chosen as the characteristics that NCER cared most about when considering which technologies to fund. How much impact NCER can have by funding climate change technologies was determined by measuring the technologies against these criteria.

A criteria matrix was devised to measure how well all the specific climate change technologies and climate change categories fit the criteria. The general climate change technology categories of GHG monitoring, efficiency and conservation, low carbon fuels, carbon capture and sequestration, and renewable energy sources and biofuels were analyzed using the criteria matrix. This analysis helped to determine which specific technologies within a category, if any, were to be discussed further. Using this analysis, six specific technologies were chosen for further discussion because of how well they met the criteria. These six technologies were: post-combustion carbon capture, pre-combustion carbon capture, oxy-combustion carbon capture, geological carbon sequestration, cellulosic energy production, and solar technology. An in depth discussion on each one of these technologies explained how the six technology areas fit the criteria.

To conclude the report recommendations were given to NCER on what climate change technologies they could fund. These recommendations were: technological and environmental effects of cellulosic energy productions, solar photovoltaics, post-combustion carbon capture, oxy-combustion carbon capture, and possible ground water contamination due to geologic carbon sequestration. It was also recommended that NCER research advanced processes and materials to enhance climate change technologies to determine if this area would be appropriate for them.

Table of Contents

Authorship Page

Sections	Primary Author(s)	Editor(s)
Abstract	Nate	Nate, Chuck, Ryan
Executive Summary	Ryan	Chuck, Nate
1. INTRODUCTION	Chuck, Nate, Ryan	Chuck, Nate, Ryan
2. BACKGROUND		
2.1 Climate Change Technologies	Nate	Chuck, Ryan
2.1.1 GHG Monitoring	Chuck	Chuck, Ryan
2.1.2 Efficiency and Conservation	Chuck, Nate, Ryan	Chuck, Nate, Ryan
2.1.3 Carbon Capture/Sequestration	Nate	Chuck, Nate
2.1.4 Low Carbon Fuels	Ryan	Ryan
2.1.5 Renewable and Biofuels	Ryan	Chuck, Nate, Ryan
3. METHODOLOGY		
Assessment of Climate Change Technology	Chuck, Ryan	Chuck, Ryan
Analysis of NCER Climate Change Technologies	Ryan	Chuck, Ryan
Analysis of U.S. Agencies and Departments Funding of Climate Change Technology Research	Chuck, Ryan	Chuck, Ryan
4. FINDINGS		
4.1 U.S. Departments and Agencies Funding Climate Change Technology	Nate	Nate
4.1.1 Climate Change Technology Program (CCTP)	Nate	Chuck, Nate, Ryan
4.1.2 Environmental Protection Agency (EPA)	Nate	Chuck, Nate, Ryan
4.1.3 Department of Energy (DOE)	Chuck	Chuck
4.1.4 National Aeronautics and Space Administration (NASA)	Chuck	Chuck
4.1.5 Department of Transportation (DOT)	Nate	Nate, Chuck, Ryan
4.1.6 United States Agency for International Development (USAID)	Ryan	Ryan
4.1.7 United States Department of Agriculture (USDA)	Ryan	Ryan
4.2 Climate Change Technologies Matrix	Chuck, Nate, Ryan	Chuck, Nate, Ryan
4.3 Projects funded by SBIR and P3	Chuck, Ryan	Chuck
5. ANALYSIS OF CLIMATE CHANGE TECHNOLOGIES		
Criteria	Ryan, Nate	Nate, Ryan
Criteria Matrix	Chuck, Nate	Chuck, Nate, Ryan
5.1 Climate Change Technology Categories	Nate	Nate, Chuck, Ryan
4.1.1 GHG Monitoring	Nate	Nate, Chuck, Ryan
4.1.2 Low Carbon Fuels	Nate	Nate, Chuck, Ryan
4.1.3 Efficiency and Conservation	Nate	Nate, Chuck, Ryan
4.1.4 Carbon Capture and Sequestration	Nate	Nate, Chuck, Ryan
4.1.5 Renewables and Biofuels	Nate	Nate, Chuck, Ryan
4.2 Specific Climate Change Technologies	Nate	Nate, Chuck, Ryan

4.2.1 Pre-Combustion Carbon Capture	Nate	Nate, Chuck, Ryan
4.2.2 Geologic Carbon Storage	Nate	Nate, Chuck, Ryan
4.2.3 Post-Combustion Carbon Capture	Nate	Nate, Chuck, Ryan
4.2.4 Cellulosic Ethanol	Ryan	Chuck, Nate, Ryan
4.2.5 Solar Energy	Chuck	Chuck
4.2.6 Oxygen-Fuel Combustion	Chuck	Chuck, Nate
6. CONCLUSION	Nate	Chuck, Nate, Ryan
7. RECOMMENDATIONS		
Cellulosic Ethanol	Ryan	Ryan
Solar Photovoltaics	Chuck	Chuck
Oxy-Fuel Combustion	Chuck	Chuck
Post-Combustion	Nate	Chuck, Nate
Advanced Materials & Processes	Nate	Nate, Chuck

List of Figures

List of Tables

List of Terms

AEI – Advanced Energy Initiative
Anthropogenic – Relating to or resulting from the influence that humans have on the natural world
Autohydrolysis – The process of breaking down a complex carbohydrate into monosaccharides by exposure to high temperature steam
CCTP – Climate Change Technology Program
CH_4 – Methane
CNG – Compressed Natural Gas
CNS – Collaborative Science & Technology Network for Sustainability
CO_2 – Carbon Dioxide
DOC – Department of Commerce
DoD – Department of Defense
DOE – Department of Energy
DOI – Department of the Interior
DOS – Department of State
DOT – Department of Transportation
EESI – Environmental and Energy Study Institute
EPA – Environmental Protection Agency
ESSP – Earth System Science Pathfinder Program
GCI – American Chemical Society Green Chemistry Institute's
GHG – Greenhouse Gas
GTSP – Global Energy Technology Strategy Program
HHS – Department of Health and Human Services
Hydrolysis – The process of breaking apart by water
ICE – Internal Combustible Engine
IEA – International Energy Agency
IGCC – Institute on Global Conflict and Cooperation
LPG – Liquefied Petroleum Gas
N_2O – Nitrous Oxide
NASA – National Aeronautics and Space Administration
NCCTI – National Climate Change Technology Initiative
NCSE – National Council for Science and the Environment
NETL – National Energy Technology Laboratory
NOAA – National Oceanic and Atmospheric Administration
NRMRL – National Risk Management Research Laboratory
NSF – National Science Foundation
OAR – Office of Air and Radiation
OCO – Orbiting Carbon Observatory
OCS – Oxygen Combustion System
ORD – Office of Research and Development
P3 – People, Prosperity, and the Planet
PPM – Parts Per Million
PV – Photovoltaic
Saccharification – The process of breaking a complex carbohydrate into monosaccharides

SAI – Solar America Initiative
SBIR – Small Business Innovation Research
Thermolysis – The process of breaking apart with heat
UNFCCC – United Nations Framework Convention on Climate Change
USAID – United States Agency for International Deployment
USDA – United States Department of Agriculture

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1. INTRODUCTION

In 1988 the World Meteorological Organization and the United Nations Environment Program began one of the first international efforts to investigate climate change. They established an international panel of scientists to examine the causes and effects of climate change. This group of scientists was the forerunner to the Intergovernmental Panel on Climate Change (IPCC). These scientists determined that the main cause of climate change is the excessive amount of greenhouse gasses (GHGs) being pumped into the atmosphere. The IPCC is now responsible for monitoring the global climate and submitting regular reports to the United Nations Framework Convention on Climate Change (UNFCCC, 2007).

Experts from many fields have documented dramatic changes in the earth's natural systems as a result of climate changes in the last 200 years. Glaciers have retreated and the extent and depth of snow cover in the northern hemisphere has declined. Snowmelt occurs earlier and the duration of ice on rivers and lakes has lessened. Because of climate change, sea ice extent and thickness have decreased. A recent article from *National Geographic News* (Sept. 17, 2007) examined the opening of the Northwest Passage due to arctic melting. There has been an observed change in growth and phenology of many plants as well. There also have been many behavioral changes in animals. For reasons such as these, there is a common understanding in the scientific community that climate change is a serious issue, that human activities are a primary cause of the changes, and that steps have to be taken to prevent or mitigate these changes.

Experts believe that humans started affecting climate change in the late 18th century because of the Industrial Revolution. The burning of fossil fuels, combined with heavy deforestation, has led to dramatic increases in the atmospheric concentration of gases, such as methane (CH_4) and carbon dioxide (CO_2). These gases are known as greenhouse gases (GHGs) because they exacerbate the normal tendency of the atmosphere to trap heat in much the same way that a greenhouse does. Since 1900, the average surface temperature of the Earth has increased by 1.2 to 1.4 º F according to both the National Aeronautics and Space Administration (NASA) and National and the National Oceanic and Atmospheric Administration (NOAA). The two warmest recorded years in the Earth's history are 1998 and 2005. According to climate models, the average surface temperature could increase by as much as 2.5 to 10.4 º F above the levels of 1900 by the year 2100 (UNFCCC, 2007)

In 1997 the member countries of the UNFCCC unanimously voted to accept the Kyoto Protocol. The Kyoto Protocol was a monumental step towards achieving global climate stability. To this day, 175 parties have signed the treaty which legally binds each of them to reduce greenhouse gas emissions to levels that are set by the Kyoto Protocol. All of the parties have a maximum 'assigned amount' of greenhouse gas emissions they can produce over a designated period. Other legal obligations imposed by the treaty include setting in place domestic policies and measures to help countries achieve their goals. While the U.S. has not ratified the protocol, due to economical and foreign policy issues, many universities and organizations have been vigorously pursuing research on climate change and possible strategies and technologies to prevent or mitigate its adverse impacts. Many of these efforts have been made possible with funding from the Environmental Protection Agency and the Department of Energy.

Industrialized countries around the world, excluding the U.S., have now adopted the Kyoto Protocol. Parts of the Kyoto Protocol dictate the amount of GHGs that industrialized countries are allowed to emit, showing that humans are taking responsibility and action for their influence on climate change. Recent legislation has been put into place in the U.S., forcing the Environmental Protection Agency (EPA) to inventory GHGs and regulate them.

Supreme Court decisions can impact the EPA's regulatory responsibilities. An example of this is when the Supreme Court decided in April, 2007, that regulation of CO_2 falls under the jurisdiction of the Clean Air Act (CAA). The EPA's role in monitoring climate change and seeking ways to eliminate its causes and mitigate its consequences has been enhanced by the Court's decision. As a result of this ruling, it is likely that EPA will pay increasing attention to climate change issues in the near future. The development of technologies to monitor and control the release of GHGs is one area of research that is likely to receive particular attention. Presently, the EPA funds a variety of extramural projects on climate change through the National Center for Environmental Research (NCER), which is within the Office of Research and Development (ORD). However, they are currently beginning to head in the direction of funding climate change technologies. It is at this critical juncture that the EPA would like an in-depth report on the comparative status of the technologies and methods being funded by NCER's research programs, as well as technologies funded and developed around the world. The EPA needs to know what climate change technologies are more likely to be “successful.” This comparative status is vital for the EPA because it will strongly influence future decisions about which climate change technologies the NCER should begin to fund in order to have the greatest impact. EPA has a relatively small budget. The issue for the agency is where to direct that budget to have maximum effectiveness. Knowing what other programs are receiving significant funding can help the agency to direct its funds in ways that will maximize the effectiveness of its limited budget.

The group had three main objectives to complete our project. First, assessment of the broad range of technologies that have been proposed to reduce or eliminate greenhouse gas emissions in areas such as GHG monitoring, power production, carbon sequestration/capture, alternative energy, and conservation while noting the economic sector these technologies affect. The second objective was to assess the status of the climate change technologies that have been promoted by the EPA through various programs like the Small Business Innovation Research (SBIR) grants, the People, Prosperity, and the Planet (P3) program, and the Collaborative Science & Technology Network for Sustainability (CNS). The last objective was to analyze the broad scope of environmental research and funding currently being pursued in the U.S. and present its findings to the EPA. To accomplish these goals, literature reviews and interviews were the primary methods used.

So that an understanding of climate change in general is obtained, a background chapter will follow this portion of the report. After the background chapter, a section discussing the spectrum of current climate change mitigation technologies is present. in the following chapter on findings, U.S. government agencies working on climate change technologies are recognized along with the technology types and amount of funding put towards this cause. An assessment of EPA climate change technologies is also presented. The next chapter discusses the level of development of various climate change technologies being pursued within the U.S., compares this to current efforts by NCER. The conclusion discusses the climate change technologies which may be appropriate for NCER funding and why they fit the requirements. Finally, the report provides recommendations to NCER as to where they should focus their funding in the future.

2. BACKGROUND

Increasing global concern over climate change has fostered the development of a myriad of technologies all over the world to combat this growing problem. It is necessary to understand the climate change technologies that are being pursued all over the world, in order to analyze the technologies researched within the EPA and identify what is appropriate from NCER funding in the future. To do this, the history of climate change, the basic science behind climate change, and many climate change technologies being developed worldwide were studied. Necessary background research also included reviewing the scientific consensus on climate change, as well as policies and legislation put into place to combat the problem. Thus, the majority of this literature review focuses on climate change technologies. Initial research revealed that several climate change technologies have been adapted to different sectors across the world's economy. For example the technologies for solar energy have the same general concept, but technologies to convert the energy harnessed from the solar panels in cars as opposed to houses are quite different. The general categories used to classify technologies are: GHG monitoring, efficiency and conservation, low carbon fuels, renewable energy sources (including biofuels), and carbon capture and sequestration/storage. Within these categories, economic sectors such as transportation, energy production and domestic energy were considered.

2.1 Basic Science

Global climate change poses a serious threat to all aspects of human life but has not been fully recognized by many countries around the world, including the U.S. The leaders of many nations who believe that humans impact climate change do not agree with immediate action. Those who question the importance of climate change maintain that the increase of Earth's temperature is merely a reoccurring phase in the Earth's life cycle. The climate of the Earth has changed many times since the planet was forged; they argue (*A Skeptics Guide*, Sen. Inhofe, 2006). These changes were caused from various occurrences such as volcanic eruptions or the changes in the Earth's orbit. While this may be a valid argument, the scientific community has almost unanimously come to believe that humans have contributed to this growing problem of a changing climate. The scientific community supports the theory that, since the Industrial Revolution, humans have greatly affected the climate of the Earth. At the beginning of the 19th century the world saw the birth of the Industrial Revolution. But it wasn't until the 20th century that we began to see large amounts of CO_2 emitted into the atmosphere (See Figure 2.1). Carbon dioxide is the most abundant GHG to date and will continue to be viewed as the most important. Since the 20^{th} century, mostly because of the combustion of fossil fuels, humans have been continually releasing CO_2 and other harmful gases into the atmosphere, thus causing the GHGs to build up over time. Within the past few decades it has been brought to light that this build up is most likely changing Earth's atmosphere and there are data accumulating in the field that support this idea (EPA, 2007E).

2.1.1 Greenhouse Gasses

The heat trapping gases that have been accumulating in the planet's atmosphere since the 19^{th} century are referred to as greenhouse gases (GHGs) because they trap heat in a way that is similar to the way in which a greenhouse traps heat from the sunlight that enters. Because of these greenhouse gases, the planet's average surface temperature has increased by 1.2 to 1.4 °F since 1900 (EPA, 2007E). If this trend continues, climate models predict that world temperature will rise 2.5 to 10.4 °F above the 1900 average by the end of the 21^{st} century (EPA, 2007E). The accumulation of GHGs affects not only the temperature: GHGs also affect rainfall patterns, snow and ice cover, as well as sea levels. Since the problem of climate change has been defined, the human sources responsible must be highlighted.

Three quarters of the GHGs produced in the U.S. come from energy related processes. Stationary sources such as power plants account for more than half of the energy-related GHGs and transportation accounts for about a third, according to the EPA. Figure 2.1 shows the relationship between the rise of CO_2 and the global temperature. It shows that the rise in CO_2 concentrations in the 1900s is directly associated with (and arguably a major cause of) global temperature increases (EPA, 2007E).

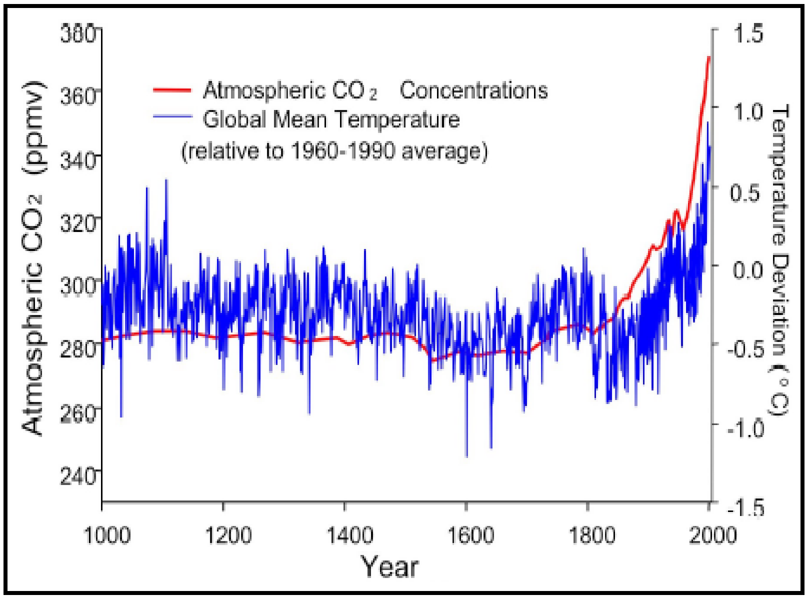

Figure 2.1: Atmospheric Concentrations of CO2 and Global Mean Temperature over Time

Source: Uncertainty estimates in regional, Brohan, 2005

One of the most famous climate graphs has to be the Mauna Loa atmospheric concentrations of CO_2 chart. In this graph, the level of CO_2 in the atmosphere (in parts per million) is plotted over a span of almost 40 years. The data gathered for the Mauna Loa graph is gathered at the atmospheric baseline station at the remote location of the Mauna Loa volcano, in Hawaii, so the gathered data is unaffected by local disturbances. Those who support the global warming theory and non-believers both agree on one thing: the CO_2 level in the atmosphere is rising and something needs to be done about it. The Mauna Loa graph (Figure 2.2) shows this increase.

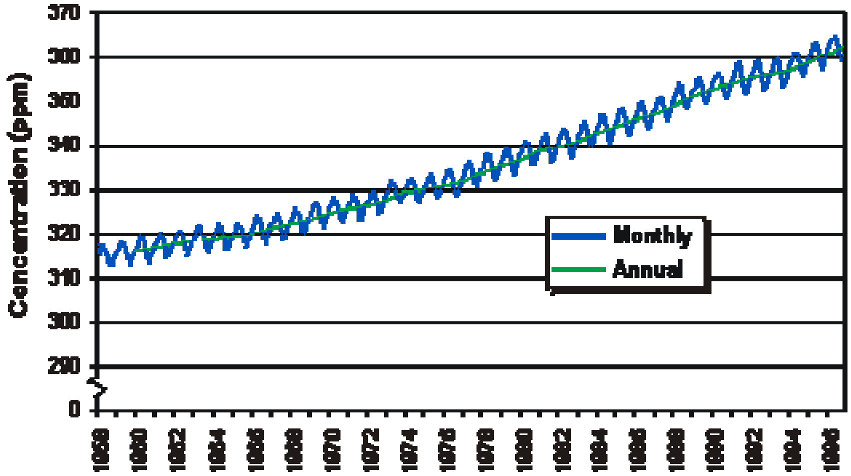

Figure 2.2: CO_2 Levels measured at Mauna Loa over 40 years

Source: Office of Oceanic and Atmospheric Research, 2007

While some GHGs occur in the atmosphere naturally, this is not true for all such gases. The major GHGs that enter the atmosphere due to human activity are CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. The focus of climate change technologies has been CO_2 because it is the most abundant GHG, although it is not the most potent. Carbon dioxide is produced in a number of ways. One way to make CO_2 is by burning fossil fuels, solid waste, or trees and wood products. The main sources of CH_4 are from agriculture, landfills, coal mining and oil and natural gas systems. Methane is 23 times more effective than CO_2 at trapping heat in the atmosphere and CH_4 concentrations in the atmosphere have more than doubled over the past 200 years, largely because of human activity. Much effort has been put into capturing CH_4 because it can be used as a clean burning fuel. The combustion of fossil fuels and solid waste, combined with industrial and agricultural processes, account for much of the release of N_2O as well. Fluorinated gases, such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, do not occur naturally and are produced by various industrial processes. Fluorinated gases normally don't occur in the atmosphere as much as the previous three; however they are extremely potent and influential to global climate change (EPA, 2007E).

In order to keep tabs on GHGs, inventories such as the one taken at Mauna Loa are created. Since the 1990s the U.S. has been tracking the trends of emissions and removals via the U.S. Greenhouse Gas Inventory. These tools were used when researching technologies like mitigation and sequestration. Projections for emissions and removals are created by various universities and the EPA (EPA, 2007E). When making these projections, many assumptions about human behavior and continued trends in society are made. When determining what gases need to be limited, we consider these projections and inventories to help decide which technologies will mitigate the specific gases causing the most harm. From background research, it is apparent that CO_2 mitigation needs to be the focus for new technologies.

Climate change not only affects humans; plants and animals are also affected by a changing climate. Some of the observed effects of the changing climate are the rising sea levels, trees blooming earlier, the growing season lengthening, the thawing of permafrost, glacial shrinking, the animal and plant distribution changes, and the ice on rivers and lakes freezing later and breaking up earlier. One key concern for scientists is how our planet will cope with all these changes from human activity (EPA, 2007B).

2.1.2 Policies and Legislation

According to a 2006 Zogby poll (a famous website like Gallup that use phone polls to track public opinion), around 70% of Americans believe that global warming is happening and 70% of those people believe global warming is affecting extreme weather conditions (intense hurricanes, droughts, heat waves) (Zogby, 2007). A poll on 9/26/07 from the World Public Opinion by the BBC World Service poll reported that 79% of 22,000 people in 21 different l climate change." (BBC World Service Poll, September 2007) The general consensus on climate change is important because legislation to counter climate change will not pass unless a sufficient percentage of the general population has come to believe in the seriousness of the issue.

Global Policy

Global climate change policy has made tremendous progress in the 21st century. It has influenced, and will continue to influence, the evolution of technologies. The end of the 20th century saw concentrations of CO_2 in the atmosphere hit all-time highs. This heightened climate change awareness around the world and stimulated the United Nations (UN) to take serious action. The United Nations Framework Convention on Climate Change (UNFCCC) was a treaty signed in 1994 and put into force in 1997. Its aim was "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system." (UNFCCC, 2007) The three goals the convention set for governments that signed the treaty are as follows:

- Gather and share information on GHG emissions and national policies
- Launch national strategies for addressing GHG emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries
- Cooperate in preparing for adaptation to the impacts of climate change.

(UNFCCC, 2007)

The Kyoto Protocol, an update to the UNFCCC proposed in 1997 just three years after the convention was started, is the most significant milestone in climate change policy history. Since its adoption, 175 countries have ratified. The protocol basically sets emissions standards of at least a 5% reduction from emissions in 1990. This 5% reduction is supposed to occur between 1990 and 2008/2012. The European Union, along with 36 other parties, have gone beyond Kyoto and set lower emissions standards for themselves. Twenty countries have not expressed their position. The United States has signed onto the UNFCCC, but announced they will not ratify the Kyoto Protocol.

National Policy

The Unites States has not signed the Kyoto protocol because of what Bush administration officials cite as a negative impact on the American economy. The U.S. agrees that regulations need to be adjusted to include developing countries like Russia and China in order for them to sign. The U.S. argues that it should not have to share the same restrictions with developing countries because of how difficult it would be to cut emissions. However, it’s not as if the U.S. does not want to research climate change. President Bush has also stated that the U.S. is “spending $20 billion to understand better the science behind climate change and to develop technologies that will enable the United States to diversify its energy source and move away from the use of fossil fuels.” (USINFO, 2005 ¶ 4). It’s apparent that the United States would like to have alternatives to coal for energy production, but the current administration doesn’t want to be tied down to having to reduce emissions by at least 5%.

The Group of Eight (Industrialized Nations) (G8) is another major worldwide organization comprised of Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States. These major industrialized countries account for approximately two-thirds of the world's economic output and consequently are responsible for most of the GHGs in the atmosphere today. They meet annually to discuss major economic and political issues such as global warming. This is a vehicle that can be used by the U.S. to influence world policy unlike the United Nations where they have little say over the Kyoto Protocol.

Over the last decade the U.S. has been rarely involved in international relations concerning climate change (Kyoto Protocol) starting with the Clinton Administration and continuing with the Bush Administration. During this last year however, perhaps in response to frequent public criticism, President Bush has begun to move the U.S. towards becoming an environmentally conscious nation. The U.S., along with many other nations, has been hesitant to give concrete figures and timelines for emission reductions. Table 2.1 outlines a few U.S. and global events important to climate change history.

Table 2.1: Major Climate Change Policies

Date	Event	U.S. or Global Action	Description
1970	**Clean Air Act passed by the U.S. congress**	U.S.	Congress passes the bill to start air pollution control in America.
1994	**UNFCCC is formed**	Global	The treaty is put into force legally binding all groups that signed it 2 years prior.
December 1997	**UNFCCC discusses Kyoto**	Global	The third global conference of climate change the Kyoto Protocol was ratified. Parties who accept are legally bound to limit or reduce their greenhouse gas emissions. Marks a major international step towards climate stability.
16 February 2005	**The Kyoto Protocol enters into force**	Global	World Wildlife Fund (WWF) calls the entry-into-force of the Kyoto Protocol the 'First of ten steps' towards a CO_2-neutral energy future. Ratified by 140 nations.
December 2005	**The first Meeting of the Parties of the Kyoto Protocol**	Global	At this first meeting of the Parties to the Kyoto Protocol, and the 11th meeting of the UNFCCC, a clear signal was sent to the world that the Kyoto Protocol will continue and that carbon markets will be at the centre of multi-lateral efforts for many years to come.
April 2007	**EPA v. Massachusetts**	U.S.	CO_2 and other Green House Gases added to the Clean Air Act to be regulated by the EPA.
8 June 2007	**G8 Summit in Heiligendamm**	Global/ U.S.	The first time G8 countries agree on the need to establish common goals for the reduction of greenhouse gases. They also agreed climate protection should lead into a UN process.

While the U.S. has not yet ratified the Kyoto Protocol, President Bush has said that, by the end of next year (2008), the U.S. and other nations plan to agree on long-term global goals for reducing greenhouse gases. He spoke briefly in August of 2007 of his plan to convene the top fifteen countries that are responsible for the bulk of the GHGs with hopes of striking a deal by next year. Leaders around the world are pleased to see the U.S. finally expressing concern for global climate change. Some critics, however, see this move as a step around the Kyoto Treaty that will only slow down the UN process. Under the Bush Administration, the U.S. has set a goal to reduce overall emissions in the U.S. by 7% from 1990 to 2008/2012, according to the UNFCCC website. However, the U.S. has still shown only mixed interest in the global fight against climate change (UNFCCC, 2007).

The most recent major policy involving the EPA was determined by the Supreme Court in April, 2007. This major policy decision was delivered in Massachusetts v. Environmental Protection Agency (Supreme Court U.S., 2007). The Bush administration has supported the development of new technologies and will partake in voluntary reductions of GHGs to mitigate GHGs. Nevertheless, these steps were not enough for certain environmental groups (Green Peace, Environmental Defense Fund and Sierra Club) and they filed a petition with the EPA. This petition stated that greenhouse gases such as CO_2 should be considered air pollutants, and therefore regulated under the Clean Air Act. Section 202 of the Clean Air Act says the federal government must regulate any air pollutant that can be reasonably anticipated to endanger public health or welfare. The EPA denied the petition, arguing that they do not have the authority to regulate GHGs. This denial influenced twelve states, including Massachusetts, to join the environmental groups and file suit against the EPA. The case went to the D.C. Circuit Court of Appeals and they sided with the EPA. The states and environmental groups appealed and the case was taken to the Supreme Court. The Supreme Court decided that the EPA should regulate GHGs under the Clean Air Act. The ruling of Massachusetts v. Environmental Protection Agency required the EPA, under the Clean Air Act, to regulate CO_2 and other gases from new motor vehicles in order to control pollutants believed to contribute to global warming. This undoubtedly will cause the EPA to concentrate the projects they fund towards reduction of emissions from new motor vehicles and stationary sources such as power plants. The shift in the goals of the EPA will play a major role in the types of technologies that this report will evaluate.

2.2 Climate Change Technologies

Many climate change technologies have been developed and put into use throughout the world. Due to policies such as the Clean Air Act and regulations set by states, GHG emissions are becoming more and more controlled in the United States. The policies being made influence the climate change technologies funded by the EPA and by other organizations. In order to evaluate the technologies being employed around the world, our group categorized these technologies. This helped to put the technologies into a specific category when analyzing projects. Being familiar with many technologies in these categories will make it easier to compare them, and get advice as to which ones the EPA should fund. There are various categories of technologies, and these different technologies can fall under different economic sectors. The categories our group has developed are GHG monitoring, efficiency and conservation, low carbon fuels, renewable and biofuels, and carbon capture and sequestration/storage. The three main economic sectors that these categories fall under are transportation, domestic heating, and energy production. The technologies in each category do not have to fall under one specific economic sector however. Renewable energy such as solar power could fall under all three of these economic sectors.

2.2.1 GHG Monitoring

GHG monitoring technologies are important in order to monitor the composition of the atmosphere, but are not essential when the EPA inventories (categorically highlights GHG sources) the GHGs in the U.S. The inventories are produced using mathematical formulas. GHG monitoring technologies can measure specific amounts of GHGs but cannot determine their sources. This is why the EPA mathematically calculates the GHGs produced by the U.S. by looking at the consumption of GHG emitting sources from fossil fuels to livestock. The consumption is broken down into economic sectors to help identify major contributors to GHG emissions. GHG monitoring technologies can be used to measure concentrations of GHGs in specific areas. Using these data, scientists can pick out patterns for human activities and natural occurring emitters of GHGs and predict future climate changes.

GHG monitoring technologies can be positioned on planes, on satellites in outer space, on the ground and under water. The goal of these technologies is to monitor "CO_2, CH_4, NO_2, HFCs, PFCs, SF_6, O_3, ozone precursors, and aerosols and black carbon." (CCTP, 2006) Remote sensing devices can be mounted on satellite or aircraft and are capable of measuring column amounts of CO_2 over a sampled area. This approach is considered to be an effective low-cost method for providing instant measurements. These devices, however, are still in their infancy and a higher level of accuracy is required before using the data.

Satellite Monitoring

NASA is currently funding the Orbiting Carbon Observatory (OCO) program through the Earth System Science Pathfinder Program (ESSP). They are working on an instrument that can be adapted to a satellite or airplane that will "provide global maps of atmospheric CO_2

concentrations with sufficient accuracy to identify sources and sinks of this gas over the entire globe." (ViPAC, 2006 p.3) The technology they propose is called the Greenhouse Gas Monitor (GGM). This technology needs to first be developed to monitor CO_2 from an airplane, then eventually from space.

Field Monitoring

There is also a field instrument called the Laser Induced Breakdown Spectroscope (LIBS), which is about the size of a briefcase. This instrument can analyze the chemical composition of the soil. According to the U.S. Climate Change Technology Program, this is a breakthrough for carbon monitoring that will reduce the cost of taking soil carbon measurements by a factor of 100. The U.S. Climate Change Technology Program website argues that this will help tremendously with terrestrial sequestration projects through testing and by allowing scientists to take measurements virtually anywhere. This is a promising technology with no apparent disadvantages. Notable organizations involved with this technology are the United States Department of Agriculture (USDA), the National Energy Technology Laboratory (NETL), and NASA. Research underway at Kansas State University is expected to help the LIBS commercialize rapidly (U.S. Climate Change Technology Program, December 2007).

Tower Monitoring

Stationary technologies include GHG monitoring towers. This is a relatively new idea, with many towers built within the last 5 years. It is rare to see these being used domestically or commercially. Towers run by the DOE are set up around the U.S. AmeriFlux towers (GHG monitoring towers in the U.S.) are part of a "network of regional networks" (FLUXNET) which coordinates regional and global analysis of observations from micrometeorological tower sites (AmeriFlux, 2007). There are 75 relatively new AmeriFlux sites across the U.S that use infrared technologies to monitor GHGs. The DOE carries out this monitoring with the support of National Science Foundation (NSF), U.S. Geological Survey (USGS), NASA, NOAA and USDA. This technology is also being used in Canada, Europe and Asia to better understand the terrestrial carbon cycle. The terrestrial cycle involves looking at the carbon stored in trees and plants and is important for scientists to understand. The U.S. Climate Change Technology Program (U.S. CCTP) describes the towers being used for "collecting, synthesizing, and disseminating long-term measurements of CO_2 and water for a variety of terrestrial landscapes across the United States" (*Enhancing Capabilities to Measure*, 2006). Figure 2.3 is an example of a GHG monitoring tower and shows some of the different technologies it uses. The myriad of technologies is required to completely understand the terrestrial cycle. Not all of these are important to understanding climate change. The infrared gas analyzer is used to take CO_2 concentrations (AmeriFlux, 2007).

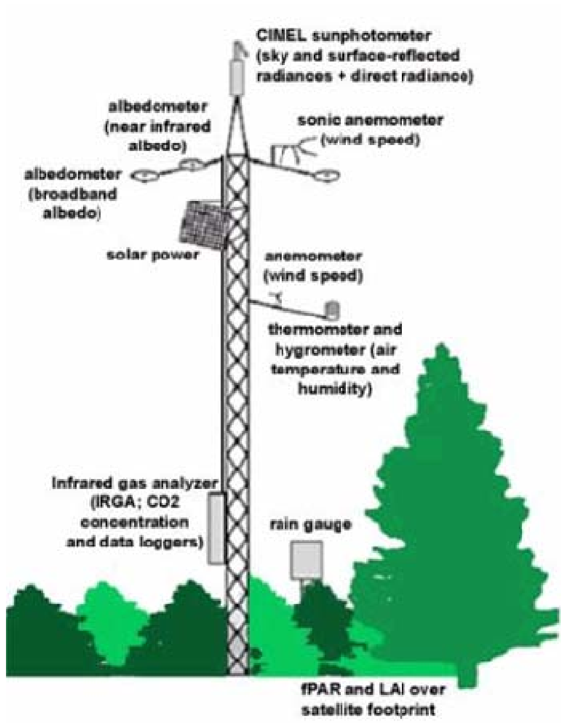

Figure 2.3: Ameriflux Tower

Source: NTSG, College of Forestry and Conservation Missoula

2.2.2 Efficiency and Conservation

One way to mitigate global climate change is through improving the efficiency of existing technologies and practicing conservation. Before the problem of worldwide energy is solved, efficient and conservative technologies and methods can be used to curb emissions. The two areas discussed below, transportation and power production contribute to about 2/3 of all emissions in the U.S.

Power Generation

Reducing CO_2 emissions from power plants is a vital element in the overall goal of mitigating global climate change. The focus of CO_2 reduction from power plants is aimed at power plants which use coal to operate. This is because coal is the main fossil fuel used to generate electricity, and it is also the leading producer of CO_2 emissions.

A technique that is applied to reduce the CO_2 emissions from power plants is creating technologies that are more efficient, and emit less CO_2. One of the leading advances of these technologies is the combined cycle gas turbine. The combined cycle gas turbine is described as "…the most dynamic development in power generation of the past 30 years" (Jim Watson, p. 2). The combined cycle gas turbine improves gas turbine efficiency by utilizing more than one thermodynamic cycle. A gas turbine is used to create electricity and the excess heat from this process is converted into steam that will produce electricity using a steam turbine. More of the energy from the fuel is used to generate electricity, making the combined turbine more efficient and thus saving fuel. "Replacing one of the UK's coal-fired power plants with a new CCGT unit brings a cut in CO_2 emissions of almost two thirds." (Jim Watson, p. 2). CCGTs have been around for over 30 years and are being used in most coal fired power plants around the world. CCGTs are pretty efficient as it is and it would take more money and research to make them better, and they would still emit large amounts of CO_2. Capturing and sequestering carbon is a better method to mitigate CO_2 since it can be combined with CCGT plants and it prevents large amounts of CO_2 from ever entering the atmosphere.

Transportation

Heavy emphasis has been placed on reducing emissions caused by automobiles. Transportation technologies related to emissions reduction and improved efficiency has taken part in the research and development supported by the EPA. These technologies will be an important area to consider when attempting to forecast the potential success of emerging technologies. The transportation sector currently accounts for approximately 1/3 of U.S. CO_2 emissions. Furthermore, half of the total emissions from the passenger fleet, worldwide, may be generated from 10% or less of the operating vehicles. A recent report from the OECD predicts that the total motor vehicle stock in developed countries will increase from 552 million vehicles in 1998 to approximately 730 million vehicles in 2020, a total growth of 32% (Geffen, Dooley and Kim, 2007). This constant growth in transportation demand has negated most gains in fuel efficiency, causing the transportation sector to continually produce more emissions annually. In order to combat the GHGs produced by transportation, improved technologies to increase efficiency and development of vehicles using alternative fuel sources are necessary.

Popular technologies that are penetrating the transportation market are hybrid, electric, and fuel cell cars. These appear to be the best solutions to the world's transportation pollution problem. Still, these types of vehicles are expensive and have many hurdles to jump before widespread adoption. Hybrid cars are a temporary replacement, said to only slightly mitigate GHG emissions. Hybrid cars use a combination of gasoline and electricity as the sources of energy. The cars can also create additional energy through regenerative braking processes. The vehicles can sometimes be attached to a power source to charge while not in use. This technology is only successful at reducing emissions directly from the vehicle. Hybrid cars also place a greater demand on the power plants from the increase in electricity usage. Therefore the power plants must work on technologies to reduce the large amount of CO_2 being released. The same can be said about electric vehicles. Fuel cell vehicles harness the electric energy produced by a special fuel cell system in the vehicle. More details on the science of fuel cells are discussed later in this report.

The largest obstacle to overcome in reducing GHG emissions is finding a feasible alternative to fossil fuels. Fossil fuels are the energy source for virtually all transportation. Unfortunately two of the byproducts of fossil fuel combustion happen to be two of the most abundant GHGs (CO_2, CH_4). Alternative sources to fossil fuels have been the focus for federal organizations such as the Department of Energy (DOE) and the EPA in their research programs. Some of the alternatives proposed are ethanol, biodiesel and hydrogen which will all be discussed in greater detail in the biofuels sections.

Some of the other technologies proposed in order to reduce emissions from transportation deal with maximizing the efficiency of vehicles. Figure 2.4 shows the energy losses throughout an average car. Arrows in the blue show the percentage of energy lost through different processes in a car.

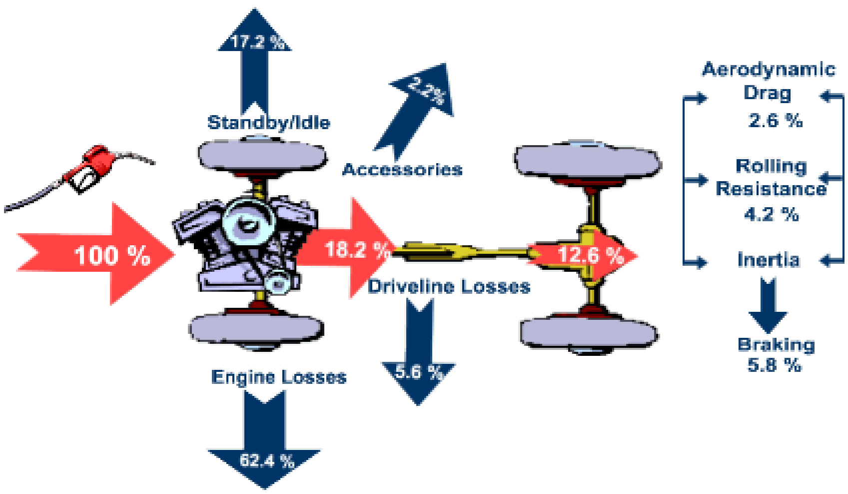

Figure 2.4: Energy Loss and Use in a Car

Source: Fuel Economy, 2007

There are several technologies to optimize efficiency from the time fuel enters the engine to when the wheels turn. The U.S. government fuel economy website (Fuel Economy, 2007) run by the DOE and EPA outlines several methods to optimize efficiency. The first logical place to start is the engine. Enhancing the performance and efficiency of the engine can successfully increase the miles per gallon of an engine.

One method called Variable Valve Timing & Lift (VVT&L) involves the valves in the engine that control air flow and fuel. The timing of these valves and how far they lift in the cylinder affects the engine's efficiency. Cylinder Deactivation is another method that can be implemented to engine when they are not needed. Superchargers and turbochargers also help improve efficiency by generating extra power from each explosion using compressed air. Direct fuel injection is a viable method that combines air and fuel before it reaches the cylinder. This forces higher compression ratios and more efficient fuel intake. These, in turn, lower fuel consumption without sacrificing high performance. A unique approach called Integrated Starter/Generator (ISG) reduces the fuel used during idle time by turning off the engine when the vehicle comes to a stop. When the accelerator is pressed, the engine will instantaneously restart. Braking power can also be stored to help to restart the engine.

Advanced transmission technologies can help improve the overall efficiency of the vehicle. One of these technologies is called Continuously Variable Transmission (CVT).

Replacing a set number of transmission gears found in conventional vehicles, the CVT "utilizes a pair of variable-diameter pulleys connected by a belt or chain that can produce an infinite number of engine/wheel speed ratios" (Fuel Economy, 2007) This results in better fuel efficiency. Another technology is the Automated Manual Transmission (AMT). These types of transmissions improve the transfer of energy from the engine to the axles. They are also more light weight than conventional transmissions. All discussed vehicle technologies save from $1,400 to $3,200 over the lifetime of a single vehicle (185,000 mi) and have the potential to improve efficiency by up to 12% (based on a fuel price of $3.07, and an average fuel economy of 21 MPG) ("Automotive Technology Cost", 2005).

2.2.3 Carbon Capture

Carbon capture is collecting CO_2 from sources that are emitting CO_2, the main contributor being power plants. The captured CO_2 is then turned into a stream that can be stored or transformed so that its impact on the environment is diminished. Carbon capture from sources emitting CO_2 focuses on power plants fueled by fossil fuels. A main focus here is capturing CO_2 from power plants fueled by coal because they produce the most CO_2. However, carbon capture techniques are also being employed in natural gas-fired power plants. In these power plants there are three main technological approaches of carbon capture taking place. These technologies are pre-combustion, post-combustion, and oxy-combustion capture.

Pre-combustion

Pre-combustion involves technologies that are used in many chemical plants, as well as some power plants. These technologies gasify fossil fuel rather than directly combusting it. This allows the CO_2 to be easily captured from the gasification exhaust stream because pre-combustion methods generally produce higher concentrations of CO_2 than conventional combustion methods. Pre-combustion is accomplished by taking a fuel source such as coal and converting it "into gaseous components by applying heat under pressure in the presence of steam. In a gasification reactor, the amount of air or oxygen (O_2) available inside the gasifier is carefully controlled so that only a portion of the fuel burns completely. This "partial oxidation" process provides the heat necessary to chemically decompose the fuel and produce synthesis gas (syngas), which is composed of hydrogen (H_2), carbon monoxide (CO), and minor amounts of other gaseous constituents." (National Energy Technology Laboratory, 2007). The syngas produced is processed in a water-gas-shift reactor. This process converts CO to CO_2 and raises the CO_2 and H_2 concentration levels to 40 and 55%, respectively. The CO_2 achieves a high partial pressure and chemical potential which facilitates the driving force for various types of separation and capture technologies. Once the CO_2 is removed, the syngas is mainly composed of H_2 which can be used to produce electrical or thermal power. Pre-combustion capture is a useful technique because it can capture a maximum of 90 – 95% of the CO_2 created. The major disadvantages of this process are that the chemical plant required is expensive, and there is low nitrous oxide combustion.

Post-combustion

Post-combustion entails capturing CO_2 from flue gases once the fossil fuel has been burned. This method is applied mainly to coal-fired power plants, but it can be used in power plants powered by natural gas. A coal-fired power plant works by burning fuel in a boiler with air. This produces steam which is used to spin a turbine and create electricity. Separation of CO_2 from flue gas, which is mainly composed of nitrogen and CO_2, is a difficult task. The process of capturing the CO_2 begins when the flue gases exiting the plant are cooled and fed into a CO_2 absorber. In this absorber there are chemical solvents such as amines that capture the CO_2. Processes like this capture approximately 85% of the CO_2 being released. The captured CO_2 is turned into a liquid by compressing and cooling it. This liquid can then be deposited in geologic formations or the ocean using sequestration methods. The major disadvantage of post-combustion carbon capture is that this technique can increase costs, and even small amounts of impurities in the flue gas can diminish the effectiveness of the CO_2 absorbing process.

Oxy-combustion

Oxy-combustion combusts coal in an atmosphere composed of pure oxygen diluted with recycled CO_2 or water. With this environment the combustion yields CO_2 and water. The CO_2 is captured by condensing the water in the exhaust stream. When the water is condensed it is separated from the CO_2 and the CO_2 is easily captured by CO_2 absorbers. In addition to removing CO_2, oxy-combustion reduces the production of nitrogen oxides by 60-70% when compared to conventional combustion processes. The biggest problem with oxy-combustion is that it is expensive because of the amount of pure oxygen needed.

2.2.4 Carbon Storage/Sequestration

Carbon sequestration refers to the process of stowing away CO_2 for long periods of time. Carbon storage/sequestration can take captured carbon, such as the captured CO_2 from the three technological approaches discussed above and store it away so that it is removed from the atmosphere. The point of this process is to take CO_2 that has been removed from the air due to carbon capture methods and store it in geologic formations or the ocean, or use vegetation to sequester the CO_2, thus reducing global warming. The major problem with carbon storage is that scientists are unsure as to how the stored CO_2 is going to behave, and what the repercussions will be. There are three main methods being used to store/sequester CO_2, as well as some relatively new methods. These methods include storing CO_2 in appropriate underground reservoirs such as abandoned oil and gas reservoirs, as well as lignite coal seams. Oceanic sequestration includes depositing CO_2 into oceans and other large bodies of water. Iron fertilization is another key oceanic sequestration method. The CO_2 can also be sequestered by identifying methods to enhance the natural terrestrial cycle which would include plant life consuming it, and storing it in soil and biomass. A relatively new method that is being researched is algal processing.

Geologic Sequestration

Storing CO_2 into geologic formations such as abandoned oil and gas reservoirs, saline and basalt formations, and unmineable coal beds requires testing to make sure that the site is suitable. Sites in which CO_2 is going to be deposited must not have any cracks or leaks in them through which CO_2 could escape. Searching for geologic formations to store CO_2 takes place over hundreds of square kilometers. Since it is such a huge search, certain methods for finding suitable sites are too expensive and time consuming. Technologies such as SEQURE(TM) may be used. “Researchers at the Office of Fossil Energy's National Energy Technology Laboratory (NETL) have launched a major breakthrough in carbon storage efforts with SEQURE(TM), the only commercially available technology that can search vast areas for abandoned oil and gas reservoirs that could be used to permanently store CO_2.” (DOE, 2007c) This technology was developed by NETL in combination with an international team of researchers from Apogee Scientific Inc. (Englewood, Colo,), Fugro Airborne Surveys (Mississauga, Ontario, Canada), and LaSen Inc. (Las Cruces, N.M.). SEQURE attaches to a helicopter and, using magnetic sensors, it identifies any steel well casings in the area. “In the 2005 proof-of-concept flight over the Salt

Creek Oilfield in Wyoming, SEQURE's magnetic sensors detected 133 of 139 wells. The remainder of the wells remained hidden because of corroded or removed casing, or because the casing was made of a non-magnetic material, such as wood." (DOE, 2007c). The magnetic sensor readings are portrayed on maps that are used for ground inspection. The SEQURE not only needs to detect the sites in which CO_2 could possibly be stored, but it has to find out whether these sites have leaks or not. To accomplish this, the SEQURE has a CH_4 detector which senses volatile components that have traveled to the earth's surface using the well bore. Figure 2.5 shows two of the three main types of carbon storage, and the power plant in which the CO_2 is captured.

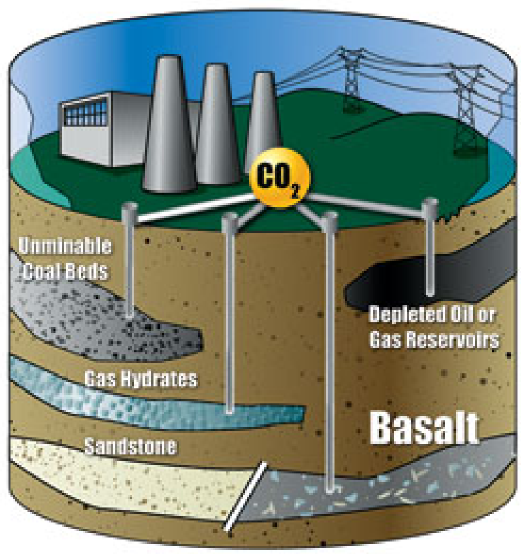

Figure 2.5: Geologic Carbon Sequestration Options

Source: Environmental Technology Directorate, 2007

Oceanic Sequestration

The two main methods being used in oceanic sequestration are injection and iron fertilization. Using injection methods, an almost pure CO_2 stream is pumped into the ocean at depths greater than 1000 meters. The deeper the carbon is injected, the longer it will stay. At depths of 1000-1500 meters, carbon could remain for hundreds of years, possibly longer. The reason CO_2 should be injected at depths greater than 1000 meters is because this is the location of the bottom of the thermocline. The thermocline "is the layer of the ocean that is stably stratified by large temperature and density gradients, thus inhibiting vertical mixing and slowing the leakage of CO_2." (Herzog, Caldeira, and Adams, p. 4).

There are five main injection methods used to drop the CO_2 into the ocean. These five methods are a droplet plume, a dense plume, dry ice, towed pipe, and a CO_2 lake. The droplet plume is liquid CO_2 injected at depths of 1000 meters or greater. A dense plume is a mixture of seawater and CO_2 mixed at a depth of around 500 to 1000 meters. The density of this mixture causes the CO_2 to sink even further. A third method is dried ice being released from a surface ship. A towed pipe attached to a surface ship that injects liquid CO_2 at depths of 1000 m is a fourth method. The CO_2 lake is liquid CO_2 being injected into sea floor indents at about 4000 meters to form a lake. Figure 2.6 below shows each method, and the approximate depth at which the CO_2 would be deployed.

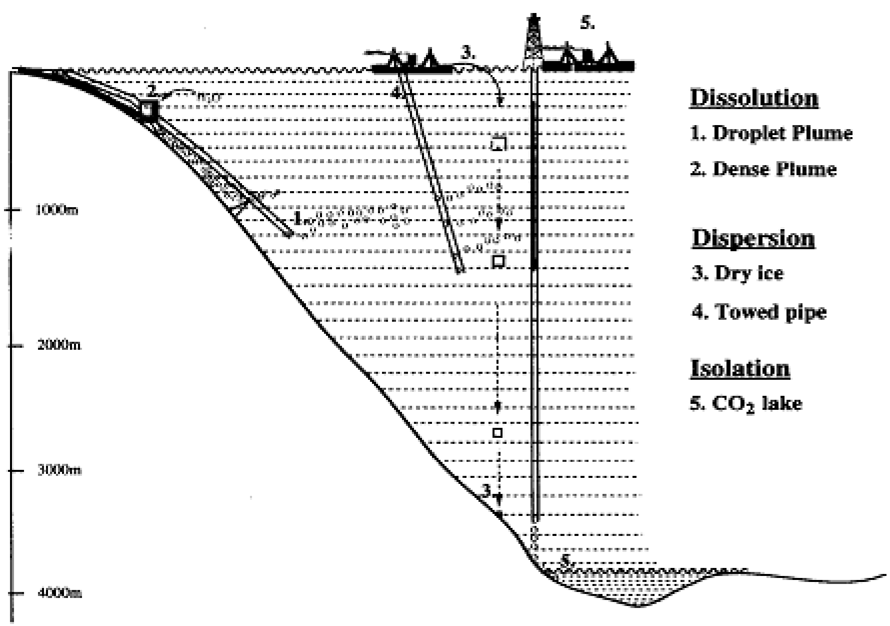

Figure 2.6: Ocean Carbon Sequestration Direct Injection Methods

Source: Herzog, 2007

The second main oceanic sequestration method is iron fertilization. This process involves sprinkling particles of iron over the ocean, resulting in enormous growth of phytoplankton. Phytoplankton is microscopic vegetation that will absorb CO_2 from the atmosphere. When phytoplankton dies, organic debris falls into the ocean. Scientists are unsure as to how much of this organic debris will reach the deep ocean waters. According to Beth Daley of the Boston Globe some believe that phytoplankton releases a gas that creates aerosol particles that will help reflect the sun's energy (Beth Daley, Seeds of a solution, 2007). Scientists are also arguing over whether this method will kill fish and harm the ecosystem, or help to reducing global warming.

Enhancing the Natural Terrestrial Cycle

Enhancing the natural terrestrial cycle is another technological method being used to reduce the amount of CO_2 in the environment. Plants naturally contribute toward sequestering CO_2 since they consume it. Given that plants naturally do this, it's a good idea to utilize them for carbon sequestration efforts. "Terrestrial carbon sequestration is defined as either the net removal of CO_2 from the atmosphere or the prevention of CO_2 net emissions from the terrestrial ecosystems into the atmosphere." (DOE, 2007d). There are two essential elements to consider when enhancing the natural terrestrial cycle to sequester carbon. Protection of the ecosystem must be considered so that vegetation depleting CO_2 is increased rather than harmed. The second aspect to consider is how to control the ecosystems so that the amount of carbon being sequestered is advanced beyond the present state.

There are five chief approaches to reducing the amount of CO_2 by enhancing the natural terrestrial cycle. These five categories are: forest lands; agricultural lands; biomass croplands; deserts and degraded lands; and boreal wetlands and peatlands. Forest lands "focus includes below-ground carbon and long-term management and utilization of standing stocks, understory, ground cover, and litter." (DOE, 2007d). Below-ground carbon, which is based on the use of forest lands, focuses on carbon dioxide removal by plants using photosynthesis and incorporating it into biomass. Agricultural lands concentrate on grasslands, crop lands, and range lands, stressing an increase in long-lasting soil CO_2. Biomass croplands centers on long-term increases in soil carbon and organic products which contribute toward CO_2 depletion. Restoring degraded lands and deserts is important because it will add additional carbon sequestering vegetation where little existed previously. Finally, boreal wetlands and peatlands focus on managing soil carbon, and possibly transforming certain areas into forest land and agricultural lands.

Algal Processing

Algal processing is a type of carbon sequestration that is being suggested to reduce the amount of CO_2 in the atmosphere. Utilizing certain plants is more viable than using others, however. Some plants such as trees grow slowly, needs lots of water, and need lots of land. Algae have high areal production compared to other plants like trees and bushes. This means that, in a much smaller area, algae will be able to consume much more CO_2 than would larger plants. Moheimani lists several factors that make algal systems attractive, since they grow in closed photobioreactors (2005). A closed photobioreactor is a system designed to cultivate algae and is not exposed to the environment. Instead, the algae are contained within transparent material. The environmental parameters are controlled within a closed system photobioreactor. The advantages to this system are that it prevents evaporation, it reduces contamination, limits CO_2 losses, creates reproducible cultivation conditions, and there is flexibility in the technical design. The main types of closed photobioreactors are continuously stirred tank reactors (carboys) and bags, tubular, airlift, and plate (flat panel). Figure 2.7 is an example of a flat panel photobioreactor.

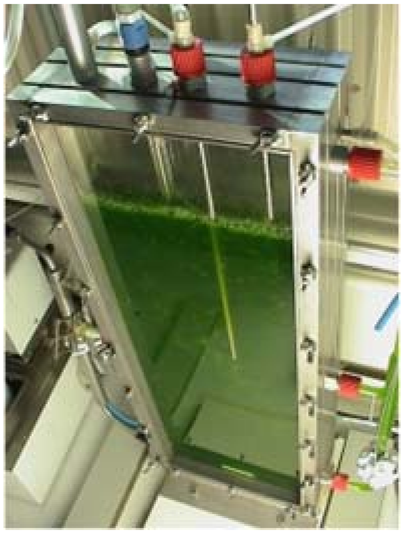

Figure 2.7: Panel Photobioreactor

Source: Wageningen UR, 2007

Another advantage of algae would be that it could be used as a biofuel or biomass for power production. According to *National Geographic,* researchers say that algae could absorb CO_2 from power plants, and produce 5,000 gallons of biodiesel per acre each year, in theory.

Another possibility is to use biomass algae in co-firing. Co-firing is when two different substances, algae and coal in this case, are combusted at the same time. According to Moheimani (2005), certain types of algal biomass could be used in biomass co-firing. Algal co-firing would be beneficial because it increases efficiency of the power plant and the cost of producing the electricity will decrease. It will also decrease the amount of CO_2 being released into the atmosphere.

2.2.5 Low Carbon Fuels

Low carbon fuels are fuels that have low carbon content. These fuels are desirable for use because when combusted, they release less CO_2 into the atmosphere than other fuels such as gasoline. One example of a low carbon fuel is natural gas. Natural gas, considered one of the cleanest fossil fuels, is being used in many places where fuels with higher carbon content have been used in the past, such as public transportation and domestic heating.

Natural Gas

Natural gas, which is comprised of mostly methane, is one of the cleaner burning fossil fuels. When combusted, natural gas emits almost 30% less CO_2 by energy output than oil, and almost 45% less CO_2 by energy output than coal (NaturalGas, 2004). Today, many cities including, Washington D.C., have buses running routes that run on natural gas. Another technology that uses natural gas for a fuel is PureComfort®. PureComfort® is a proprietary technology developed by UTC Power. This system is a cooling, heating, and power providing unit appropriate for big buildings such as schools and hospitals that runs on natural gas. PureComfort® can be run either on the grid or off. The system consists of three to six 60 kilowatt microturbines and a heater/chiller. The PureComfort® system can cool with an astonishing operating efficiency of 93% (UTC Power, 2007). When technology runs at high efficiencies, like this unit, they conserve fuel. The appeal of using a PureComfort® system is that the unit limits the amount of harmful emissions it produces.

2.2.6 Renewable and Biofuels

One category of technology that has serious potential to mitigate climate change is renewables and biofuels. Technologies that are fueled by energy sources that will not become depleted, such as the sun and the waves in the ocean, fall under the renewable category.

Renewable energy and biofuel technologies have the potential to mitigate climate change because they will lessen the use of processes that use fossil fuels for energy, therefore mitigating GHG emissions. Biofuels are energy sources that are derived from biological material, such as plants. Ethanol and biodiesel, both biofuels, will be discussed in this section. The renewable technology areas that will be discussed in this section include fuel cells, geothermal energy, solar energy, wind energy, ocean energy, and hydro energy.

Hydrogen Technologies

In order for a technology that runs on hydrogen, like fuel cells, to be diffused and utilized, hydrogen has to be readily available for consumption. Technologies that produce hydrogen, as seen in Figure 2.8 below, are referred to as hydrogen technologies. One technology that produces hydrogen is FutureGen. This technology, which is being worked on extensively by DOE currently, is a coal-fired power plant with zero net emissions that produces hydrogen (DOE, 2007b). Technologies are being introduced that produce hydrogen from chemical hydrides for portable uses (RTI, 2007). Also, hydrogen can be produced by hydrolysis and thermolysis of hydrides and metals, and this hydrogen can be converted to electrical energy via a proton exchange membrane fuel cell, which is discussed further in this chapter (RTI, 2007).

Figure 2.8: Hydrogen Production Technology

Source: RTI International

Fuel Cells

Fuel cells are an alternative energy source that many people see in the future of transportation. The first fuel cell was created in 1839 by Sir William Robert Grove using a dilute acid electrolyte and platinum electrodes. Surprisingly, after almost 170 years, the same principles are employed in making fuel cells now including today's version of Grove's cell, the phosphoric acid fuel cell. The fuel cells use protons from an electrolyte solution (usually acidic) which are transferred from a proton rich environment to a proton depleted environment, generating electric power from chemical potential (Datta, 2007).

There are several different types of fuel cells, but one type that has been suggested for automotive use is the proton exchange membrane (PEM) fuel cell. PEM fuel cells have the basic parts of most fuel cells and use hydrogen fuel combined with oxygen from the air to produce power (see Figure 2.9). Today there is a fleet of Hyundai Tucson FCEV® sport utility vehicles on the road that utilize PEM fuel cell technology. Two of the issues that have arisen for fuel cells are cost and durability. The cost to produce a fuel cell system for a car is about five times as much as it costs to make the standard internal combustion engine. Also a fuel cell system for a vehicle will last only approximately 1,000 hours compared to the average 5,000 hours an internal combustion engine will last (Datta, 2007). It appears that fuel cell technology will impact the transportation industry greatly because it will reduce the amount of emissions being produced by automobiles.

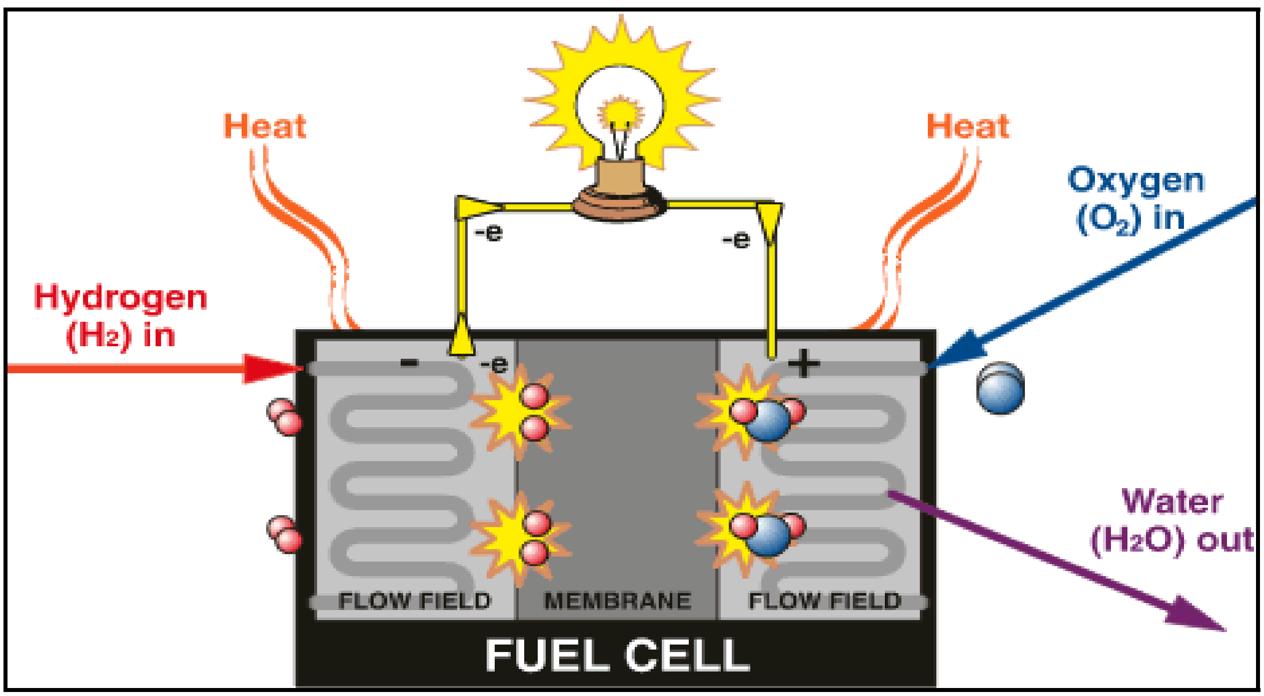

Figure 2.9: Basic Structure of PEM Fuel Cell

Source: Environment Canada, 2007

PureCell™ is a technology, made by UTC Power, which uses fuel cells to produce power for large buildings such as hotels and public buildings. The PureCell™ 200 Power Solution is a fuel cell power plant. The PureCell™ 200 generates 200 kilowatts of power and can produce up to 925,000 British thermal units (Btu) per hour when combining power and heating capabilities of the unit (UTC Power, 2007). The PureCell™ 200 is defined as a grid-connect unit that works in parallel with electric units. This power generator can operate either on the local power grid or it can operate completely independently from the grid. Along with the low operating noise level, this product is especially appealing to those who have an interest in becoming independent from the local power grid. Also, this technology produces no harmful emissions (UTC Power, 2007).

Biofuels

Biofuels are an emerging possibility for the next energy source, not only for the United States, but for the world as well.

The biofuel cycle, as shown in Figure 2.10, starts with biological matter. This biological material is then converted into sugars fermentable sugars which are converted to alcohol. When producing a biofuel, energy is used. Some of this energy comes from fossil fuels. An example of this is the tractor that is used to harvest corn to make corn-based ethanol often runs on gasoline or diesel. Energy from fossil fuels that is spent in the production of a biofuel will be referred to as the fossil fuel energy input. The energy that comes from the combustion of the produced biofuel will be referred to as energy output.

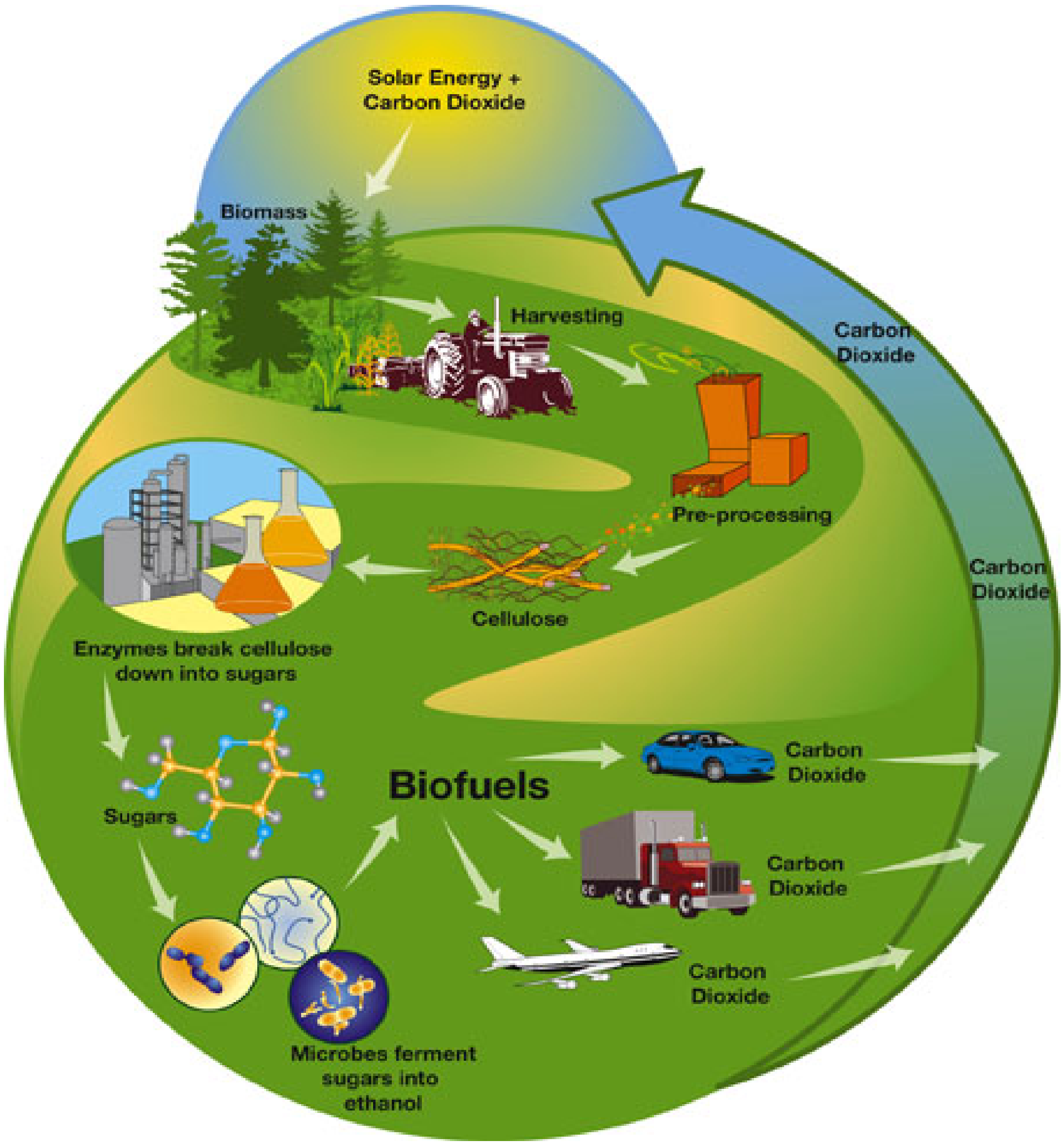

Figure 2.10: Biofuel Cycle

Source: DOE Joint Genome Institute, 2007

One type of biofuel that can replace fossil fuels is ethanol. Ethanol is made by reducing plant material to its basic sugars and fermenting those sugars into alcohol. The energy content of ethanol isn't as high as gasoline; ethanol contains 67% as much energy as gasoline by volume (*National Geographic*, 2007). Currently, the U.S. produces most of its ethanol from yellow feed corn and it is used as a gasoline additive. The corn kernels are the only part of the plant that gets used in the production of corn ethanol. The starches in the kernel are transformed to sugars with costly enzymes, then the sugars ferment into an alcohol (*National Geographic*, 2007). The ratio of the energy output to the fossil fuel energy input for corn ethanol is a woeful 1.3:1, however the production and use of corn-based ethanol emits 22% less GHGs than the production and use of gasoline (*National Geographic,* 2007). If the U.S. is to use corn-based ethanol for fuel, it will put a substantial strain on the food market of corn both in regard to the price of corn and corn-derived products and land use. The low energy output to energy input ratio along with the strains that the production of corn-based ethanol would create make corn ethanol a poor choice for an energy source.

An alternative to corn for a source of ethanol is sugarcane. Sugarcane seems more promising than corn because the stalk of the sugarcane plant is 20% sugar (*National Geographic*, 2007). This cuts down the process of converting the starches of the plant to sugars. This is why, in Brazil, the consumer can pay 25% more for a gallon of gasoline than for a volume of ethanol with the same energy content (*National Geographic*, 2007). Also, the ratio of the energy output to the fossil fuel energy input for sugarcane ethanol is 8:1 and the production and use of sugarcane ethanol emits 56% less GHGs than the combustion of the same mass of gasoline (*National Geographic,* 2007).

The most promising type of ethanol is cellulosic ethanol. This is ethanol that is produced from parts of the plant including cellulosic parts. Cellulose, the component that gives a plant their rigidity, is found in almost all green plants. Thus, there are numerous feedstock sources. In particular, switchgrass (see Figure 2.11) is so attractive because it can be grown on land areas unsuitable for other important crops like corn. Also switchgrass needs no irrigation or fertilization. Other sources for cellulosic ethanol include stalks, leaves, husks, wood chips, sawdust, bark, paper pulp, and other fast growing prairie grasses. Depending on the method used to produce ethanol from the cellulosic material, the ratio of the energy output to the fossil fuel energy input for cellulosic ethanol ranges from 2:1 to 36:1 (*National Geographic,* 2007). Also, the production and use of cellulosic ethanol yields an astounding 91% less GHGs than the equivalence of gasoline (*National Geographic*, 2007). The major downside to generating ethanol from cellulosic plant parts is the low level of development. There is no easy way yet to break down the lignin within these cellulosic parts.

Figure 2.11: Switch Grass Field

Source: National Renewable Energy Laboratory, 2007

Another biofuel that is being considered as a replacement for gasoline is biodiesel. Biodiesel is a fuel derived from biological sources that can be used in unmodified diesel engines. Biodiesel is produced from vegetable oil or animal fats by a process called transesterification. This is a complex process where the fatty acids are replaced with short alcohol chains. Biodiesel is an appealing option for an alternative energy source when thinking of sustainability because the U.S. can produce biodiesel from its soybean crops. Two of the drawbacks of using biodiesel are that it produces low yields and its high cost. Biodiesel contains 86% of the energy that regular diesel does (*National Geographic*, 2007). The ratio of the energy output to the fossil fuel energy input of biodiesel is 2.5:1 and biodiesel emits 68% less GHGs in the production and use of the final product (*National Geographic*, 2007).

Geothermal Energy

Geothermal energy is energy that emanates from Earth's core. The Earth's core, over 4,000 miles deep, is estimated to reach temperatures as high as 9,000º F (GEO, 2000). The heat from the center of the planet melts some of the rock layers that surround it, creating magma. This magma is less dense than the solid rock layers so it slowly moves outward toward the surface of the Earth. This magma increases the temperature of any rock layers within the vicinity. Rainwater penetrates deep into the Earth and when this rainwater is heated by the hot rock layers and magma, it is called a geothermal reservoir (GEO, 2000). Systems are used to tap into the energy made available via geothermal reservoirs and heated rock layers. One such system is a geothermal heat exchanger.

Geothermal heat pumps are an efficient technology and are viable for small scale use. (DOE, 2007b). Due to the efficiency of these systems, and the lack of negative environmental impacts, geothermal heat pumps are being used for space heating and cooling, as well as water heating in residential and commercial buildings. This technology works by concentrating natural constant heat from below the Earth’s surface rather than combusting fuels to create heat. This is very beneficial because it doesn’t produce harmful GHGs. The geothermal heat pump transfers heat that is underground into the home or building in the winter, and transfers heat that is in the home or building in the summer out. Essentially the ground is a heat source in the winter and a heat sink in the summer.

According to the Geothermal Technologies Program, run by the DOE, the geothermal heat pump consists of three main components. These components are a geothermal earth connection system, a geothermal heat pump subsystem, and a geothermal heat distribution subsystem. The earth connection system is a system of pipes, generally referred to as a loop, that is buried in the ground close to the home or building using the geothermal heat pump system. There are several types of loops being used for the earth connection subsystem. These types of loops are, horizontal ground closed loops, vertical ground closed loops, pond closed loops, open loop system, and a standing column well system.

According to Geoexchange, horizontal ground closed loops are usually buried 3-6 feet deep and are 400-600 feet long per ton of heating and cooling capacity. A trench is dug to install the pipes for this system. Once the pipes are laid out in the trench, it’s carefully backfilled. Since it is a closed system the fluid runs through the pipes. This system is generally the most cost effective of all the loop systems when there is enough yard space and the ground in the area is easy to dig.

Vertical ground closed loops require the drilling of holes 150-400 feet deep (Geoexchange, 2003). A pipe is placed in each one of these holes. These pipes are then connected to a short horizontal pipe, which is also underground, and this horizontal pipe carries the fluid to the heat exchanger. For the initial installation vertical loops are more expensive, but they require less tubing than horizontal loops since deeper down the Earth is cooler in summer and warmer in winter. Figure 2.12 below depicts what a home with a vertical ground closed loop system would look like.

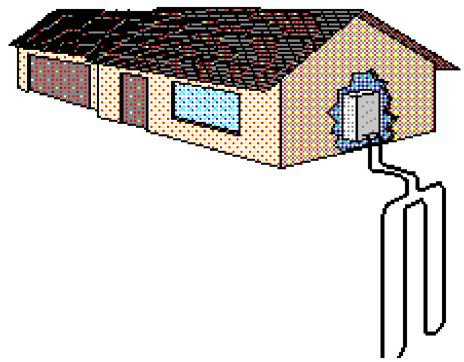

Figure 2.12: Vertical Ground Closed Loop System

Source: Geoexchange, 2003

Pond closed loop systems are an advantageous design to use if the home or building employing the heat pump is close to a pond or lake. The pipe is directed to the water and then long sections are submerged. This system should not be used if the pond or lake water level ever drops below 6-8 feet. This is so that there is adequate heat transfer capability. A benefit of using pond closed loops is that they do not harm the aquatic ecology (Geoexchange, 2003).

Open loop systems are generally employed where there are ample amounts of ground water. These systems are easy to install if the local code allows it. The process is as follows: "…ground water from an aquifer is piped directly from the well to the building, where it transfers its heat to a heat pump" (Geoexchange, 2003). Once the water exits the building it is pumped back into the aquifer it came from using a discharge well.

Standing column well systems, which are also called turbulent wells, are the last main type of loop that is used. A standing well system may be as small as 6 inches in diameter, but they can go down as far as 1500 feet (GeoExchange, 2003). Water at the bottom of the well is pumped up to the heat exchanger, and then it is returned to the top of the water column in the same well. The standing well system generally provides drinkable water as well. The problem with this system is that it needs lots of ground water to be able to operate efficiently. For example if the ground water was too deep where the system was installed it would be far too costly to pump up.

The geothermal heat pump subsystem is the system that uses a heat pump to extract the heat from the liquid in the earth connection. Once the heat is extracted it is concentrated and transferred to the home or building. For cooling a home or building, the process is simply reversed. The third and final component is a geothermal heat distribution subsystem. In most cases, to distribute the heated or cooled air from the heat pump throughout the home or building, typical ductwork is used.

Installing a geothermal heat pump in homes or buildings is beneficial for many reasons. "According to the Environmental Protection Agency (EPA), GeoExchange systems are the most energy efficient, environmentally clean, and cost-effective space conditioning systems available (source: "Space Conditioning: The Next Frontier," EPA 430-R-93-004, April 1993) (Geothermal Technologies Program, 1999). To date, geothermal heat pumps remain one of the most energy efficient, cost-effective, and environmentally clean climate change technologies. Not only are geothermal heat pumps energy efficient, environmentally clean, and cost effective, they are durable, require low maintenance, and quiet. According to the DOE's geothermal program (Geothermal Technologies Program), the energy cost of heating, cooling, and hot water per day for a home of 1,500 ft^2 with a good building envelope would be about $1. The reason every home does not have one of these systems is because homes that are already built are difficult to retrofit, and the initial cost of this system when building a new home can be expensive.

Commercial Geothermal Products

An example of a commercial geothermal unit that is being used today is PureCycle®. PureCycle® is a closed-cycle geothermal system that uses ground water to generate 225 kilowatts of power (UTC Power, 2007). Because this system is entirely closed and is driven by simple evaporation of ground water, this process produces no emissions and the fuel source is renewable. PureCycle® has a wide range of geothermal resource temperature that starts as low as 74 degrees Celsius (UTC Power, 2007). While this technology can only be used at locations that provide geothermal heat greater than 74º C, this system runs extremely cleanly. If this process were to replace standard power production where possible, emissions would decrease greatly, therefore affecting climate change.

Solar Energy

There are three ways to use the sun's light rays for energy (Envocare, 2006). The first two, active and passive, have been used for many years, however the last way, photovoltaic, holds promise for the future of energy production. The passive method for using the sun for energy consists of designing dwellings so that the sunlight enters and is absorbed by the structure and its contents, thereby heating the area (Envocare, 2006). Greenhouses use this method to trap heat to aid in plant growth. The active method is when a medium is used, usually water, to trap the heat and then transport that medium by a small pump or gravity to a central storage tank. From here it can be used to supply hot water or run through a radiator for heating. Photovoltaic (PV) panels transform sunlight into electrical energy.

Photovoltaics

Currently PV technology can only run at about 15% efficiency (Envocare, 2006), however strides are being made and an efficiency more than double that of today looks to be possible in the near future. Solar energy offers energy from a renewable source; however this technology has run into issues with efficiency. Figure 2.13 shows solar panels being used on the roof of a home. This is a popular use for solar panels that can cut the cost of home heating and electricity.

Figure 2.13: Domestic Photovoltaic Solar Panels

Source: Inhabitat.com, Nov. 2007

Solar Updraft Towers

Solar updraft towers, shown in Figure 2.14 below, are systems designed to convert solar energy into electrical energy, which consist of a tall exhaust stack surrounded by a large, circular collection field. The sunlight hits the surface of the collection field heating up the air inside. This heated air wants to rise, and the only way up is through the exhaust stack (EnviroMission, 2007). When this heated air travels through the exhaust stack, it spins turbines so that electrical energy can be produced. A small-scale pilot plant operated in Spain from 1982 to 1989 that consistently produced 50 kilowatts of power (EnviroMission, 2007). According to EnviroMission, a single 200 megawatt solar updraft tower will prevent the emission of 900,000,000 kilograms of GHGs annually.

Figure 2.14: Solar Updraft Tower

Source: EnviroMission

Solar Mirror Towers

Solar mirror towers, depicted in Figure 2.15 below, work by concentrating sunlight onto one centrally located receiver. Thousands of mirrors, often parabolic, focus the sunlight onto a receiver that located centrally with a high elevation (EERE, 2001). This heat is then transferred to a steam generator where it is converted to electrical energy (EERE, 2001). While solar mirror towers and solar updraft towers may look similar, they are not because of the different process that is used to produce electricity. According to EERE, a solar mirror tower system of 350 megawatts displaces the energy content of 2.3 million barrels of oil.

Figure 2.15: Solar Mirror Tower

Source: Inhabitat

Wind Energy

Wind energy works by converting the kinetic energy in wind into power. Horizontal-axis, the typical four pronged windmill type, makes up most of the "utility scale" turbines on the market (AWEA, 2007). Utility scale turbines are rated at 100 kilowatt capacity or higher. Electrical energy derived from wind turbines usually is added into utility power lines where electricity from power plants is already flowing. The way that electricity is obtained from the wind is similar to how electricity is generated from water in water turbine systems. The wind turns the turbine causing the generator shaft to spin and produce electricity (AWEA, 2007). Wind turbines are used today because of their lack of emissions and their renewable energy source. One issue that has arisen with wind turbines is the aesthetic aspect of the technology. Often wind turbines are grouped together to produce large amounts of energy in places called wind farms. Many people don't want wind farms near their property because they find them aesthetically displeasing. Figure 2.16 below shows the internal components of a wind turbine.

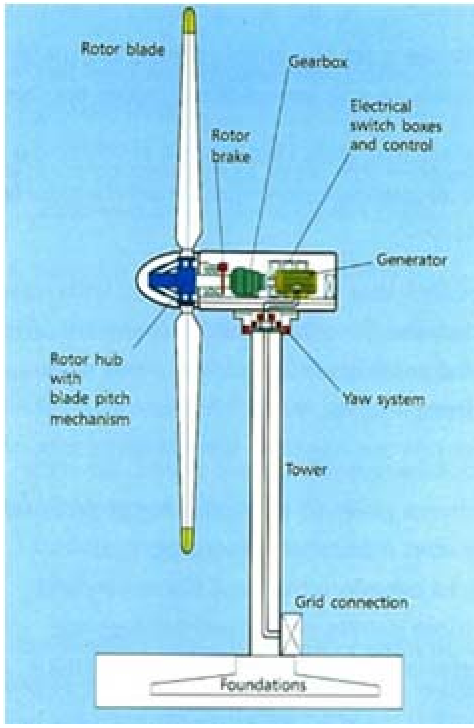

Figure 2.16: Wind Turbine Mechanical Components, Side View

Source: South Ayrshire, 2007

Ocean Energy

Earth's oceans are another resource that can be used to produce energy. A technology called the Archimedes Wave Swing (AWS) energy converter uses the ocean's waves to produce electrical energy (AWS, 2006). The system consists of a cylindrical buoy, which has a fixed lower cylinder overlapped by an upper cylinder that is designed for vertical motion. The system is anchored to the sea floor so that, when a wave crest approaches, more pressure is applied to the upper cylinder, by the extra water, causing it to move downward. When the wave crest passes the buoy, the upper cylinder, returns to its original height. The vertical movement of the upper cylinder, combined with the buoy's hydraulic system and motor generator, produces electrical energy (AWS, 2006). One of the best qualities about this technology is its simplicity. A full scale pilot plant constructed off the coast of Portugal proved the concept behind this technology and started talks of commercial engineering. AWS hopes to have this technology in commercial use by 2010. This technology is useful because it uses a renewable source of energy and its lack of emissions will affect climate change in a positive way. Figure 2.17 is a computer generated image of several AWSs.

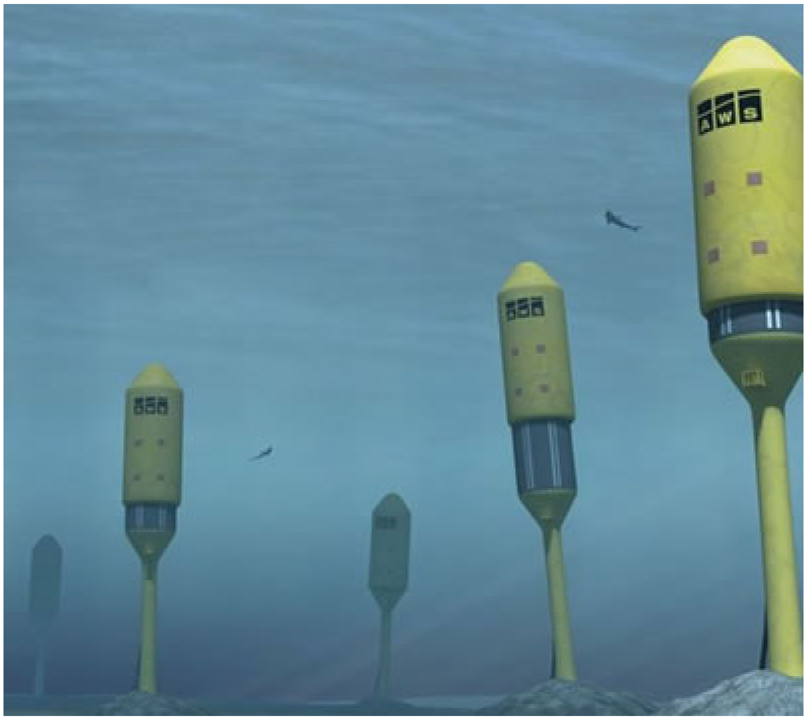

Figure 2.17: AWS Buoys

Source: Elektronika, 2007

Hydropower

Another type of technology that can have an impact on global climate change is hydropower. Hydropower is the process that uses the water cycle to produce power, which can take the form of electricity. Like other climate change technologies, the source of energy for hydropower is the sun. Water on the earth, such as lake and river water, evaporates when exposed to sunlight. This evaporated water accumulates in clouds in the atmosphere, and when cooled enough, returns to the surface of the planet as rain. When this rain falls on terrain that has elevation, the water will naturally move to the lowest point (USGS, 2006). This phenomenon is the reason why rivers and lakes are a major part of the planet's water cycle. Hydropower uses turbines and generators to convert the kinetic energy from the moving water and turn it into power people can use. Figure 2.18 below shows how an impoundment hydro powered dam works.

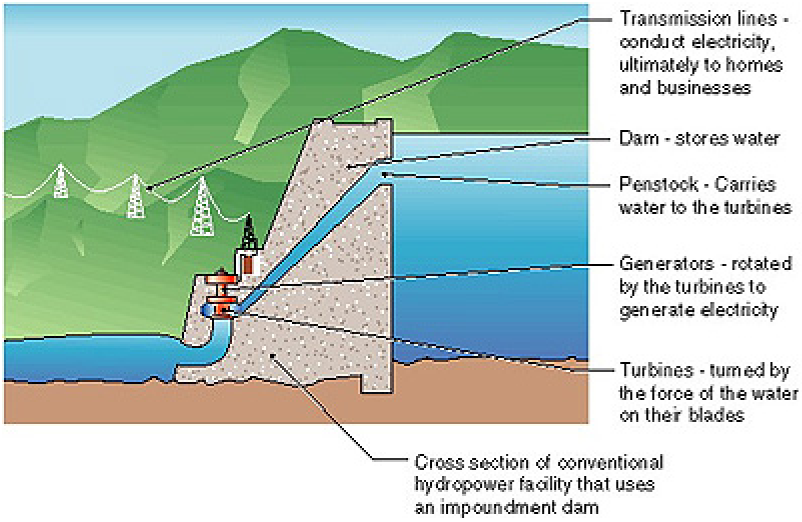

Figure 2.18: Impoundment Hydropower Plant Components

Source: EERE, 2007

Impoundment, diversion, and pumped storage are the three different types of hydropower systems. Impoundment, the most common form of hydropower, uses a dam to store large amounts of water (USGS, 2006). The dammed water flows through a system that moves a turbine and powers a generator, thus producing energy. Often, the flow rate for impoundment systems can be controlled to accommodate the local power needs. In a diversion system, water from a flowing source is diverted to turn a turbine and power a generator. Pumped storage works by pumping large amounts of water from a low elevation to a high elevation, and then releasing the water at the high elevation through a turbine to produce power. This is done so that energy needs can be met at times of high necessity (USGS, 2006). Pumped storage system will not be considered for further analysis because of the energy it takes to pump the water to a higher elevation.

Hydropower use a completely renewable source. This technology has been used for many years to produce energy. Hydropower boasts the ability to produce energy from a naturally occurring phenomenon. One issue on hydropower is the initial investment that is required to start using hydropower technology to make energy. Other issues with building dams include the severe impact to the surrounding ecosystem. Dams completely change the surrounding landscape and are harmful to the biodiversity in the area. Often, the construction of dams necessitates flooding of large areas, forcing thousands of people to relocate to new homes (Roy, 1999).

Whether the increase of CO_2 over the years is natural or anthropogenic is irrelevant. New technologies must be developed to mitigate the increase of CO_2 and other GHGs. These technologies can range from more efficient technologies to renewable energy to carbon capture and carbon storage/sequestration. Many of the technologies discussed above require more research and development before they can be effectively applied.

3. METHODOLOGY

When looking at our project a saying came to mind: “Success always comes when preparation meets opportunity”. Our group was granted the opportunity to work with the Environmental Protection Agency (EPA) on climate change research and technology. Our project with the EPA focused on three main objectives. The first objective was to assess the broad range of technologies that have been proposed to reduce, monitor, or eliminate greenhouse gas (GHG) emissions, such as alternative energy, carbon sequestration, and conservation in various sectors like transportation and power production. The second objective of this project was to assess the status of the climate change technologies that have been promoted and researched by the EPA and specifically the National Center for Environmental Research (NCER) through various programs, including the Collaborative Science & Technology Network for Sustainability (CNS), People, Prosperity and Planet (P3) and the Small Business Innovation Research (SBIR) programs. The third objective was to research governmental agencies and departments such as EPA, Department of Energy (DOE), Department of Transportation (DOT), and National Aeronautics and Space Administration (NASA), analyze their budget reports, and interview employees to gain a comprehensive understanding of their role and involvement within the U.S. on climate change technologies. Through this analysis, NCER will be able to better focus their funding for extramural research to make a greater impact to developing climate change technologies.

One method used to gather information was interviews. Several interviews were conducted with people working both within and outside of the EPA. All interviews conducted were semi-structured and in person, whenever possible. One team member headed the interviews while another took notes and the last took minutes, however all teammates provided appropriate questions that arose. The reason why one team member took notes while another took minutes was so that if the minute-taker missed a key statement while trying to keep up with the minutes, the note-taker would write it down for later reference. The head of the interview established the interviewee’s credentials at the start of each interview so that later, if necessary, references could be made to the interview. Requests to cite or quote any interviewee were sent via email or verbally over the phone. It was important that the interviewees feel comfortable so that as much information as possible could be gained in the meetings with these busy professionals. In person interviews were preferred because information is often lost or misunderstood when relayed over the telephone; however phone interviews did occur because of interviewee availability and location.

Assessment of Climate Change Technology

The assessment of the spectrum of current climate change technology, required two tasks. The first task was to extend the literature review on climate change technology. Continuing the literature review helped fill research gaps on the current climate changing technologies. Gaps included technologies like geothermal that were researched on a large-scale use but not smaller, domestic uses. If there was trouble comprehending a certain technology or if a technology specialist was discovered in the literature, an interview may have been in order, depending on the specialist's availability and the need for them. These interviews gave some insight on the future direction of that technology. Whenever an interview with a technology specialist was conducted, a member of the team asked the specialist about the development of this technology and how he or she gauged that technology's future success. The information gained through interviews was used to further refine the scope of what areas of technology we researched for future NCER focus. All interview feedback, along with information derived from suggested further literature to research was used to construct our final assessments on the development and future success of the technology.

Another task for assessing climate change technology was to refine the classification system for the technologies we worked with. This was done by examining existing taxonomy schemes. There was a technology taxonomy system already in place in documentation provided by NCER, so it was used to create our own system that was based closely on the system that is in place. The method of presenting our preliminary findings on technology and our preliminary classification system to our liaison for feedback on a periodic basis was adopted. By looking at an existing classification system, it became possible to create a system that works efficiently with the least amount of overlapping in technology categories.

Using these categories, technologies were categorized in a matrix. Different aspects of all the technologies such as level of development, potential economic sectors for implementation and research funding sources for the technologies were evaluated. The matrix gave a visual display of all the collected data and helped the team discover gaps in our research and identify technologies better suited for NCER. This visual representation made it possible to easily eliminate technologies inappropriate for NCER. This matrix served as a checklist of technologies; technologies that did not pass NCER criteria were eliminated while legitimate possibilities were retained.

Analysis of NCER Climate Change Technologies

The assessment of current NCER technology and research included a review of all documentation within NCER on the projects they sponsor and programs they head. This documentation included project proposals and budget reports. By looking at program trends, we were able to better analyze the progress of climate change technology within NCER. A table of climate change projects under the P3 and SBIR programs was created. Beyond this, the technologies researched in each project were grouped and classified, using the categorical system previously developed. Based on this matrix, the types of technologies NCER has researched most recently were determined, and this information was used to analyze the technologies NCER has focused on in the past.

Analysis of U.S. Agencies and Departments Funding of Climate Change Technology Research

The overall objective of the project was to provide a detailed analysis of climate change technology research within U.S. agencies and departments including the EPA and give recommendations for future NCER funding. For this objective the assessment of all climate change technologies and the analysis of government funded climate change technology, both within the EPA and outside of it, were combined to help recommend possible funding opportunities for NCER.

One task completed for the analysis of government agency and department funding was examining the department or agency and writing a brief summary of their mission and goals. Budget reports over the past few years were analyzed next to give a scope of how much influence the agency had in climate change technology research and development.

Interviews with EPA, DOT and DOE staff were conducted to fill any knowledge gaps in agency climate change technology funding and to determine technology development and future direction. Dr. Andrew Miller, an EPA employee in the National Risk Management Research Lab

(NRMRL), helped the group understand the issues associated with development of technologies. Understanding goals and objectives of other agencies that fund climate change research such as the DOT and DOE was an important part of the project. Gaining a better understanding of these agencies and where they focus their resources involving climate change helped us complete the objective of assessing climate change technologies conducted by other agencies and departments.

Interviews were conducted with Dr. Diana Bauer and Russell Conklin, employees from the DOT and DOE respectively to gain valuable first hand experience about the departments. In the interview with Russel, a policy analyst with the DOE's Office of Climate Change Policy and Technology, an understanding of how DOE allocates their climate change funding was obtained along with a better understanding of how the CCTP functions. Dr. Bauer, an environmental engineer serving as coordinator of the Center for Climate Change and Environmental Forecasting for the EPA, provided information on the relationship between EPA (more specifically NCER) and DOT. This helped shape the understanding of what agencies are doing for climate change research and development. Both interviewees gave information beyond what was found online and through emails. This information about what types of climate change technologies the departments were focused on and approximately how much of their budget they put towards them was used to accurately develop a picture of the role of these two important departments. Information on other climate change funding government agencies was obtained through that agency's or department's website. The budgets, found on these websites, provided the information needed about which climate change technologies have been funded.

The completed literature review and the interviews both played major parts in giving the recommendations. To recommend a technology, many factors were considered such as research on technologies conducted by other agencies. If research was being conducted thoroughly on a certain technology by another agency, that area was not recommended for future NCER funding. Conversely, important areas of climate change technology not being pursued by other departments were recommended for NCER extramural research. These recommendations were essentially the final product presented to NCER.

4. FINDINGS

In order to give adequate recommendations to NCER as to what areas of technology would be most fruitful for the agency to focus their research and development efforts on; an analysis was conducted on climate change technologies that have been previously developed. This is necessary because it is vital that NCER does not use its limited resources to research areas of technology that have been previously investigated. This step can also help NCER use past climate change research done through other agencies to make a greater impact. This can be done by promoting research in areas that might have been missed by other agencies on certain technologies or by funding research on the impact of implementing technologies that have been funded in the past. One program that combines and utilizes climate change funding from several government agencies to mitigate climate change, is the Climate Change Technology Program (CCTP).

4.1 U.S. Departments and Agencies Funding Climate Change Technology

Various government agencies were examined to determine which climate change technologies are being funded by what agencies. This was important because it was essential to see how much money is going towards climate change technologies, and where this money is coming from. Since there are many government agencies it was necessary to narrow down the list of possibilities to the main contributors of climate change technology funding. The Climate Change Technology Program (CCTP) assisted in narrowing down the government agencies to six. These agencies were the EPA, DOE, DOT, NASA, USAID, and USDA. A description of how the CCTP was used to select these six agencies, as well as a description of the agencies and their budget, is below.

4.1.1 Climate Change Technology Program (CCTP)

The CCTP was established on February 14, 2002 to implement the President’s National Climate Change Technology Initiative (NCCTI). According to the Climate Change Science Program (CCSP), the purpose of the President’s NCCTI is to support federal leadership on climate change technology research and development. This is accomplished by improving how federal agencies coordinate their research and development funds, as well as focusing the federal research and development portfolio on the President's climate change goals, near and long term. "The CCTP is a multi-agency research and development coordination activity" (CCTP, 2006). The organizational structure of the CCTP is shown below, in Figure 4.1.

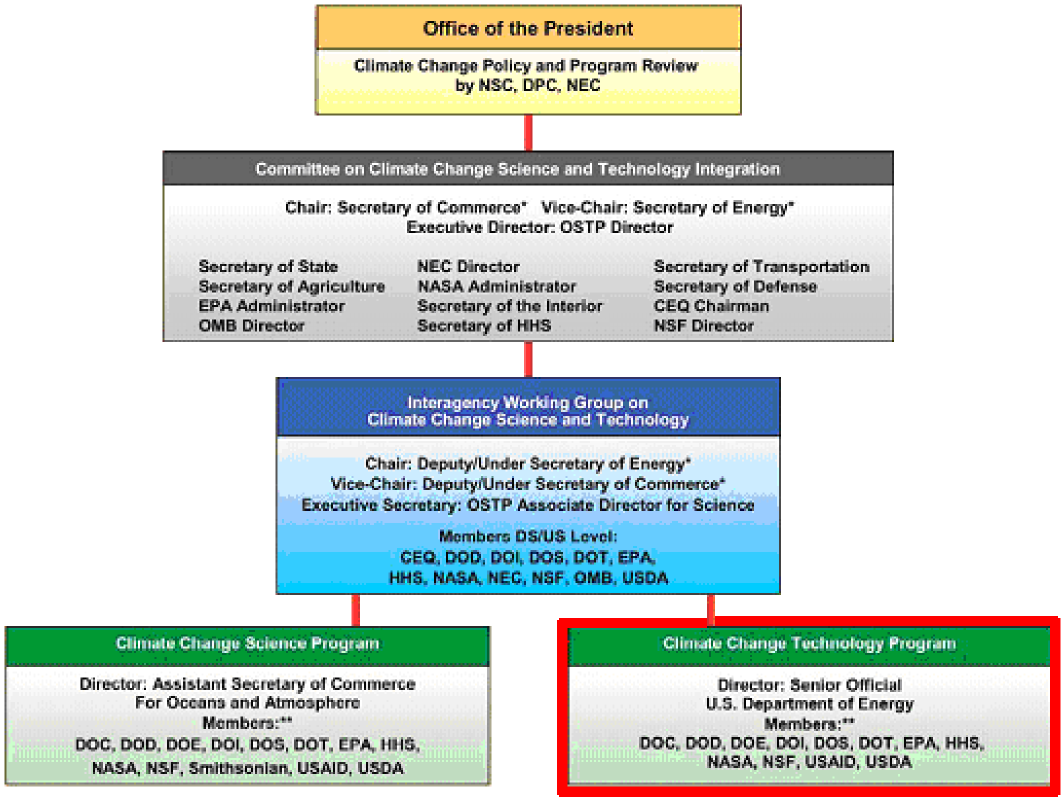

Figure 4.1: CCTP Organizational Structure

Source: CCTP, 2006

As depicted in Figure 4.1 and outlined in red, the CCTP involves 12 different agencies. Each one of these agencies is responsible for research and development of different climate change technologies. The goal of the CCTP, similar to that of the NCCTI "is to focus research and development activities more effectively on the President's climate change goals, near, and long-term." (CCTP, 2006). The CCTPs multi-agency structure allows it to be able to coordinate across the Federal Government "a comprehensive, coherent, multi-agency, multi-year research and development program plan for the development of climate change technology, tied to specific climate change goals and objectives." (CCTP, 2006). This type of system is extremely beneficial because different agencies are tied to researching and developing different technologies across a broad spectrum. Figure 4.2 illustrates the different agencies involved with the CCTP, as well as an example of what climate change technology fields they are performing research and development in.

AGENCY*	SELECTED EXAMPLES OF CLIMATE CHANGE-RELATED TECHNOLOGY R&D ACTIVITIES
DOC	Instrumentation, standards, ocean sequestration, decision support tools
DoD	Aircraft, engines, fuels, trucks, equipment, power, fuel cells, lasers, energy management, basic research
DOE	Energy efficiency, renewable energy, nuclear fission and fusion, fossil fuels and power, carbon sequestration, basic energy sciences, hydrogen, electric grid and infrastructure
DOI	Land, forest, and prairie management, mining, sequestration, geothermal, terrestrial sequestration technology development
DOS	International science and technology cooperation, oceans, environment
DOT	Aviation, highways, rail, freight, maritime, urban mass transit, transportation systems, efficiency and safety
EPA	Mitigation of CO_2 and non-CO_2 GHG emissions through voluntary partnership programs, including ENERGY STAR®, Climate Leaders, Green Power, combined heat and power, state and local clean energy, methane and high-GWP gases, and transportation; GHG emissions inventory
HHS	Environmental sciences, biotechnology, genome sequencing, health effects
NASA	Earth observations, measuring, monitoring, aviation equipment, operations and infrastructure efficiency
NSF	Geosciences, oceans, nanoscale science and engineering, computational sciences
USAID	International assistance, technology deployment, land use, human impacts
USDA	Carbon fluxes in soils, forests and other vegetation, carbon sequestration, nutrient management, cropping systems, forest and forest products management, livestock and waste management, biomass energy and bio-based products development

Figure 4.2: CCTP Agencies & Examples of Funding

Source: CCTP, 2006

The 12 agencies depicted in the figure above are the main agencies funding climate change technology research and development. Each of these agencies receives varying amounts of funding from the government and each one grants different amounts of money to fund different climate change technology research and development for the CCTP. When the climate change technology program created their strategic plan in 2006, each department had already committed funding for the CCTP for FY 2006. Since the CCTP is a government run agency it requires that certain agencies contribute a specific amount of money towards different climate change technology research for their program. Appendix A4 contains Table A1.1 which shows many of the departments in the CCTP, what programs they fund, and approximately how much money they are contributing. Figure 4.3, based on Table A1.1 in Appendix A4, depicts the approximate percentages of total CCTP funding that various agencies contributed in FY 2006.

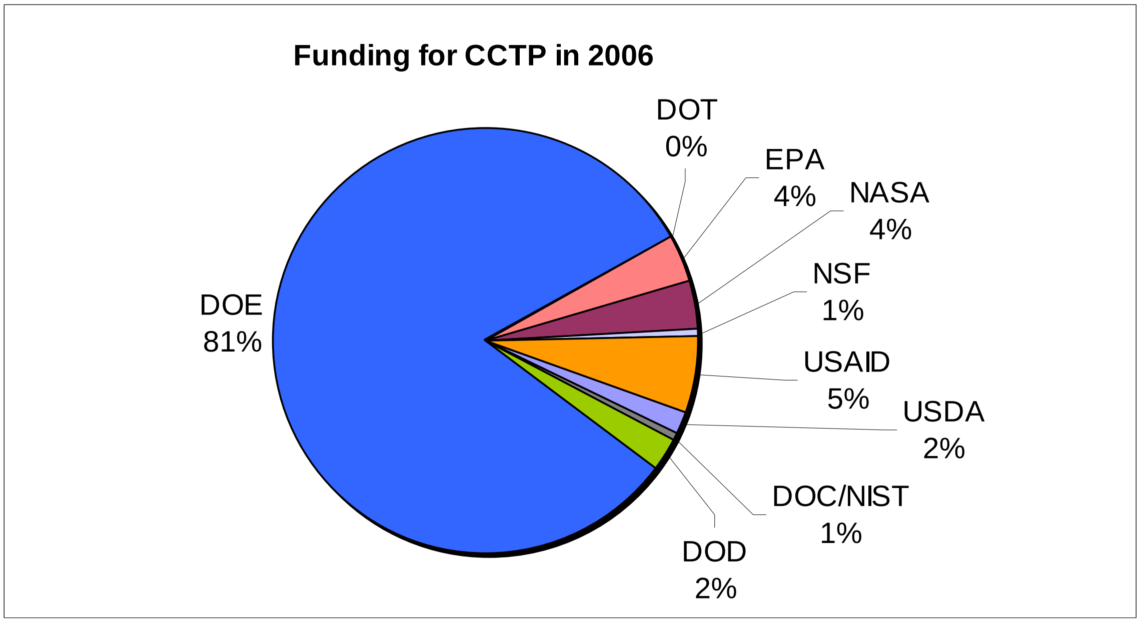

Figure 4.3: Approximate funding percentages for CTTP in FY 2006

Source: CCTP 2006

4.1.2 Environmental Protection Agency (EPA)

The EPA was established in 1970 in order to protect human health and the environment in the United States. The EPA was created in order to repair the damage done by pollutants to water, air, and land while establishing a set of criteria to lead Americans in improving the environment and making it cleaner (EPA, 2007E). The EPA is also responsible for establishing environmental principles, and enforcing policies set up to guarantee that the environment is protected. The EPA does not receive as much funding as many of the other agencies within the CCTP, and thus they do not do very much climate change technology research and development.

In Fiscal Year (FY) 2007 the EPA's budget was $7.3 billion, and in FY 2008 the projected budget is $7.2 billion. In the "Summary of the EPA's Budget" for fiscal year 2008, the EPA has ranked the following goals one through five respectively: clean air and global climate change, clean and safe water, land preservation and restoration, healthy communities and ecosystems, and compliance and environmental stewardship (EPA, 2007E). Some of these goals are more likely to incorporate climate change technology research and development into their agenda. These five goals and the amount they take up of EPA's budget are shown below, in Table 4.1.

Table 4.1: FY 2008 Funding for EPA Goals

Goals	Funding ($ in Millions)
Clean air and global climate change	911.568
Clean and safe water	2,714.315
Land preservation and restoration	1,663.120
Healthy communities and ecosystems	1,171.565
Compliance and environmental stewardship	743.832

The EPA does not do much climate change technology research in comparison to DOE but is higher than other agencies in the CCTP.

Current Work

Examples of the programs EPA is involved in are Energy Star and SmartWay Transport. "Voluntary programs such as Energy Star and SmartWay Transport have increased the use of energy-efficient products and practices and reduced emissions of CO_2 as well as methane and other greenhouse gases with very high global warming potentials. These partnership programs spur investment in advanced energy technologies" (EPA, 2007E). Energy Star is a program that is helping people protect the environment while saving money. Energy Star does this by promoting energy efficient products and practices (Energy Star, 2007). These products can range from lighting, such as fluorescent light bulbs, to electronics such as TV's, to appliances such as refrigerators, and many other products. According to Energy Star, the EPA works in conjunction with the DOE and over 9,000 public and private sector organizations on the Energy Star program. The purpose of the SmartWay Transport partnership is to "increase energy efficiency while significantly reducing greenhouse gases and air pollution." (SmartWay Transport Partnership, 2007). Partners in this program improve fuel efficiency, reduce energy consumption, and reduce their environmental impact. Due to this, the partners in the SmartWay Transport program save fuel, money, and protect the environment. SmartWay Transport describes EPA as working in collaboration with the freight industry, which includes many truck carrier companies and freight shippers, on the SmartWay Transport program.

The EPA is also performing research and development through their air research program on methods for controlling sources emissions. The EPA is requesting $48.6 million in FY 2008 to improve science and research for land preservation and restoration programs. Some of the activities that will take place include researching contaminated sediments, site characterization, and ground water contamination. Ground water contamination is important for this project because that is necessary to know the potential environmental impacts before employing geologic carbon storage methods.

4.1.3 Department of Energy (DOE)

The Department of Energy (DOE) was created on October 1, 1977 and assumed the responsibilities of the Federal Energy Administration, the Energy Research and Development Administration, the Federal Power Commission, and programs of several other agencies that were once separate entities. According to their website, the DOE's mission is "to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex" (DOE, 2007a). The Department's strategic goals to achieve the mission are designed to deliver results along five strategic themes:

- **Energy Security:** Promoting America's energy security through reliable, clean, and affordable energy
- **Nuclear Security:** Ensuring America's nuclear security
- **Scientific Discovery and Innovation:** Strengthening U.S. scientific discovery, economic competitiveness, and improving quality of life through innovations in science and technology
- **Environmental Responsibility:** Protecting the environment by providing a responsible resolution to the environmental legacy of nuclear weapons production
- **Management Excellence:** Enabling the mission through sound management

(DOE, 2007)

The Office of Energy Efficiency and Renewable Energy (EERE) of the DOE is one of seven offices under the Office of the Under Secretary. The only position above this is the Office of the Secretary. EERE is particularly important to climate change technologies. The technologies researched by EERE solve two major problems at the same time, mitigation of emissions and energy security of the U.S.

Current Work

The DOE's current goals surrounding alternative energy involve those set by the President. The President's goals are to achieve the following:

- Foster breakthrough technologies needed to make cellulosic ethanol cost competitive with corn-based ethanol by 2012
- Increase the supply of renewable and alternative fuels to 35 billion gallons by 2017

(DOE, 2007a)

As a result of the President's goals, the U.S supply of fuel ethanol increased by 13.5% in 2005 and was up an additional 28% in 2006. In 2005 the U.S. consumed 100 quadrillion BTUs of energy; biomass accounted for just over 3% (653 million gallons or 0.758 quadrillion BTUs) of the total energy consumption. The EERE's funding of six biorefinery projects aims to accelerate the production of biofuels, which also furthers the President's Twenty in Ten Plan. The plan aims to increase the use of clean, renewable fuels in the transportation sector to the equivalent of 35 billion gallons of ethanol per year by 2017. When fully operational, these biorefineries are expected to produce more than 130 million gallons of cellulosic ethanol per year (DOE, 2007b). These projects help promote wide-scale use of non-food based biomass, such as agricultural waste, trees, forest residues, and perennial grasses in the production of transportation fuels, electricity, and other products.

The Office of EERE was awarded about 5% of the total DOE budget at $1.162 billion in 2006. For 2008 the DOE is requesting to increase their budget to $1.236 billion, a 15% increase. They work on all aspects of renewable energies like hydrogen technologies, solar energy, wind energy, and vehicle technologies. For example, for fuel cell technologies they conduct Production and Delivery research and development, Hydrogen Storage research and development, Fuel Cell Stack Component research and development, Technology Validation, Transportation Fuel Cell Systems, Education (outreach) and Manufacturing research and development just to name a few (EERE, 2007). From this information, it is sufficient to say that this office carries out research and development of climate change technologies from developmental to commercialization stages.

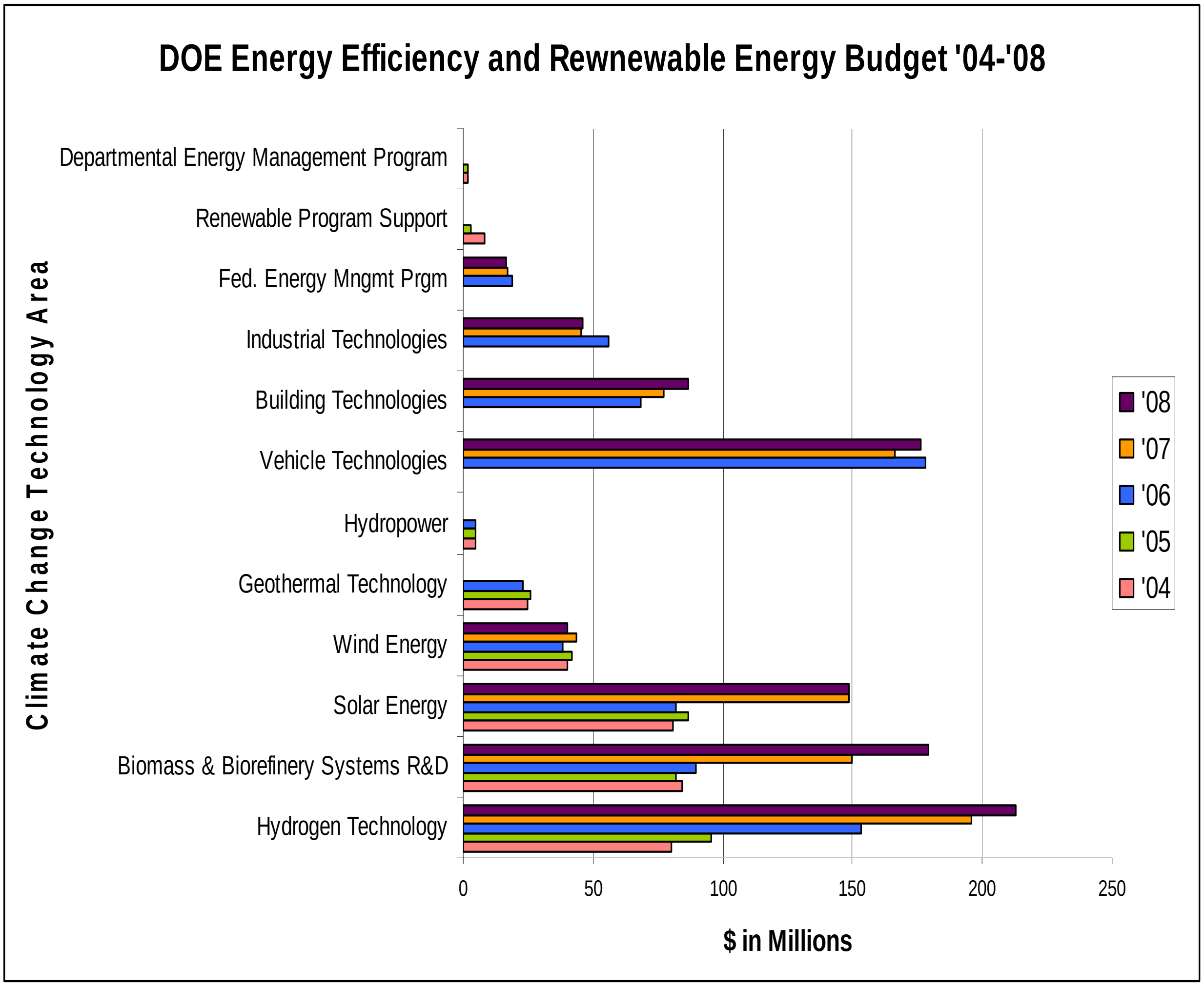

Figure 4.4: Office of the EERE Budget from '04-'08

Source: DOE, 2007

Figure 4.4 points out the focus of the Office of EERE, which handles most of the climate change technologies within the DOE. Based on the graph it is easy to see the DOE is placing more importance on the program offices of Hydrogen Technology, Biomass & Biorefinery Systems, Solar Energy and Vehicle Technologies. The data in the graph imply that the DOE finds these technologies to be the most promising and the most important to reduce U.S. dependency on foreign oil in the future while reducing the anthropogenic (caused by human influence) effects of climate change. The increase in budget to the program offices of Hydrogen Technology, Biomass & Biorefinery Systems and Solar Energies, specifically is also worth noting. From FY 2005 to FY 2008 (requests) the budget for hydrogen technologies more than doubles, from under $100 million to over $200 million. Funding for biomass & biorefinery systems programs will increase by 218% and funding for solar energy programs by 171% in the same time period (FY 2005-FY 2008). Within the offices of Hydrogen Technology, Biomass & Biorefinery Systems, Solar Energy, and Vehicle Technologies, there are specific programs such as the Biomass Program that research and develop important climate change technologies.

DOE Research and Development of Bioenergy

DOE conducts a substantial amount of research and development with biomass as stated above. The following is the progress, results and analysis of their research in the bioenergy field.

Cellulosic Biomass

- First generation technology for production is now in the demonstration phase
- Worked on the performance of ethanol as low-volume (E10) gasoline blend and higher (E85)

Evaluation of Market Acceptance

- Ethanol, from grain-based wet and dry mills, is a well-established commodity fuel with wide market acceptance. Continued success and growth of the ethanol industry can help pave the way for the future introduction of cellulosic ethanol into the marketplace.
- Flexible Fuel Vehicle (FFV) technology is commercially available from a number of U.S. automakers, and several have plans to significantly increase FFV production volumes and expand FFV marketing efforts in the coming years.

(DOE, 2007b)

According to the DOE, established markets for bioenergy exist today in the U.S. and around the world but the unused potential is massive. With a stronger infrastructure, lower production costs, non-competing energy technologies, and without other market barriers, bioenergy could break out into a competitive market. Some market incentives and legislative mandates are helping to overcome some of these barriers but need to continue. Based on the information from their site, DOE is placing a serious focus and a big part of their budget on biofuels, which indicates DOE sees them as a major part of America’s and the world’s future for alternative energy sources. (DOE, 2007b)

The EERE office performs research and development of climate change technologies and alternative fuels for all their program offices. The DOE plays a major role in other areas as well, such as solar energy, hydrogen technologies and biorefineries, and will continue to push the U.S. towards energy independence. Figures 4.5-4.7 below show DOE's involvement with the CCTP. It describes the funding for each climate change area within three offices of the DOE and what types of research questions and problems they work on.

Department of Energy

AGENCY/ PROGRAM/ ACTIVITY	FY 2005 ACTUAL BUDGET AUTHORITY	FY 2006 ENACTED BUDGET AUTHORITY	FY 2007 PROPOSED BUDGET AUTHORITY	NCCTI PRIORITY ACTIVITIES DESCRIPTION
Energy Efficiency and Renewable Energy				
Hydrogen Storage	22.4	26.6	34.6	Addresses key challenge to advancing a hydrogen-based transportation system, which could substitute for oil and dramatically reduce GHG emissions. A major technological breakthrough is needed to be able to store enough hydrogen on board a fuel cell vehicle to provide a driving range comparable to today's vehicles.
Low Wind Speed Technology	9.9	5.0	19.1	Currently, wind power is only cost competitive in areas of high-wind speeds, which are relatively sparse and not near major load centers. Improving technologies to make wind power competitive in low-wind speed areas could expand this GHG-free power producer and displace (or reduce future need for) coal- and gas-fired electricity generation. Includes R&D on deepwater off-shore systems.
Solid State Lighting	13.8	19.3	19.3	Such lighting has the potential to double the efficiency of conventional lighting. Deployment could reduce GHG emissions and slow the growth of future base load electricity generation capacity, which will largely use coal.
Cellulosic Biomass (Biochemical Platform R&D)	11.1	10.4	32.8	The research focuses on converting complex cellulosic carbohydrates of biomass into simple sugars. Ultimately, this could lead to use of "waste" biomass to produce power, chemicals, and fuel, such as ethanol. Cellulosic biofuels can displaces fossil fuel products and have the potential to be nearly "carbon neutral" by cyclically capturing and releasing carbon dioxide, the main GHG, to the atmosphere.
Transportation Fuel Cell Systems	7.5	1.1	7.5	This activity works to incorporate fuel cells into vehicles—converting hydrogen into electricity and water vapor—directly displacing the burning of fossil fuels in vehicles.
EERE Sub-total	**64.7**	**62.4**	**113.3**	

Figure 4.5: Office of EERE Funding Climate Change Areas in CCTP

Nuclear Energy

Nuclear Hydrogen Initiative	8.7	24.8	18.7	This program aims to develop technologies that will apply heat available from advanced nuclear energy systems, in combination with power production, to produce hydrogen at a cost that is competitive with other alternative transportation fuels. Although it is but one of many hydrogen production methods, nuclear energy provides an emissions-free way to produce large amounts of hydrogen.
Advanced Fuel Cycle/Advanced Burner Reactor	0.0	5.0	25.0	Advances in nuclear fuel recycling can make nuclear power, which emits no GHG emissions, more attractive. The Advanced Burner Reactor (ABR) is a component of a multifaceted research program aimed at recycling spent nuclear fuel; reducing waste; promoting non-proliferation; and enabling the expansion of nuclear power—a GHG-free energy source. With ABR technology, the only waste to be placed in a repository is of a less challenging content, absent long-lived radioactive isotopes and other transuranics. One Yucca Mountain size repository would be able to accommodate the waste from many reactor-years of operation—a content that would fill as many as 21 equal repositories taking all that spent fuel directly.
NE Sub-total	**8.7**	**29.8**	**43.7**	

Figure 4.6: Office of Nuclear Energy Funding Climate Change Areas in CCTP

Fossil Energy

Sequestration	44.3	66.3	78.2	The continued use of fossil fuels, particularly coal, to generate electricity may be important to maintain both a diversified fuel mix and ensure adequate energy supplies at a reasonable price. A successful carbon sequestration research and development effort could allow the continued use of economical fossil fuels, while also limiting GHG emissions to the atmosphere.
Integrated Gasification Combined Cycle (IGCC)	44.6	55.9	55.6	Instead of burning coal, IGCC technology gasifies coal in such a way so as to enable the more efficient conversion of coal and other carbon-based feedstocks into electricity and other useful products, providing the potential for over 50 percent reduction in CO_2 emissions, compared to today's more conventional combustion technologies. It also facilitates capture and sequestration processes.
FE Subtotal	**89.0**	**122.2**	**133.8**	
Climate Change Technology Program Direction	–[2]	0.0	1.0	The CCTP is the multi-agency planning and coordination activity, led by DOE, that carries out the President's climate change technology initiative and implements relevant climate change provisions of the Energy Policy Act of 2005. CCTP provides strategic direction, planning, analysis and multi-agency coordination for the participating Federal R&D agencies.
Total – DOE	**162.4**	**214.4**	**291.8**	

Figure 4.7: Office of Fossil Energy Funding Climate Change Areas in CCTP

4.1.4 National Aeronautics and Space Administration (NASA)

Under President Dwight D. Eisenhower the National Aeronautics and Space Administration (NASA) was established in 1958. The mission of NASA is to "pioneer the future in space exploration, scientific discovery, and aeronautics research" (NASA, 2007). NASA continued the work started 40 years earlier by the National Advisory Committee on Aeronautics (NACA). NASA works on high-technology based projects including the Mercury and Gemini projects that helped put Neil Armstrong on the Moon. Like other departments and agencies within the government, NASA's projects and missions change depending on the needs of the country and goals set by the President.

Current Work

Since the new millennium, NASA's projects have shifted slightly towards GHG monitoring technologies. This is the only type of climate change technology NASA is involved with, but they are the only agency working on GHG monitoring from space. NASA put $104.2 million towards the CCTP in 2007 in the areas of exploration, science and aeronautics, and has requested to invest $85.8 million in 2008. The major project with GHG monitoring is the Orbiting Carbon Observatory (OCO) which is an Earth System Science Pathfinder Project (ESSP). This technology, scheduled to launch in 2008 has been "designed to make precise, time-dependent global measurements of atmospheric CO_2 from an Earth orbiting satellite." (NASA, 2007) The OCO, in conjunction with the ground-based network of monitoring systems and the 'A-Train', will help scientists understand the processes that regulate atmospheric CO_2 and its role in the carbon cycle. The A-Train, or the Earth Observing System Afternoon Constellation, is a formation of satellites that aims to improve our understanding of aspects of the Earth's climate (NASA, 2007).

Currently, anthropogenic emissions are calculated using mathematical formulas based on industry estimates. For example, emissions from the transportation sector are calculated based on the amount of oil consumed. The A-Train (including the OCO) will help scientists understand the scope of worldwide CO_2 emissions and more accurately predict the effects that increases of atmospheric CO_2 have on global climate change. According to NASA this information could help policy makers and business leaders make well-informed decisions to achieve climate stability.

4.1.5 Department of Transportation (DOT)

The DOT was created on October 15, 1966 by act of Congress. The agency was set up in order to "serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future" (DOT, 2007).

The DOT has a budget of $67 billion for fiscal year 2008. With this money the Department of Transportation is focusing on five major areas. These areas are safety, reduced congestion, global connectivity, environmental stewardship, and security preparedness and response. These five goals and how much they contribute towards DOTs total budget are shown below, in Table 4.1.5.

Table 4.2: FY 2008 Funding for DOT Goals

Goals	Funding (In Billions of Dollars)
Safety	20.5
Reduced Congestion	36.5
Global Connectivity	1.5
Environmental Stewardship	6.5
Security Preparedness and Response	1

The majority of DOT funding that pertains to climate change deals with efficiency of systems to reduce emissions. An example of this is reducing congestion on highways which improves the efficiency of the system and will reduce emissions. The DOT is also helping to reduce emissions under the clean fuels grant program by purchasing clean fuel buses as well as new facilities for these buses or upgrading existing facilities. The DOT plans to put forth $49 million towards this objective. According to the DOT, the clean fuels these buses will run on are compressed natural gas, biodiesel fuels, batteries, alcohol-based fuels, hybrid electric, fuel cells, and other various low or zero emissions technologies (DOT, 2007). Of the five major areas DOT is funding, only one is doing significant research in terms of climate change technology research and development. The area performing this research and development on climate change technologies is environmental stewardship. This work involves researching technologies to reduce emissions. Of environmental stewardships entire budget, reducing emissions receives around half, or \$2.8 billion. To reduce emissions technologies such as more efficient vehicles, and alternative fuels are researched and developed.

The DOT funds research and development on emissions control technologies, but this is not their focus. They play a small role in the CCTP program due to the fact that most of their budget is for reducing congestion, which will reduce emissions, and increasing the safety of vehicles and roadways.

4.1.6 United States Agency for International Development (USAID)

The United States Agency for International Development (USAID) is another agency that works to mitigate climate change. USAID works to expand democracy and free markets as well as improve the lives of people in developing countries. USAID came into existence in 1961 when the Foreign Assistance Act was passed, separating military and non-military foreign aid. Some areas of technology that USAID works with are energy efficiency, conservation and solar energy. In 2002 President Bush announced that USAID would be “a primary vehicle for transferring American energy and sequestration technologies to developing countries to promote sustainable development and minimize their greenhouse gas emissions growth.” (USAID, 2007). In 2006 USAID allotted \$92 million for energy technology RESEARCH AND DEVELOPMENT and \$80.3 million for carbon capture and sequestration measures (CCTP, 2006). By seeking to improve energy and industrial efficiency, and achieving advances in renewable energy, methane capture, and clean technologies, USAID has helped prevent the equivalence of over 15 million metric tons of CO_2 emissions over the past five years (USAID, 2007). Also, USAID is encouraging the use of low cost solar water heating units in South Africa. This along with other conservation goals will help reduce the total amount of GHGs emitted by the world’s population, therefore mitigating climate change.

4.1.7 United States Department of Agriculture (USDA)

The United States Department of Agriculture (USDA), which was formed in 1862, provides leadership on food, agriculture, natural resources, and related issues based on sound public policy, the best available science, and efficient management (USDA, 2007). The USDA strives to do this through several activities including “expanding markets for agricultural products and support international economic development, further developing alternative markets for agricultural products and activities, providing financing needed to help expand job opportunities, improve housing, utilities and infrastructure in rural America, enhancing food safety by taking steps to reduce the prevalence of food borne hazards from farm to table, improving nutrition and health by providing food assistance and nutrition education and promotion, and managing and protecting America's public and private lands working cooperatively with other levels of government and the private sector" (USDA, 2004). The total budget for the USDA for 2007 was an estimated $92.8 billion (USDA, 2007). According to the CCTP's Strategic Plan for 2006, the USDA provided a total of $47.8 million towards the CCTP's Research, Development, Demonstration, and Deployment (RDD&D) program in 2006; Figure 4.5, below, depicts what areas this $47.8 million is used in.

4.2 Climate Change Technologies Matrix

In addition to the technologies that are researched and developed by the departments and agencies discussed above, looking at a broad spectrum of technologies is important. Tables 4.3-4.10 show the wide array of climate change technologies. The tables also list which parties are most likely to fund research and development and conduct the research and development in these areas. It also evaluates the level of development and potential sectors for implementation once commercialized. The technology's importance to NCER helps filter out technologies not suitable for NCER research and development. NCER and DOE's focus helps show where each of these agencies has put past research and development efforts which will also help determine technologies appropriate for NCER research and development in the future. DOE's focus column is based on the DOE's budget and NCER's focus was based on the analysis of the projects funded by the SBIR and P3 programs later in this chapter. Specific criteria for the level of development, along with other columns in this matrix can be found in Appendix A5.

4.2.1 Classifications for Technologies Matrix

Technology Categories

All technologies will fall under the following categories which have been based closely on the category system established by National Geographic 2007

- Low Carbon Fuels
- GHG Monitoring
- Efficiency and Conservation

- Renewables and Biofuels
- Carbon Capture and Storage

Technology Development

- **Research/Proof of Concept**
  - A technological approach or idea with potential to solve various types of expensive and challenging problems
  - Results from this stage should show technical promise and market potential to be able to be supported further down the line

- **Development**
  - A "pilot stage" research that may require many trials to correct to deem it unique technology
  - This stage must show promise technically and economically in order to gain support for full scale testing

- **Demonstration**
  - This is the first time the technology sees early stage full-scale demonstrations to observe performance, determine its applicability and weaknesses and determine cost
  - Results from this stage may be used to market the technology to receive additional support from possible customers

- **Verification**
  - Final testing by developers and independent organizations is completed and results will be made public
  - Results, if positive, are used to market the product to customers

- **Commercialization**
  - This stage prepares the technology for full-scale manufacturing and marketing activities

- **Diffusion / Utilization**
  - Implementation of a full-scale marketing plan for the technology
  - Encourages the adoption and/or purchase of the final product

Source: Environmental Technology Opportunities Portal, 2007

Research Funding

- Government
  - A national government is funding research for the area
- Commercial
  - Funding for the area is provided by private companies

Researching Bodies

- Government
  - A government agency is conducting the research on the area themselves
- Commercial
  - A private company is conducting the research on the area
- Universities
  - A university is conducting the research on the area

Potential Sectors for Implementation

Once the technology is commercially available it will be characterized in one of the following sectors. Some technologies might not be suitable for domestic use in which case it will be utilized by the government or commercially. Government programs for certain technologies could be set up once a technology comes to fruition (i.e. carbon sequestration).

- Domestic energy (heating/cooling)
- Commercial energy
- Government
- Transportation (passenger, freight)

Relevance to NCER Research

Technologies will be categorized as either yes or no depending on many factors including previous funding in the area by NCER and funding in other departments working with climate change. If a technology is very well developed, it will be categorized as ‘no’ because NCER only has interested in less developed areas. If a technology does not have potential a high CO_2 avoidance factor on mitigating emissions, based on research and interviews, it will be categorized as ‘no’ as well because NCER only has interest in technologies that have potentially high impact. This category will be further discussed in the analysis chapter and will eventually aid in recommendations to NCER.

DOE’s Focus

Using extensive budget summaries from 2006-2008 put out by the DOE we were able to analyze specific areas of climate change technologies the DOE is interested in. Technologies were ranked Low-High based on budget percentages from FY05-FY08 budget summaries.

NCER's Focus

This column in the matrix is based on Tables 4.11-4.13 and shows whether or not a technology has been part of NCER research and development in the last three to four years where the majority of climate change technology research and development has been done. Technologies are rated on a scale from low-high. Technologies with only one or two projects were given low or low/none. Technologies that been researched in three to five projects were given a medium score. All others were given a high ranking. Phase I and Phase II projects were taken into consideration when evaluating NCER's focus.

Key	
	Level of Development
C=Commercial D=Domestic G=Government T=Transportation U=University	1=Research/Proof of Concept 2=Development 3=Demonstration 4=Verification 5=Commercialization 6=Diffusion/Utilization

Table 4.3: GHG Monitoring Technologies

GHG Monitoring										
Technology Type	**Specific Tech.**	**Product**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Potential Sectors for Implementation**	**Relevant to NCER Research**	**NCER's Focus**	**DOE's Focus**
Portable Devices					C	6		No	Low/ None	Low
	Laser Induced Breakdown Spectroscopy		Portable field device that analyzes chemical make-up of the soil	G	G,C	4	C			
		Air Sense ™	Accurately measure the parts per million (ppm) CO_2 concentration levels typically found in inhabited spaces	G,C	C	5	C,D			
Tower Monitoring			Long-term measurements of CO_2 and water		U,G,C	6	G,C	No	Low/ None	Low
	Ameriflux Tower		Towers spread over the North America that provide regional measurements of CO_2	G	U,G,C	6	G			
Aerial Monitoring			Monitor CO_2 and other GHGs from a plane	G	G,C	6	G	No	Low/ None	Low
Satellite Monitoring					G		G	No	Low/ None	Low
	Orbiting Carbon Observatory (OCO)		Satellite atmospheric GHG monitoring technology developed by NASA	G	G	2	G			
	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)		Near simultaneous measurements of aerosols, clouds, temperature, relative humidity, and radiative fluxes (the change of radiation in a layer) will be obtained over globe during all seasons	G	G	6	G			

Table 4.4: Efficiency and Conservation Technologies

Efficiency & Conservation									
Technology[1] Type	**Specific Tech.**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Potential Sectors for Implementation**	**Relevant to NCER Research**	**NCER's Focus**	**DOE's Focus**
Power Generator									
	FutureGen		G						
	Combined Cycle Gas Turbine (CCGT)	Uses a combustion and steam turbine to increase efficiency	C	C	6	C	No	Low/ None	Low
	Integrated Gasification Combined Cycle (IGCC)	Used in power plants. Operates with very low emissions. Reuses energy captured in steam turbine to provide a very high efficiency	C	C	5	C,D	Maybe		
Hybrid Vehicle		Uses 2 or more main fuel sources. Usually electricity and gasoline	G,C	C,U	6	C,D	Yes		
Electric Vehicle		Uses electricity to power the vehicle	G,C	C,U	6	C,D	Yes		

[1] Green buildings are a technology under the efficiency and conservation category that was not researched. Green buildings involve a combination of many different technologies such as solar, heat pumps, and wind turbines, that are included in the matrix. Green buildings often use conservation and efficiency techniques that do not necessarily deal with any specific technology, such as design of the house to have more windows or face a certain direction to maximize solar gain, reducing heating costs. This is not to say that these technologies/techniques are less effective at limiting the anthropogenic effects to global climate change.

Table 4.5: Low Carbon Fuels

Low Carbon Fuels									
Technology Type	**Product**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Potential Sectors for Implementation**	**Relevant to NCER Research**	**NCER's Focus**	**DOE's Focus**
Compressed Natural Gas (CNG)		Natural gas under pressure often used as a fuel source for vehicles	C	C,U	6	D,T	Yes	Med	Med
	Pure Comfort	Natural gas powered turbines	C	C	6	C,D			
Liquefied petroleum gas (LPG)		LPG, otherwise known as propane, is often used as a fuel for vehicles and barbeques.	C	C,U	6	C,D	Yes		

Table 4.6: Carbon Capture Technologies

Carbon Capture										
Technology Type	**Specific Tech.**	**Product**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Pot. Sect. for Implm.**	**Relevant to NCER Research**	**NCER Focus**	**DOE Focus**
Pre-Combustion			Gasify fossil fuel before combustion	G,C	G,C	5	C	No	Low/ None	Mediu m/ Low
	IGCC		IGCC's are 'capture ready'	G,C	G,C	5	C			
Oxy-Combustion			Combust in almost pure oxygen environment	G,C	G,C	4	C	Yes	Low/ None	Mediu m/ Low
Post-Combustion			Capture CO_2 from Flue gas, or from the air	G,C	G,C,U	5	C	Yes	Low/ None	Mediu m/ Low
	CO_2 Scrubber s		Remove CO_2 from the air using sorbents	G,C	G,C,U	2	G,C	Yes	Low/ None	Low/ None
		Artificial Trees	The CO2 could be captured from the artificial trees and recycled back into synthetic gasoline or synthetic diesel fuel	G,C	C	2	G,C			
		CO2 Scrubbe r Series II	Scrubbers for CO2 control inside Controlled Atmosphere apple warehouse storage rooms	G,C	C	6	C			

Table 4.7: Carbon Storage Technologies

Carbon Capture										
Technology Type	**Specific Tech.**	**Product**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Pot. Sect. for Implm**	**Relevant to NCER Research**	**NCER Focus**	**DOE Focus**
Pre-Combustion			Gasify fossil fuel before combustion	G,C	G,C	5	C	No	Low/ None	Medium/ Low
	IGCC		IGCC's are 'capture ready'	G,C	G,C	5	C			
Oxy-Combustion			Combust in almost pure oxygen environment	G,C	G,C	4	C	Yes	Low/ None	Medium/ Low
Post-Combustion			Capture CO_2 from Flue gas, or from the air	G,C	G,C,U	5	C	Yes	Low/ None	Medium/ Low
	CO_2 Scrubbers		Remove CO_2 from the air using sorbents	G,C	G,C,U	2	G,C	Yes	Low/ None	Low/ None
		Artificial Trees	The CO2 could be captured from the artificial trees and recycled back into synthetic gasoline or synthetic diesel fuel	G,C	C	2	G,C			
		CO2 Scrubber Series II	Scrubbers for CO2 control inside Controlled Atmosphere apple warehouse storage rooms	G,C	C	6	C			
Oceanic			When CO_2 is deposited into the ocean for long term storage	G	G,C	3	G,C	Yes	Low/ None	Medium/ High
	Direct Injection - Droplet plume		Droplet plume is liquid CO2 injected at depths of 1000 meters or greater	G	G,C	2	G,C			
	Direct Injection - Dense plume		Dense plume is a mixture of seawater and CO_2 mixed at a depth of around 500 to 1000 meters.	G	G,C	2	G,C			
	Direct Injection - Dry Ice		Dried ice being released from a surface ship. Will sink to depths of 1000m or greater	G	G,C	2	G,C			
	Direct Injection - Towed Pipe		Towed pipe attached to a surface ship that injects liquid CO_2 at depths of 1000 m	G	G,C	2	G,C			
	Direct Injection - CO_2 Lake		CO_2 lake is liquid CO_2 being injected into sea floor indents at about 4000 meters to form a lake	G	G,C	2	G,C			
Geologic			Stores carbon into natural ground reservoirs	G,C,U	G,C	4	G,C	Yes	Low/ None	Medium/ High

Table 4.8: Carbon Sequestration Technologies

Carbon Sequestration										
Technology Type	**Specific Tech.**	**Product**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Pot. Sect. for Implm**	**Relevant to NCER Research**	**NCER's Focus**	**DOE's Focus**
Terrestrial			Sequestering CO_2 using plant life	G	G,C	5	G,C	Yes	Low/ None	Medium
	Algal Processing		Sequester CO_2 with algae, algae can then be used for biomass	G,C,U	C	3	G,C	Yes	Medium	Low
Oceanic							G,C	No	Low/ None	Low/ None
	Iron Fertilization		Sprinkle Iron over ocean to create phytoplankton which consume CO_2	G,C	C,U	3	G,C			

Table 4.9: Biofuel Technologies

Biofuels									
Technology Type	**Specific Tech.**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Pot. Sectors for Implem.**	**Relevant to NCER Research**	**NCER Focus**	**DOE Focus**
Bioreactors		The reactor that converts the biomass into a useable energy source	G,C	G,C	4	C	Yes	No	Yes
Biofuel		Fuels derived from plant material	G,C	G,C,U		C,D	Yes	High	High
	Ethanol - Sugar Cane	Ethanol derived from sugar cane	G,C	G,C,U	6(Brazil)	C,D,T	No	Mediu m/ High	High
	Ethanol - Cellulosic	Ethanol derived a from cellulosic process which uses most of the mass from the feedstock to produce ethanol (Corn stover, switchgrass, miscanthus and woodchip)	G,C	G,C,U	2	C,D,T	Yes	Mediu m/ Low	High
	Ethanol - Corn	Ethanol derived from corn	G,C	G,C,U	6	C,D,T	Yes	Mediu m/ Low	High
	Ethanol - Soy bean	Ethanol derived from soy beans	G,C	G,C,U	6	C,D,T	Yes	Low/ None	Low/ None

Table 4.10: Renewable Technologies

Renewables										
Technology Type	**Specific Tech.**	**Product**	**Description**	**Research Funding**	**Researching Bodies**	**Level of Development**	**Poten. Sectors for Implem.**	**Rel. to NCER Research**	**NCER's Focus**	**DOE's Focus**
Hydrogen			Chemical potential to electrical energy				C,D,T	Yes	Medium / Low	High
		PEM Fuel Cell	Hydrogen fuel cell suggested for automotive use	C	C,U	3	T			
		PureCell	One site hydrogen fuel cell power solution	C	C	6	C,D			
Geothermal			Electrical Energy from Earth's heated core	G,C	C,U		C,D	Yes	Low/ None	Low
	Heat pumps		Uses the Earth's ability to store heat in the ground and water thermal masses and pump into homes and businesses	G,C	C	6	C,D			
		Pure Cycle		C	C	6	C,D			
Solar			Sun's rays to electrical energy	G,C	G,C,U	6	C,D	Yes	Medium / High	Medium
	Solar Updraft Tower		Sun's radiation is used to heat a large body of air, which is then forced by the laws of physics (hot air rises) to move as a hot wind through large turbines to generate electricity	C	C	2	C			
	Solar Mirror Tower		Large field of sun-tracking mirrors, called heliostats, which focus solar energy on a receiver atop a centrally located tower. This heats water that is harnessed by a steam turbine	C	C	6	C			
	Photovoltaic (PV)		Direct conversion of sunlight to electricity using semiconductor devices called solar cells	G,C	G,C,U	6	C,D			
	Active		Active solar collector systems take advantage of the sun to provide energy for domestic water heating, pool heating, ventilation air preheat, and space heating		C	6	C,D			
	Passive		Passive solar systems make use of natural energy flows as the primary means of harvesting solar energy		C	6	C,D			
Wind			Kinetic energy in moving air to electrical energy	G,C	G,C,U	6	C,D	No	Medium	Medium/ Low
	Horizontal-axis wind turbines (HAWT)		Main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind	G,C	G,C,U	6	C,D			
	Vertical-axis wind turbines (VAWT)		Main rotor shaft running vertically	C	G,C,U	6	C,D			

Hydro			Kinetic energy in moving water to electrical energy	G,C	G,C,U	6	C	No	Low	Low
Oceanic			Kinetic energy in ocean motion to electrical energy	G,C	C	2	C,D	No	Low/ None	Low
	Tidal Turbine		Underwater fans that harness power from tides going in and out, also currents	C	C	1	C,D			
		Stingra y		C	C	1	C			
	Pelamis "the snake"		Four 40 meter long steel tubes, which float on the surface of the sea. The action of the waves makes each section flex against the next one. Hydraulic rams drive fluid, which then drives generators	C (Europe)	C	4	C			
	Wave Power Station		Stationary structure built on the shore that harnesses the waves in a generator to turn into electricity	C	C	5	C			
	Offshore Floating Wave Energy Device		A floating device that can convert wave energy to electricity	C	C	4	C			
		Mighty Whale System	Uses oscillating water column, and contains three air chambers that convert wave energy into pneumatic energy. Wave action causes the internal water level in each chamber to rise and fall, forcing a bi-directional airflow over an air turbine	C (Japan)	C	4	C			
	Archimedes Wave Swing (AWS)		Uses waves to produce energy	C	C	3	C,D			

4.3 Projects funded by SBIR and P3

To accurately fill out the NCER's focus column in Tables 4.3-4.10, a review of all the funded projects from SBIR and P3 was completed. Tables 4.11-4.13 below show the projects in the P3 and SBIR programs that involve climate change technologies. SBIR and P3 are extramural research programs within the NCER that grant funding through a solicitation process. For P3 this solicitation goes out to Universities and Colleges while SBIR solicits to small businesses (less than 500 employees). Each program has Phase I & II funding for each project. Most never make it to Phase II, where a project can receive up to $75,000 for P3 and $225,000 for SBIR projects. The title, year of project, technology involved and phase of the projects are identified.

Table 4.11: Climate Change Technology SBIR Projects

SBIR '04-07 Projects				
Project Title	**Year**	**Category**	**Phase I, Phase II**	**Funding**
Enhanced Ethanol Diesel Blends for Emission Reduction	2006	Biofuel	I	$ 70,000
Power for Animal Wastes System Gasifier	2006	Biofuel	I	$ 70,000
Advanced Slagging Gasifier for Biomass Wastes	2006	Biofuel	I	$ 70,000
Low-Cost Biodiesel Production Process Using Meat-Rendering Wastes, Recycled Greases and Unrefined Vegetable Oil Feedstocks	2007	Biofuel	I	$ 70,000
Technology for Enhanced Biodiesel Economics	2007	Biofuel	I	$ 70,000
Small Scale Ethanol Drying	2007	Biofuel	I	$ 70,000
Synthetic Gasoline From Biomass	2007	Biofuel	I	$ 70,000
Liquid Hydrocarbon Fuels From Biomass Materials	2007	Biofuel	I	$ 70,000
A Biomass Energy Process for Poultry Growing Operations	2007	Biofuel	I	$ 70,000
Handheld MEMS-Based Detector of Toxins and Toxigenic Organisms Indicative of Harmful Algal Bloom	2007	Carbon Sequestration	I	$ 70,000
Novel Membrane Systems for Off-Road Diesel Engine NOx Reduction	2004	Efficiency	I	$ 70,000
A Retrofit and Low-Cost Small Industrial Boiler Flue Gas Purification Technology	2005	Efficiency	I	$ 70,000
Reduction of NO_x Using On-Board Plasma Generated Hydrogen	2007	Efficiency	I	$ 70,000
An Innovative Transport Membrane Condenser for Water Recovery From Gas and Its Reuse	2007	Efficiency	I	$ 70,000
HybridAir: An Integrated Ventilation, Vapor Compression, and Indirect Evaporative Cooling System	2006	Efficiency	I	$ 70,000
Quiet Reliable and Compact Fuel Cell Based APU (QRCFC-APU)	2006-2009	Fuel Cell	I, II	$ 295,000
Nanocrystalline Materials for Removal of Reduced Sulfur and Nitrogen Compounds From Fuel Gas	2007	GHG Capture	I	$ 70,000
Hot Fuel-Gas Sorbent System	2007	GHG Capture	I	$ 70,000
Robust Diode Lasers for Monitoring and Measurement Technologies	2004-2005	GHG Monitoring	II	$ 225,000
Development of a Fine and Coarse Particulate Continuous Emissions Monitoring System	2005-2007	GHG Monitoring	I, II	$ 295,000
Streamlining Green Building Design: Developing the Sustainable Design Suite	2005-2007	Green Bldg	I, II	$ 295,000
			TOTAL	$ 2,300,000

Source: (SBIR Awards List, 2007)

Table 4.12: Climate Change Technology P3 Projects 2006-2007

P3 2006-2007 Projects				
Project Title	**Year**	**Category**	**Phase I, Phase II**	**Funding**
Production of Biodiesel from Algae applied to Agricultural Wastewater Treatment	2007	Biofuel	I	$ 10,000
A Bio-Diesel Baja Vehicle and Student Competition	2007	Biofuel	I	$ 10,000
A New Approach for Biodiesel Production from Algae	2007	Biofuel	I	$ 10,000
Bio-Methane for Transportation	2007	Biofuel	I	$ 10,000
Biodiesel in the Loop: Outreach, Education, and Research	2007	Biofuel	II	$ 75,000
GREEN KIT: A Modular, Variable Application System for Sustainable Cooling	2007	Efficiency & Conservation	I	$ 10,000
Converting Energy from Reclaimed Heat: Thermal Electric Generator	2007	Efficiency & Conservation	I	$ 10,000
Environmental and Economic Impact Analysis of Manure Digester Biogas-Powered Fuel Cells for the Agricultural Sector	2007	Fuel Cell	I	$ 10,000
Photosynthetic Biohydrogen, An All-Worlds Solution to Global Energy Production	2007	Fuel Cell	I	$ 10,000
The Affordable Bioshelters Project: Testing Technologies for Affordable Bioshelters	2007	Green Bldg	I	$ 10,000
Optimizing Green Roof Technologies in the Midwest	2007	Green Bldg	I	$ 10,000
Harnessing Ocean Wave Energy to Generate Electricity: A Scalable Model Designed to Harness a Large Range of Surface Waves on the Ocean	2007	Oceanic	I	$ 10,000
Performance of Solar Hot Water Collectors for Electricity Production and Climate Control	2007	Solar	I	$ 10,000
The Design and Fabrication of a Lower Cost Heliostat Mirror System for Utilizing Solar Energy	2007	Solar	I	$ 10,000
Solar Photovoltaic System Design for a Remote Community in Panama	2007	Solar	I	$ 10,000
Solar LED Lanterns for the Replacement of Kerosene in the Developing World	2007	Solar	I	$ 10,000
Closing the Biodiesel Loop: Self Sustaining Community Based Biodiesel Production	2006	Biofuel	I	$ 10,000
Biodiesel as a Sustainable Alternative to Petroleum Diesel in School Buses	2006	Biofuel	I	$ 10,000
Design of a Trap Grease Upgrader for BioFuel Processing	2006	Biofuel	I	$ 10,000
Photobioreactor for Hydrogen Production from Cattle Manure	2006	Fuel Cell	I	$ 10,000
Knudsen Cell Reactor for Catalyst Research Related to Hydrogen Technologies	2006	Fuel Cell	I	$ 10,000
Renewable Resources To Power A University - A Model For Regional Sustainable Development	2006	Green Bldg	I	$ 10,000
The Green Dorm: a Sustainable Residence and Living Laboratory for Stanford University	2006	Green Bldg	I	$ 10,000
Growing Alternative Sustainable Buildings: Bio-composite Products from Natural Fiber, Biodegradable and Recyclable Polymer Materials for Load-bearing Construction Components	2006	Green Bldg	I	$ 10,000
Solar Thermal Heating System for a Zero Energy House	2006	Solar	I	$ 10,000
S.T.E.P. (Solar Thermal/Electric Panel):Full-Scale Performance Data and Energy Testing	2006	Solar	I	$ 10,000

Table 4.13: P3 Climate Change Technology P3 Projects 2004-2005

P3 2004-2005 Projects				
Project Title	**Year**	**Category**	**Phase I, Phase II**	**Funding**
Community-Scale Biodiesel: An Affordable, Renewable Resource	2005	Biofuel	II	$ 75,000
Moving Towards a Sustainable Campus: Design of a Green Roof Monitoring Experiment	2005	Green Bldg	I	$ 10,000
Sustainable Energy Systems Design for a Tribal Village in India	2005	Green Bldg	II	$ 75,000
AWARE@home: Profitably Integrating Conservation into the American Home	2005	Green Bldg	II	$ 75,000
Design and Implementation of a Low Cost, Regionally Appropriate Solar Oven with Minimum Ecological Impact for Developing Countries	2005	Solar	II	$ 75,000
Demonstrating the Feasibility of a Biofuel: Production and Use of Biodiesel from Waste Oil Feedstock and Bio-based Methanol at Middlebury College	2004	Biofuel	I	$ 10,000
Community-Scale Biodiesel: An Affordable, Renewable Resource	2004	Biofuel	I	$ 10,000
From Field to Fuel Tank: Exploring the Implementation of Biodiesel as a Sustainable Alternative to Petroleum Diesel in Oregon's Willamette Valley	2004	Biofuel	I	$ 10,000
Reduction of Use of Petroleum Enrgy Resources by Conversion of Waste Cooking Oils into Diesel Fuel	2004	Biofuel	I	$ 10,000
Energy Management Innovation in the US Ski Industry	2004	Efficiency & Conservation	I	$ 10,000
Design of an Anaerobic Digester and Fuel Cell System for Energy Generation from Dairy Waste	2004	Fuel Cell	I	$ 10,000
Pollution Reduction and Resources Saving Through the Use of Waste Derived Gas for Fueling a High Temperature Fuel Cell	2004	Fuel Cell	I	$ 10,000
Capstone Senior Design - Supramolecular Proton Exchange Membranes for Fuel Cells	2004	Fuel Cell	I	$ 10,000
Photoelectrochemical Hydrogen Production Prototype	2004	Fuel Cell	I	$ 23,000
Conversion of Wind Power to Hydrogen Fuel: Design of an Alternative Energy System for an Injection Molding Facility	2004	Fuel Cell / Wind	I	$ 10,000
Greening Standards for Green Structures: Process and Products	2004	Green Bldg	I	$ 10,000
The Evergreen Roof Project: Standards, Methods and Software for Evaluating Living Roof Systems	2004	Green Bldg	I	$ 10,000
Scrap Tire Recycling: Convincing Businesses to Integrate Inexpensive, Cutting-edge Technology to Convert Tires Into Various Construction Materials	2004	Green Bldg	I	$ 10,000
Eco-Wall Systems: Using Recycled Material in the Design of Commercial Interior Wall Systems for Buildings	2004	Green Bldg	I	$ 10,000
Smart Windows for Smart Buildings	2004	Green Bldg	I	$ 10,000
Sustainable Energy Systems Design for a Tribal Village in India	2004	Green Bldg	I	$ 10,000

Beyond Green Buildings: An Integrated Holistic Design Approach	2004	Green Bldg	I	$ 10,000
Fostering Sustainability: Designing a Green Science Building at a Small Maine College	2004	Green Bldg	I	$ 10,000
Healthy and Energy-Efficient Housing in Hot and Humid Climates: A Model Design	2004	Green Bldg	I	$ 10,000
AWARE@home: Profitably Integrating Conservation into the American Home	2004	Green Bldg	I	$ 10,000
Zero Net Energy Homes Project	2004	Green Bldg	I	$ 10,000
Renewable Energy for the RiverSphere	2004	Hydro	I	$ 10,000
Adoption of Alternative Energy Sources in Chico, CA: Facilitating an Action Plan	2004	Solar	I	$ 10,000
Accurate Building Integrated Photovoltaic System (BIPV) Architectural Design Tool	2004	Solar	I	$ 7,000
City in a Box: A New Paradigm for Sustainable Living	2004	Solar, Wind, Biofuel, Geothermal, Green Building	I	$ 10,000
The Wind Energy Research Program (WERP): Design and Construction of a Wind Turbine to Facilitate Education and Research in Sustainable Technologies	2004	Wind	I	$ 30,000
Ground water remediation powered with renewable energy	2004	Wind, Solar	I	$ 10,000
			TOTAL	$ 935,000

Source: P3 Awards List, 2007

The projects above can be analyzed and graphed to highlight areas where these programs focus their extramural funding and to what extent they fund. The first step in the analysis of these programs was to look at the number of projects related to climate change technologies. The numbers of climate change projects that undergo research and development in these two programs are graphed below in Figure 4.7. The graph below is based on the table of projects and shows what types of technologies each program has funded over the past 3 years.

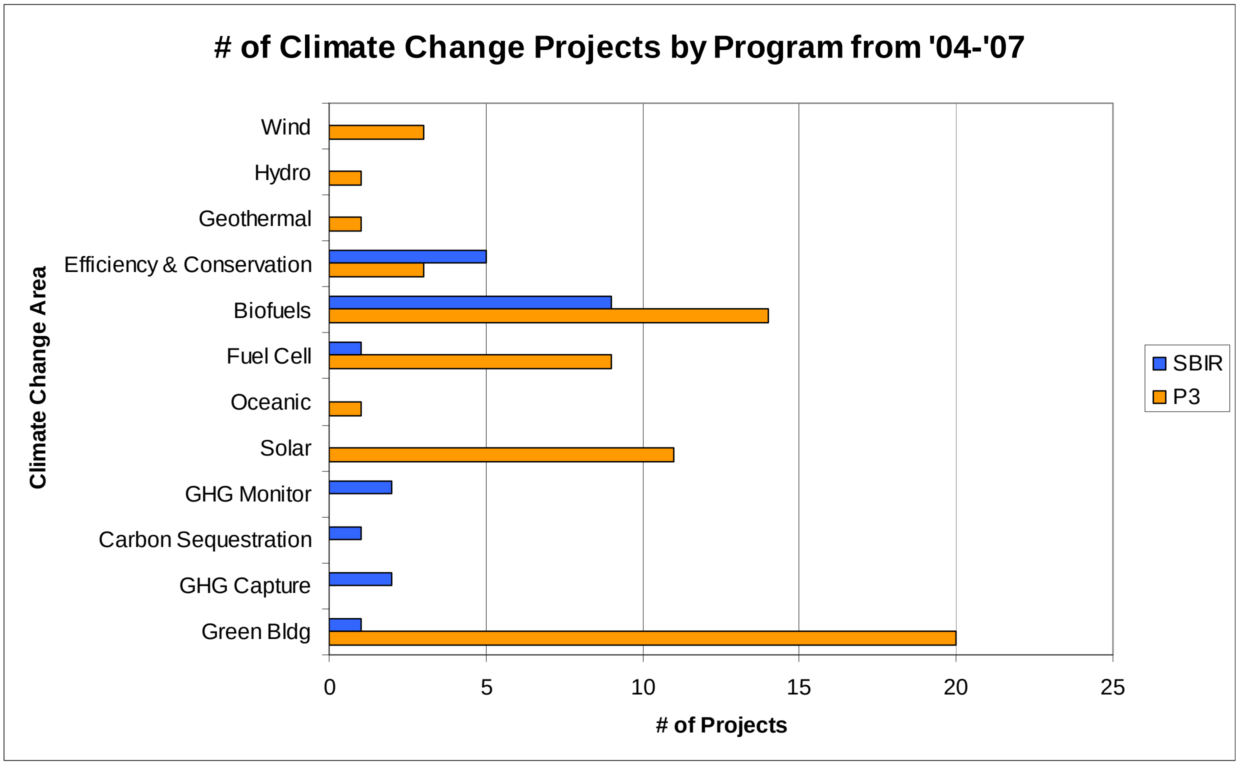

Figure 4.7: Number of Projects by Program from '04-'07

From Figure 4.7 it is easy to see that P3 bases their climate change research and development around green buildings, solar power, biofuel and fuel cells. What can not be seen in this graph is the theme of sustainability projects they conduct. The climate change technologies used in these projects are applications for a specific geographic area or a specific group of people. Examples of these types of P3 project is "Solar LED Lanterns for the Replacement of Kerosene in the Developing World and Solar Photovoltaic System Design for a Remote Community in Panama." These projects focus on "benefiting people, promoting prosperity, and protecting the planet through innovative designs to address challenges to sustainability in both the developed and developing world." (P3, 2007) This type of research and development produces practical uses for these technologies and does not foster as many breakthroughs or further the technology through development like some of the SBIR projects do. This is important information because NCER will be trying to place more focus on research that will bring a technology from a lower level of development to commercialization and possibly provide funding throughout the commercialization process.

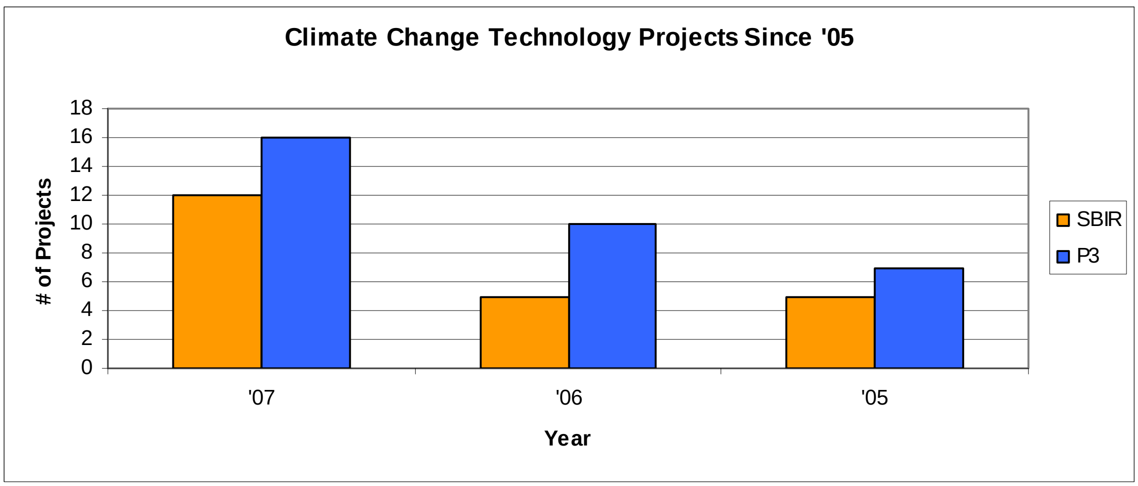

Figure 4.8: Climate Change Technology Based Project Since '05

The numbers of funded climate change projects over the past few years are increasing in both programs based on Figure 4.8. NCER hopes to become more involved with climate change technology research and development and will increase the number of projects it funds in this area. Both programs issue a public solicitation for research and development. Before the increase in funding can occur, these programs must be analyzed in order for NCER to fund research appropriately and effectively advance specific climate change technologies to ultimately mitigate emissions in the U.S. From Figure 4.8, it is also easy to see that P3 funds projects involving approximately twice as many climate change technologies as the SBIR program. However, SBIR Phase I projects receive $70,000 while P3 Phase I projects receive just $10,000; Phase II projects receive $225,000 and $75,000 respectively. The following graphs (Figure 4.10) show the amount of money each program has invested towards each climate change technology category from 2004-2007.

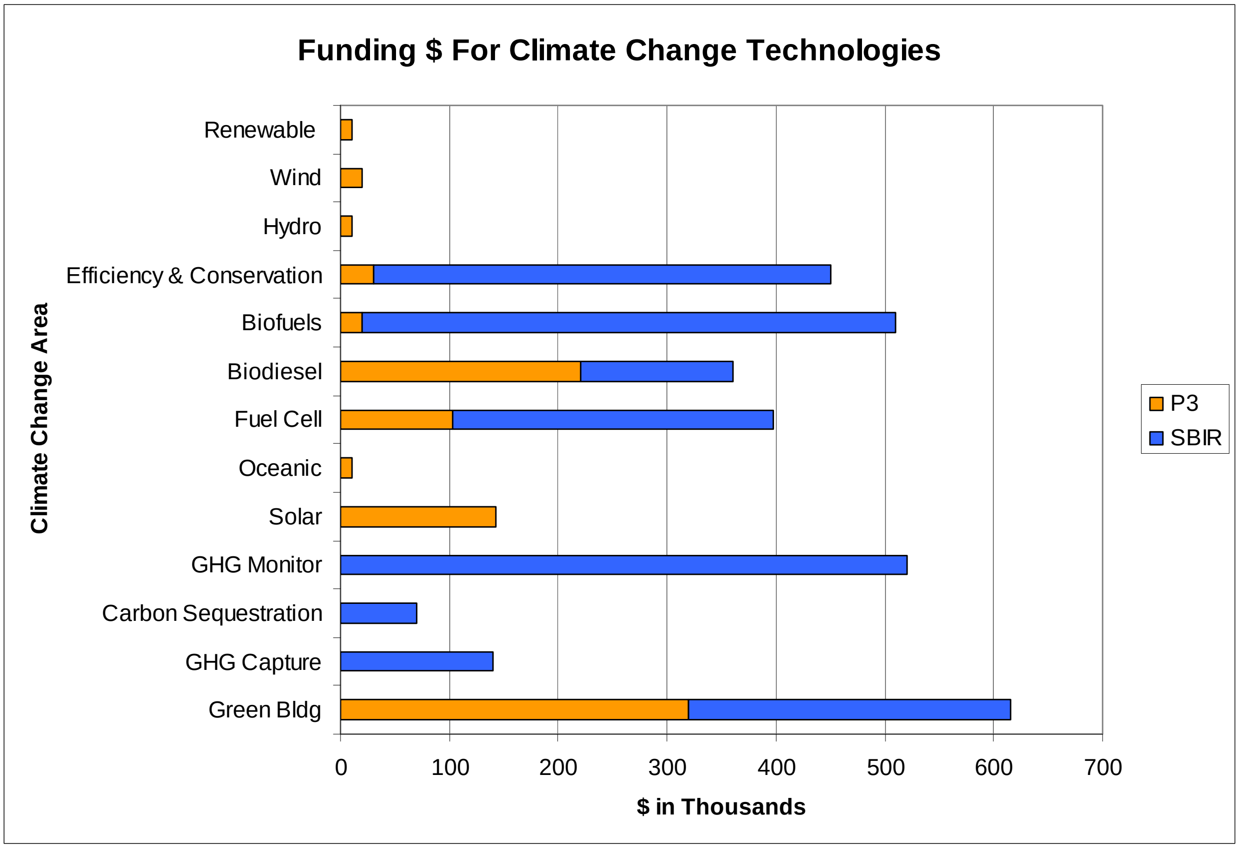

Figure 4.10: P3 Funding for Climate Change Technologies of SBIR and P3 from 2004-2007

Although SBIR has only funded twenty-one climate change technology based project over the past three years compared to P3's fifty-seven, SBIR has put almost $140,000 more towards green buildings, $180,000 more towards fuel cells and around $300,000 more towards biofuels.

Analyzing the CCTP and various agencies involved with the CCTP such as the DOE, EPA, USDA, NASA, and USAID was an important step in order to realize what types of climate change technology research and development is taking place within these agencies. This was an essential step to take in order to recommend climate change technology research and development, or effects of climate change technology implementation that NCER could fund. The climate change technology matrix was also beneficial because it gives a broad scope of climate change technologies in existence, not just the technologies within CCTP agencies. The review of projects sponsored by SBIR and P3 was used to evaluate where NCER has funded climate change technology research and development to date. An important part of this project was to evaluate what other agencies within the U.S. are doing with climate change technology before we made recommendations to NCER.

5. ANALYSIS OF CLIMATE CHANGE TECHNOLOGIES

The analysis section contains the description of the criteria used for evaluating climate change technologies. Using these criteria, a matrix of all the climate change technologies was created. This matrix was split into the five climate change technology categories of GHG monitoring, low carbon fuels, efficiency and conservation, carbon capture and sequestration, and renewables and biofuels. These categories and the technologies within them were analyzed to determine if specific technologies from a category would be investigated further. The technologies that were chosen for further investigation were evaluated more in depth to determine if they would be viable as recommendations to NCER.

5.1 Criteria for Analysis

A set of criteria for analyzing climate change technologies was developed to help choose which areas of climate change technology best fit NCER. It is important that NCER funded projects have a high potential for CO_2 avoidance and that NCER could be the leaders or play roles in the research of the project, or find a unique funding niche. To analyze whether or not technologies fit into these goals for NCER a set of six criteria was developed. The six criteria for the climate change technologies analysis are level of CO_2 avoidance, amount of funding from other agencies, level of development, type of research needed for progress, fit with the EPA's mission and goals, and fit with the existing NCER funding profile. Some of these criteria were more important than others. CO_2 avoidance, amount of funding from other agencies, and level of development were the most important criteria and were a more decisive factor than whether or not the technologies fit into NCERs existing profile.

CO_2 Avoidance

The first criterion considered when analyzing possible technologies for NCER funding was potential for CO_2 avoidance. A level of the potential for how much the diffusion and utilization of this technology will mitigate CO_2 was analyzed. The rating system for CO_2 avoidance is based on an analysis conducted by the International Energy Agency; details are described in Appendix A5. NCER would like to be able to fund technologies with a high potential for CO_2 avoidance since these technologies will be the most important ones toward mitigating climate change. This is also an important topic of consideration since only technology areas with the highest potential for CO_2 avoidance are appropriate for NCER due to their limited budget.

Level of Funding

Another criterion considered during the analysis was a technology's current funding level and funding providers. In order to have the highest level of impact possible, it is important for NCER not to dedicate funding resources to areas of technology that are already receiving significant funding from other agencies. In some cases agencies are putting more money toward research and development of a climate change technology than the EPA could afford with over half their budget. NCER would like to have a role in which they can lead the direction of research and development of a technology. This is more likely to happen when there are fewer agencies funding work on a technology area. In the matrix the level of funding ranges from 1-5, 1 being the lowest and 5 being the highest. For a technology to receive a 1 it means that this technology is not being looked into much by other agencies and is receiving a minimal amount of funding. To receive a five for this category the technology must be being funded and researched heavily by one or more agencies. If the DOE is providing a significant amount of funding towards a technology then it will receive a five since the DOE is the main agency funding climate change technology research. The technologies in the matrix were examined and the amount of funding each one was receiving was analyzed to determine whether it will receive a 1-5.

Level of Development

The level of development is also one of the criteria considered in the analysis of the technologies. Technologies were classified as 1-6 for level of development. Level 1, research/proof of concept, is the lowest level of development while level 6, diffusion/utilization, is the highest level of development. A more thorough description of these levels of development classifications and how they were developed is described in Appendix A5. To evaluate each technology and assign a level of development ranking the technologies were evaluated based on all the research conducted on the technologies, and compared to the level of development classification scheme. Since NCER would like to be able to lead the direction of progress in some areas of climate change technologies they work with, it is important that they fund technologies with low levels of development. Technologies that have a high level of development and are more mature would have less room for innovation and fundamental research, which would hinder NCER in its ability to play a leading or supporting role in the development of the technology.

Type of Research Needed

One criterion that was closely associated with the level of development is type of research needed in the technology area. Technologies were classified as either needing fundamental research or applied research. These two types of research are important because of NCERs P3, STAR and SBIR programs. Generally, the STAR program funds fundamental research, the SBIR program funds applied research, and the P3 program funds both types. Technologies that need fundamental research are usually those with lower levels of development and, conversely, more developed technologies usually need applied research. For example, a technology classified as in the "research/proof of concept" phase of development would most likely need fundamental research to catalyze technology progress. However, technologies with higher levels of development can still require fundamental research. Technologies that are utilizing new processes or materials need fundamental research conducted to understand exactly how the process works; this research is also needed to make these systems more efficient.

EPA's Mission & Goals

An additional criterion that was considered was how a technology area fit into the EPA's mission and goals. The EPA's mission is to protect human health and the environment, and the five EPA goals for FY 2008 are clean air and global climate change, clean and safe water, land preservation and restoration, healthy communities and ecosystems, and compliance and environmental stewardship (EPA, 2007E). Climate change technologies were compared to the EPA goals for FY 2008 to determine whether or not they fit EPAs missions and if NCER should have interest in them.

NCER's Existing Portfolio

A final criterion for the climate change technologies was how they fit with NCER's existing funding portfolio. For this category a technology would receive a yes if it has been researched in one of NCERs programs such as SBIR, and P3, or a no if NCER has not dealt with it in the past. If NCER has funded projects dealing with certain technology areas, it is evident that they have interest in that area of technology. If NCER hasn't funded any projects in an area of technology it means that either NCER doesn't have interest in this area of technology, or that this area of technology has been introduced so recently that NCER hasn't had the opportunity to fund it yet. It is important that trends and lack of trends are observed so that the technology areas recommended to NCER are of interest to them. This criterion was not as important in determining which technologies to recommend as the others. It was valuable to see if they have funded technologies in the past, and could continue to fund these technologies in the specific areas recommended to them.

The criteria explained above were used in a criteria matrix to evaluate which technologies would be appropriate for NCER to fund. These criteria matrixes are depicted below, in Tables 5.1-5.4. The matrix are split into different technology categories so that technologies of the same genre could be compared to one another.

Table 5.1: GHG Monitoring Criteria Matrix

GHG Monitoring							
Technology Type	**Specific Tech.**	**CO_2 Avoidance Factor (1-5)**	**Various Agency Funding (1-5)**	**Applied or Fundamental Research**	**Level of Development (1-6)**	**EPA's Mission**	**NCER's Existing Portfolio**
Portable Devices		1	2	Applied	6	Yes	No
	Laser Induced Breakdown Spectroscopy	1	2	Applied	4	Yes	No
Tower Monitoring		2	2	Applied	6	Yes	No
	Ameriflux Tower	1	2	Applied	6	Yes	No
Aerial Monitoring		1	1	Applied	6	Yes	No
Satellite Monitoring		1	4	Both	2	No	No
	Orbiting Carbon Obseratory (OCO)	1	4	Both	2	No	No
	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)	1	3	Both	3	No	No

Table 5.2: Efficiency & Conservation Criteria Matrix

Efficiency & Conservation							
Technology Type	**Specific Tech.**	**CO_2 Avoidance Factor (1-5)**	**Various Agency Funding (1-5)**	**Applied or Fundamental Research**	**Level of Development (1-6)**	**EPA's Mission**	**NCER's Existing Portfolio**
Power Generator		5	5	Both	5	No	No
	FutureGen	5	5	Both	3	No	No
	Combined Cycle Gas Turbine (CCGT)	1	2	Applied	6	No	No
	Integrated Gasification Combined Cycle (IGCC)	4	5	Both	4	No	No
Hybrid motor		3	2	Both	6	No	No
Electric motor		3	2	Both	6	No	No

Table 5.3: Low Carbon Fuels Criteria Matrix

Low Carbon Fuels							
Technology Type	**Specific Tech.**	**CO_2 Avoidance Factor (1-5)**	**Various Agency Funding (1-5)**	**Applied or Fundamental Research**	**Level of Development (1-6)**	**EPA's Mission**	**NCER's Existing Portfolio**
Compressed Natural Gas (CNG)		2	3	Applied	6	No	No
Liquefied petroleum gas (LPG)		2	1	Applied	6	No	No

Table 5.4: Carbon Capture Criteria Matrix

Carbon Capture							
Technology Type	**Specific Tech.**	**CO_2 Avoidance Factor (1-5)**	**Various Agency Funding (1-5)**	**Applied or Fundamental Research**	**Level of Development (1-6)**	**EPA's Mission**	**NCER's Existing Portfolio**
Pre-Combustion		4	5	Both	4	No	No
	IGCC	4	5	Both	4	No	No
Oxy-Combustion		4	2	Both	2	No	No
Post-Combustion		4	2	Both	2	No	No
	CO_2 Scrubbers	4	2	Both	2	No	No

Table 5.5: Carbon Storage & Sequestration Criteria Matrix

Carbon Storage & Sequestration							
Technology Type	**Specific Tech.**	**CO_2 Avoidance Factor (1-5)**	**Various Agency Funding (1-5)**	**Applied or Fundamental Research**	**Level of Development (1-6)**	**EPA's Mission**	**NCER's Existing Portfolio**
Oceanic Storage		2	1	Fundamental	1	Yes	No
	Direct Injection - Droplet plume	2	1	Fundamental	1	Yes	No
	Direct Injection - Dense plume	2	1	Fundamental	1	Yes	No
	Direct Injection - Dry Ice	2	1	Fundamental	1	Yes	No
	Direct Injection - Towed Pipe	2	1	Fundamental	1	Yes	No
	Direct Injection - CO_2 Lake	2	1	Fundamental	1	Yes	No
Geologic		4	5	Both	2	Yes	No
Terrestrial		5	2	Both	4	Yes	No
	Algal Processing	3	1	Both	2	Yes	No
Oceanic Seq.			1	Both	1	Yes	No
	Iron Fertilization	3	2	Applied	3	Yes	No

Table 5.6: Renewables & Biofuels Criteria Matrix

Renewable & Biofuel							
Technology Type	**Specific Tech.**	**CO_2 Avoidance Factor (1-5)**	**Various Agency Funding (1-5)**	**Applied or Fundamental Research**	**Level of Development (1-6)**	**EPA's Mission**	**NCER's Existing Portfolio**
Bioreactors		2	4	Both	4	Yes	No
Biofuel		3	4	Both	3	Yes	Yes
	Ethanol – Sugar Cane	1	1	Applied	6 (Brazil)	Yes	Yes
	Ethanol – Cellulosic	3	4	Both	2	Yes	No
	Ethanol – Corn	1	3	Applied	6	Yes	Yes
	Ethanol – Soy bean	1	1	Applied	6	Yes	Yes
Hydrogen		1	3	Both	4	Yes	Yes
Geothermal		1	2	Applied	5	No	Yes
	Heat pumps	1	2	Applied	6	No	Yes
Solar			3	Both	6	Yes	Yes
	Solar Updraft Tower	2	1	Applied	2	No	No
	Solar Mirror Tower	2	1	Applied	6	No	No
	Photovoltaic	2	3	Fundamental	6	Yes	Yes

5.2 Climate Change Technology Categories

Based on the criteria matrix above, the technologies within the categories of GHG monitoring, low carbon fuels, efficiency and conservation, carbon capture and sequestration, and renewables and biofuels from this matrix were evaluated to determine whether specific technologies would be suitable candidates for NCER funding. In some situations entire categories and the technologies within these categories were able to be eliminated from further discussion and as possibilities for recommendations to NCER. In situations where the entire category was not eliminated, then certain technologies were chosen for further discussion and as possible recommendations to NCER based on the criteria matrix. Below is the analysis of the categories and the technologies within these categories, used to determine which technologies would be analyzed further.

5.2.1 GHG Monitoring

Technologies in the GHG monitoring category consist of portable devices, tower monitoring, aerial monitoring, and satellite monitoring. These technologies do not contribute to any direct CO_2 avoidance. Besides satellite monitoring, the funding of these monitoring devices is relatively low.

Satellite monitoring is being funded by NASA, and that is also NASA's objective in the CCTP program. An additional aspect of these technologies to consider is whether or not they require fundamental or applied research. The technologies listed require applied research, and the satellite monitoring technology needs fundamental and applied research.

Level of development is another essential facet to think about when considering what technologies are viable for NCER. The level of development of these monitoring technologies is high, in the range of 4-6, excluding the satellite monitoring which was rated 2-3. The two last criteria to inspect about these technologies are if they fit in with EPA's mission, and NCERs existing portfolio.

EPA's mission of making an inventory for GHGs incorporates these monitoring technologies, excluding the satellites, and none of these technologies have been researched in NCERs existing portfolio. The EPA does not use technologies for GHG monitoring, industry estimates are used instead, but they could contribute funding to earth bound monitoring devices in the future. These technologies are already at a high level of development, and appear to be adequately funded by other agencies, therefore, they will not be recommended for NCER funding.

5.2.2 Low Carbon Fuels

Low carbon fuels encompass compressed natural gas (CNG) and liquefied petroleum gas (LPG) technologies. Both of these technologies were rated at a 2 for CO_2 avoidance because they emit about 30% less CO_2 than petroleum does, but that is still a significant amount.

Various agencies are funding projects for use of CNG in buses and other forms of transportation, which is why it received a 3 for the funding category. LPG received a 1 for that category because LPG is simply propane and use of that is not being heavily funded and researched. Both of these technologies require applied research due to the fact that they are both a 6 for level of development and do not need fundamental breakthroughs.

Neither of these technologies fit in EPA's mission, or are a part of NCERs portfolio. These technologies will not be discussed further because they are mature technologies, and do not fit in with EPA's mission or NCER's current portfolio.

5.2.3 Efficiency and Conservation

The technology category of efficiency and conservation incorporates FutureGen technology, combined cycle gas turbine (CCGT) technology, integrated gasification combined cycle (IGCC) technology, and hybrid and electric motors.

The CO_2 avoidance factor of these technologies ranges from 1-5. The FutureGen project and IGCC achieved marks of 5 and 4, respectively, because the FutureGen is a completely clean plant, and IGCC plants are near zero CO_2 emissions. The CCGT plant was only rated at 1 because almost all of today's modern plants include CCGTs and still emit an excessive amount of CO_2. Electric and hybrid motors were rated at 3 due to the fact that they will still emit CO_2, but in less quantity than internal combustion gas engines.

In terms of the funding landscape for these technologies the FutureGen and IGCC were rated at a 5 because the DOE and other private sector organizations are investing heavily into these areas, and the CCGT was a 2 because it's well developed and not much work is going into it. Both the hybrid and electric motors were a 2 because most of the funding is coming private industry car manufacturers. These technologies all require fundamental and applied research except CCGTs which only need applied research because their level of development was rated 6. The hybrid and electric motors were also a 6 for level of development, and the FutureGen and IGCC were rated 3 and 4, respectively.

None of these technologies fall under EPA's mission or NCERs existing portfolio. The only one of these technologies that will be discussed further is the IGCC power plant, because it utilizes pre-combustion carbon capture technology. The remainder of these technologies will not be considered for NCER funding because there appears to be adequate funding from other agencies going toward them, or they are already highly developed.

5.2.4 Carbon Capture and Sequestration

The carbon capture and sequestration category is split into three main sections composed of capture, storage, and sequestration. The capture section involves pre-combustion, oxy-combustion, and post-combustion carbon capture technologies.

Carbon Capture

All three carbon capture technologies were given a 4 for CO_2 avoidance factor because they will be capable of either being retrofitted onto existing power plants and mitigating emissions or employed in new relatively clean power plants. For the various agencies' funding, pre-combustion received a 5 because of all the work DOE is doing with IGCC power plants and the amount of money being put into these power plants, which use pre-combustion technology. Since these power plants use pre-combustion technology the DOE is funding significant amount of research on this specific technology. Oxy-combustion received a 3 and post-combustion received a 2 due to the fact that the DOE is putting money toward these technologies, but not nearly as much as pre-combustion.

All of these technologies require both fundamental and applied research. The level of development for pre-combustion is 4, while oxy- and post- were both rated at 2. The reason for this is that IGCCs are capable of being used presently, while post-combustion needs more work on CO_2 scrubbers, and oxy-combustion is expensive comparatively. These three technologies do not fit into EPA's mission or NCERs existing portfolio. However, they will be discussed in more detail in the analysis due to the fact that they have great potential for CO_2 avoidance, they require fundamental and applied research, and their level of development isn't high.

Carbon Storage

The next section of this category is storage, which includes oceanic and geologic. There are various methods for storing CO_2 in both of these technology types. Oceanic carbon storage received a rating of 2 for the criterion of CO_2 avoidance and geologic carbon storage was rated at 4. Geologic storage has the potential to mitigate massive amounts of CO_2, and it could be used in the near future, which is why it was rated at 4. Oceanic carbon storage only received a two because in appendix A5, the figure CO_2 avoidance factors were based on were only taking the CO_2 avoidance factor until 2050 into account. Since Oceanic carbon storage may not have potential to be fully utilized and diffused by then the CO_2 avoidance factor was rated at 2.

For the funding section, oceanic storage obtained a rating of 1 and geologic storage was rated 5, due to the fact that hardly any money is going toward ocean research and development, and there are substantial amounts being used on geologic. Ocean sequestration needs fundamental research and geologic requires both fundamental and applied.

The level of development for these technologies was 1 for oceanic storage and 2 for geologic storage because both need significant amount of work. Geologic storage has been worked on more exclusively than oceanic storage however. These technologies pertain to EPA's goal of clean air and climate change, but do not fit in with NCERs existing portfolio. Geologic storage will be discussed further in the analysis because research needs to be done on possible environmental effects. Research on the actual technology used to inject the CO_2 into ground reservoirs will not be reviewed further because this research is being heavily funded already. Oceanic storage will not be analyzed further due to its low CO_2 avoidance factor.

Carbon Sequestration

The final section of the carbon capture and sequestration category is sequestration. This section includes terrestrial sequestration and oceanic sequestration, or iron fertilization. For CO_2 avoidance terrestrial was awarded a 1 and oceanic sequestration was rated at 1. Terrestrial sequestration receives a 1 because creating more plant life will not reduce the amount of CO_2 in the atmosphere by a significant amount. Home Depot has a pledged to plant 3 million trees over the next 10 years. These three million trees would consume the amount of CO_2 produced by a 500-megawatt coal plant in 10 days over their entire lifetime. (USA Today, 2007). Iron fertilization does not have the potential to mitigate large amounts of CO_2, and according to an interview with an NCER employee this technology would only be a band aid at best for mitigating CO_2. For the funding of these two categories terrestrial sequestration was rated 2 and ocean sequestration was rated 3. Oceanic sequestration was rated 3 because agencies are doing some work and funding private sector organizations to research this technology. Terrestrial sequestration was rated at a 2 for level of funding because this method does not have a lot of money being put towards it, since plant life does not have the potential to mitigate the amount of CO_2 as other climate change technologies.

Both these technologies require fundamental and applied research. Since the concept behind terrestrial sequestration isn't overly complicated the level of development is at 4, and iron seeding is at 3. Iron seeding is at 3 because tests have been conducted, but commercial scale tests have not been completed to this point.

Terrestrial sequestration fits into EPA's goal of land preservation and restoration, and iron seeding does not fit into any of EPA's goals. These technologies do not coincide with NCERs existing portfolio. Since these technologies are well-developed, don't fit into any of EPA's goals, or don't have a high CO_2 avoidance factor and the potential to mitigate climate change, they will not be analyzed further.

5.2.5 Renewables and Biofuels

The last section of the criteria matrix is renewable technology and biofuels. Within the biofuel section the technology options are bioreactors, and ethanol made from sugar cane, corn, soy bean, and cellulosic technology.

Biofuels

For the CO_2 avoidance factor bioreactors were rated at 2, sugar cane ethanol, corn, and soy at 1, and cellulosic at 3. Bioreactors are at a 2 since they create the ethanol for fuel, but current ethanol production is inefficient. The reason for sugar cane, corn, and soy bean being so low is that ethanol does reduce emissions, but the production of these particular biofuels is inefficient since the whole plant cannot be used, therefore a lot of energy is used to create the ethanol, which will create emissions and the amount of ethanol produced is barely more than petroleum used to manufacture it. Cellulosic ethanol is rated higher because this technology will allow the whole plant to be used, as well as other materials containing cellulose that were previously unable to convert to ethanol.

For the various agencies funding, the bioreactors were given a 4, sugar cane and soy bean received a 1, corn a 3, and cellulosic a 4. Bioreactors and cellulosic were high because agencies are investing a lot of money into these technologies to improve the process and efficiency of creating ethanol. For example, the DOE allotted approximately $150 million towards biomass and biorefinery research and development. Corn ethanol is receiving moderate levels of funding because the process of producing ethanol from corn kernels is extremely inefficient, and research is being done on how to improve this since it is the main ethanol being used in the U.S. the level of finding for sugar cane and soy bean is very low because they are inefficient like corn, but they are not produced at the level of corn ethanol in the U.S. Bioreactors and cellulosic technology both need fundamental and applied research, while corn, soy bean, and sugar cane only need applied research.

These technologies are all fully developed and commercialized, except for cellulosic ethanol production, which received a 2. Although bioreactors have a high level of development, they still need work. Bioreactors for corn, soy bean, and sugar cane ethanol are highly developed, but cellulosic bioreactors need to be researched more. The biofuels, with the exception of cellulosic alcohol, are being used and are well developed. Cellulosic ethanol technologies still need a lot of fundamental and applied research to advance.

All of these technologies fit into EPA's mission of mitigating GHG emissions. Besides bioreactors and cellulosic technology, the rest of these technologies are a part of NCERs existing portfolio. Soybean ethanol, corn ethanol, and sugarcane ethanol will not be discussed further due to their level of development, the funding from other agencies, and the CO_2 avoidance factor. The two technologies that will be analyzed further are bioreactors and cellulosic technology, because of their potential for CO_2 avoidance, as well as the development they need.

Renewables

The renewable energy portion of this technology category is made up of hydrogen technology, geothermal energy, and solar energy. The solar energy portion consists of the solar updraft tower, solar mirror tower, and photovoltaic cells. The CO_2 avoidance factors for these technologies are 1 for hydrogen and geothermal, and 2 for the solar updraft tower, solar mirror tower, and photovoltaic cells. The reason hydrogen and geothermal technologies are rated low is because hydrogen is unlikely to see widespread adoption in the near future and geothermal cannot be commercially used everywhere. The grading for CO_2 avoidance is based on how many gigatons of GHGs will be prevented from entering the atmosphere by the implementation of this technology, and this is explained in Appendix A5. Solar updraft towers, solar mirror towers and photovoltaic cells are rated at 2 because solar technologies are not practical in many places. Again this is depicted in Appendix A5.

Hydrogen and geothermal technologies are being researched by the DOE and other various agencies, and were thus rated at 3 and 2 for funding levels, respectively. Solar updraft towers and solar mirror towers are mainly being looked into by private sector organizations, hence the ranking of 1. The DOE and private sector organizations are investing a lot of money into photovoltaic research, which is why it received a 3.

Geothermal technology, solar updraft towers, and solar mirror towers only need applied research since there is not a need for fundamental breakthroughs. Hydrogen technology and photovoltaic cells require fundamental and applied research since these technologies could greatly benefit from breakthroughs. Hydrogen technology is rated 4 for level of development since it can be used, but fundamental breakthroughs would greatly improve this technology. Geothermal technology was rated at 5 because some geothermal technologies could use work, but others such as geothermal heat pumps are well developed. Solar updraft towers were rated at 2 because they are not commercially viable at this point in time. Solar mirror towers and photovoltaic cells received a 6 because they are commercially viable and being used around the world. Photovoltaic cells were rated at 6, but they still could use research to improve their ability to perform.

Hydrogen and photovoltaic cells were included in EPA's mission because the EPA has worked with these technologies in the past, and research in these technologies is included in NCERs existing portfolio. The only one of these technologies that will be analyzed further is photovoltaic cells. The reason for this is because photovoltaic cells need improvements from fundamental and applied research, the funding from various agencies isn't extremely high, and this technology fits in with NCERs existing portfolio.

Using the criteria matrix, several technologies were chosen to be analyzed further for possible recommendations. These technologies were post-combustion carbon capture, pre-combustion carbon capture, oxy-combustion carbon capture, effects of geological sequestration, cellulosic energy production, and solar energy. A more thorough description of these technologies is below.

5.2 Selected Climate Change Technologies

Based on the analysis of the criteria matrix, post-combustion carbon capture, pre-combustion carbon capture, oxy-combustion carbon capture, geological carbon sequestration, cellulosic energy production, and solar technology seem among the most promising areas for research investment.

5.2.1 Pre-Combustion Carbon Capture

Pre-combustion carbon capture is a technology area which will be important in the upcoming years since geological carbon sequestration is going to be important for mitigating CO_2. This will mean that pre-combustion captured carbon dioxide will be deposited into geologic reservoirs. Since the carbon will be sequestered, pre-combustion allows power plants to continue to run on fossil fuel such as coal with near-zero GHG emissions.

Pre-combustion capture technology will be used in power plants which utilize Integrated Gasification Combined Cycle (IGCC) technology. Research on IGCC technology is being performed and funded by agencies such as the DOE, as well as by private sector organizations such as General Electric (GE), and American Electric Power (AEP).

IGCC consists of four distinct processes. These four processes are: gasification of the fossil fuel, which is the pre-combustion aspect; syngas cleanup; gas turbine combined cycle; and cryogenic air separation (GE, 2007). Pre-combustion, or gasification of the fossil fuel to create syngas, is described in detail in the pre-combustion section of the literature review. Syngas clean up is cleansing the syngas from the reactor of materials such as sulphur compounds, ammonia, metals, alkalytes, ash, and particulates. The reason for doing this is so the gas turbine’s fuel specifications are met. The gas turbine combined cycle is where the syngas, which has been cleaned, is combusted. The final process is cryogenic air separation and this provides pure oxygen to the gasification reactor (GE, 2007). Cryogenic air separation is the process where air is taken in from the atmosphere, and then “compressed and purified before entering the cryogenic equipment package.” (PRAXAIR, 2007). This compressed and purified air is cooled to around -300°F, and then separated into elemental components of liquid oxygen, nitrogen, and argon by utilizing their different boiling points (PRAXAIR, 2007).

The DOE is performing research and development on a project called FutureGen, which incorporates IGCC technology. The FutureGen project is a power plant that will integrate carbon sequestration and hydrogen production research. The goal of this project is to create a zero-emissions fossil fuel power plant, which would be the first of its kind, and the cleanest fossil fuel fired power plant in the world. This project was announced in 2003, and the DOE plans to spend $1.5 billion on this project for 10 years, or until 2013 (DOE, 2007b). The project will determine the "technical and economic feasibility of producing electricity and hydrogen from coal (the lowest cost and most abundant domestic energy resource)" in a fashion consistent with clean environment goals (DOE, 2007b).

General Electric equipment provides electricity around the world using fossil fuels such as coal, oil, natural gas, and renewable energy sources such as nuclear, water, and wind energy. GE has been researching and developing pre-combustion technology due to their involvement with research and development for IGCC power plants. GE claims to have been main contributor towards research and development of IGCC technology from the beginning (GE, 2007). Another private sector firm working with IGCC technology is the American Electric Power (AEP) company. The AEP is one of the largest electric providers in the United States, and they deliver electricity to over 5 million customers. Currently the AEP has plans to build an IGCC power plant and put it into commercial operation by 2010. This plant will be the largest commercial-scale IGCC power plant in the world, and will be located in the U.S.

Pre-combustion carbon capture and IGCC power plants will have a great impact on the overall goal of mitigating the amount of CO_2 in the atmosphere. Many agencies are funding research to develop IGCC power plants which incorporate pre-combustion capture and will allow large amounts of CO_2 to be sequestered. Pre-combustion capture could fall under the EPA's goal of clean air and global climate change since sequestering the CO_2 captured from pre-combustion methods keeps the air cleaner. Overall pre-combustion carbon capture does not seem as if it would be a viable technology for NCER and the EPA to fund research and development on. This technology is mature and there are not enough areas for NCER to play a large role in, the associated research is expensive, and this technology is being adequately funded by agencies or private sector organizations. According to GE, IGCC technology became an established option in 2000, and “is now considered a mature technology and a viable coal power plant option.” (GE, 2007).

Frank Princiotta, head of the Air Pollution and Prevention Control Division of EPA, believes pre-combustion and IGCCs aren’t the best solution to the problem of mitigating CO_2 emissions from power plants. He described them as being complex, not reliable, and inefficient.

5.2.2 Oxygen-Fuel Combustion

Oxygen fuel combustion (oxy-fuel combustion) is one technology used to reduce GHG emissions from coal-fired power plants. It is a new, undeveloped technology that combusts coal in a 95% oxygen environment instead of air. This helps make CO_2 in the flue gas easy to sequester with CO_2 scrubbers. A current Oxy-Fuel Combustion System (OCS) sold by Praxair only produces half as much flue gas (exhaust containing GHGs) as conventional coal plants (Praxair, 2007). The flue gas can also be recycled to co-fire with the oxygen environment. Oxy-Fuel Combustion Systems are currently being developed for both turbine power cycles, and for pulverized coal plants. By retro-fitting with these technologies, power plants can reduce their emissions significantly to near-zero emissions with geologic carbon storage. This technology has attracted some attention from DOE and private businesses because of its promise.

The DOE conducts intramural research on oxy-fuel combustion through the National Energy Technology Laboratory (NETL). The DOE places great emphasis on pre-combustion technologies but nowhere near the same amount for oxy-combustion. An undergoing project in the NETL labs has objectives to:

1) Develop a better understanding of the oxy-combustion flame and of heat and mass transfer in oxy-combustion systems
2) Develop an understanding of the character and distribution of ash and slag in oxy-combustion systems
3) Develop solutions for the potential low-pressure steam turbine imbalance in retrofit applications
4) Support development of improved systems and models and modeling tools

(NETL, 2007)

The fundamental challenges involving oxy-fuel combustion are pointed out above. These challenges are appropriate for university research. Oxy-fuel combustion systems have potential to make a huge impact on the power production sector which is why research is needed to construct a sound commercial demonstration. If the fundamental engineering questions can be solved, cost can be lowered enough to become economically viable. This was confirmed in an interview with Mr. Princiotta. However, oxy-fuel combustion research has never been conducted by NCER and would be a completely new area for the programs.

This type of research doesn't fall under directly under the mission of the EPA in the CCTP. Although this technology reduces all GHGs, it is mainly focused on CO_2 reduction, which falls under the EPA's primary goal of clean air and global climate change.

5.2.3 Post-Combustion Carbon Capture

Post-combustion carbon capture technology is similar to the process of pre-combustion carbon capture technology in that they are both important pieces in the overall effort to mitigate CO_2 using sequestration of CO_2. Post-combustion is also similar to pre-combustion in that it will allow power plants to continue to run on fossil fuels such as coal, without polluting the environment nearly as much as do current coal-fired plants. Unlike pre-combustion carbon capturing technologies however, post-combustion can be retrofitted onto fossil fuel power plants that are already in existence. This is important because it is far less expensive to retrofit existing power plants than to create new IGCC power plants. It's also extremely important because there will not be enough IGCC power plants to provide the U.S. with electricity in the near future. Post-combustion technology renders old power plants that once harmed the environment much cleaner. Since, in the United States, 99% of coal-fired power plants are pulverized coal power plants (DOE, 2007d); post-combustion processes will become essential for the successful adaptation of these plants.

The technology used in post-combustion carbon capture is CO_2 scrubbers. CO_2 scrubbers currently in existence are capable of removing large amounts of CO_2 from the flue gas exiting the power plants. Frank Princiotta, who is the director of the Air Pollution and Prevention Control Division of EPA, described one of the CO_2 scrubbers his facility is developing. His facility is one of the only facilities capable of large scale testing of CO_2 scrubbers. Since his facility is one of few capable of this testing the DOE is funding them to perform the research and development. The scrubber currently being worked on is capable of removing 90% or more CO_2 from the flue gas; however the process reduces power generation by about 30%. This particular scrubber is currently one of the best scrubbers at limiting the inefficiency to the power plants caused by post-combustion carbon capture. Clearly, CO_2 scrubbers still need a lot of development so that they don't reduce the power generation efficiency nearly as much as they currently do.

Post-combustion carbon capture pertains to EPA's goal of clean air and climate change. This technology will allow current power plants to continue to run without polluting the environment with as much CO_2 as would otherwise be emitted. CO_2 scrubbers will need more development to fit into the goal of clean air and climate change since they cause the plants to be less efficient and require more coal.

NCER could contribute towards the research and development needed for CO_2 scrubbers. Because CO_2 scrubbers are not highly developed, and there aren't many agencies performing research and development on this technology, post-combustion scrubbing technology research presents a unique funding niche for NCER.

5.2.4 Geologic Carbon Storage

Geologic carbon storage has the potential to be one of the most important technological innovations employed to mitigate global warming in the near future. Carbon capture and sequestration efforts are increasingly important because of the high environmental concentration in parts per million (PPM) of CO_2. Atmospheric CO_2 is currently at about 375 (PPM), and there are estimations that it will be at around 700 PPM by the year 2100 if it is not mitigated. At this current pace, the average temperature is expected to increase by about 6.4° C by 2100. Figure 5.1, below, depicts a graph from the film *An Inconvenient Truth* which shows the CO_2 PPM increase and decrease over the past 600,000 years and the temperature increase and decrease over the same time period. The blue line represents the CO_2, while the white line is the temperature. As shown, CO_2 has steadily increased and decreased over the years, but levels of 375 PPM that had never been reached before appear at the end of the graph, or 2005. The red line illustrates 45 years into the future, or 2050, and predicts levels of 600 PPM of CO2.

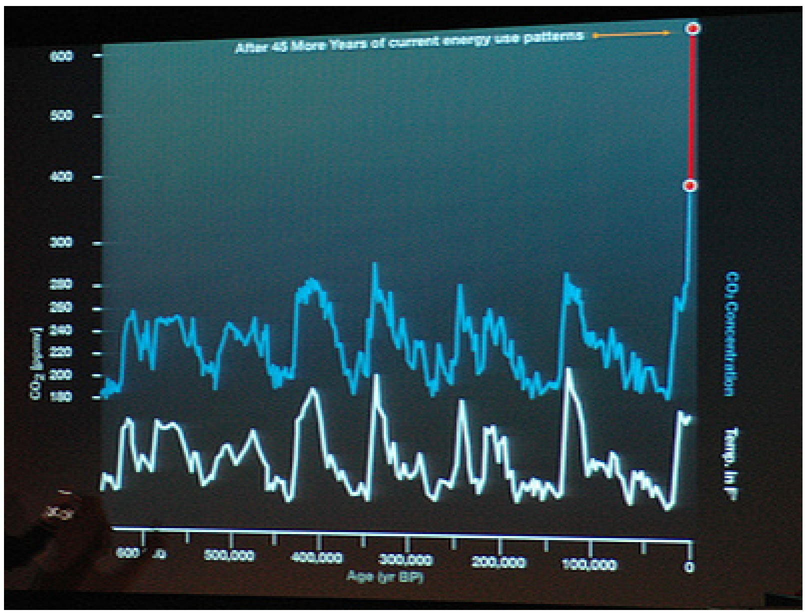

Figure 5.1: CO_2 PPM Over Time

Source: An Inconvenient Truth

Geologic carbon storage could greatly reduce these predicted levels of CO_2. However, there are arguments against sequestration of CO_2 through geologic or oceanic means. One of the bases of such arguments is that scientists are unsure about what will happen to the sequestered CO_2, and what effects it could have on the environment while it's buried away, or whether it can be sufficiently contained over long periods of time. However, an EPA employee who works through the Office of Air and Radiation (OAR) stated that many informed people who were once unsupportive of carbon sequestration are currently changing their views. The ambitious goals of CO_2 reductions will prove to be extremely difficult, or impossible, without carbon sequestration. In order to inhibit the rapid increase of CO_2, carbon sequestration must be utilized, and agencies such as the DOE are working on this.

A DOE employee stated that the DOE is focusing on geologic CO_2 sequestration. The DOE is planning on spending $197 million on three large-scale carbon sequestration projects over the next ten years. These three projects will operate in the United States, and one of these projects is the largest carbon sequestration effort in the world to date. These projects are the Plains Carbon Dioxide Reduction Partnership, the Southeast Regional Carbon Sequestration Partnership, and the Southwest Regional Partnership for Carbon Sequestration. The partners in these projects consist of 27 states, and the Canadian provinces of Alberta, Saskatchewan, and Manitoba (DOE, 2007d). The three projects are testing sequestration of volumes of one million or more tons of CO_2 which will be injected into deep saline reservoirs. These three projects alone have the capability "to store more than one hundred years of CO_2 emissions from all major point sources in North America." (DOE, 2007d). Major point sources in North America include power plants and other industrial facilities. According to the DOE, current assessments indicate that there are many places in the U.S. where CO_2 could be geologically stored. Of the largest 500 major point CO_2 sources in the U.S., evaluations show that 95% are within fifty miles of a possible storage site for CO_2 (EPA, 2007E). According to the DOE, the initial research and development on these projects involves characterizing the injection sites, and completing the modeling, monitoring, and improvements to the infrastructure so the CO_2 can be deposited (DOE, 2007a). Once this research and development is complete the projects will inject the CO_2 into the reservoirs, and then monitor it to determine if the reservoir is capable of containing it.

There are elements of geologic carbon storage that are not currently being extensively researched. One of the concerns about sequestration is whether or not ground water, which is used for drinking, will be contaminated due to CO_2 leakage. According to Audrey Levine at the EPA, ground water could be contaminated due to CO_2 leaking into an aquifer, or by saline ground water that enters an aquifer as a result of being displaced by injected CO_2. An NCER staff member suggested that geologic carbon storage would be an important area to focus on, especially considering such environmental impacts as contaminated drinking water.

Geologically sequestered CO_2 could be one of the most important mitigation technologies in the near future, but many aspects of this technology need more research. A CO_2 capture and geologic storage report, written by the Global Energy Technology Strategy Program (GTSP) in 2006, outlines geologic carbon storage and points out what needs to be done to put this method into use. The report states that more research and development is needed on capture technologies, transportation, injection and storage of CO_2, and monitoring, measurement, and verification of stored CO_2 (GTSP, 2006). Agencies such as the DOE are investing significant funding into researching capture and injection technologies for geological sequestration of CO_2. Agencies are also funding investigation into monitoring whether the carbon will leak out or not, and the DOE is doing a lot of this technology and monitoring research. However, ground water contamination is not an aspect of geological sequestration that is adequately understood and it is a critical step before carbon sequestration can be fully implemented. The Office of Water, which is part of the EPA, is preparing to perform and fund research on whether or not ground water will be contaminated because of geologic carbon storage. An interviewee from the Office of Water believes that NCER could contribute toward the study of ground water contamination due to geologic carbon storage. The study of ground water contamination due to geologic carbon storage would provide NCER with a role to play in this important technology, and it fits in with goal 2 of the EPA's proposed budget for FY 2008, which is clean and safe water.

5.2.5 Cellulosic Ethanol

One of the more promising areas of climate change technology seems to be in the production and use of cellulosic ethanol. The production and use of cellulosic ethanol emits 91% less GHGs than the production and use of gasoline. Also, when one unit of fossil fuel energy is put into the production of cellulosic ethanol, between 2 and 36 units of energy are returned in the form of ethanol depending on the process used to convert the cellulose to alcohol (*National Geographic*, 2007). A 91% reduction in GHGs provides significant environmental impact in the mitigation of climate change.

Cellulosic ethanol is presently not a fully advanced technology. Cellulosic ethanol has been produced at pilot scale plants for years, however the production costs need to be lowered considerably in order for this technology to be more widely implemented in society. Scientists are still finding new bacteria that can be used to convert the cellulose into ethanol while helping to lower the cost (Genomics, 2007). The bacteria produce enzymes that process the cellulose into fermentable sugars which over time, ferment into ethanol. A bacterium called *Clostridium thermocellum* has been identified recently as a microorganism that can convert the cellulose in the biomass directly into ethanol, skipping the conversion into sugars and fermentation of those sugars.

Cellulosic ethanol production and use have been researched in some depth by other agencies such as the DOE, and while this usually deters NCER, this was not the case here. Generally, if another agency, especially one with as much funding resources such as the DOE, is doing extensive research in a particular area of technology, it is not the best idea for NCER to promote further funding in this area. However since the production and use of cellulosic ethanol is at such a low level of development, there are still various possibilities to provide leadership that will influence other funding bodies to follow in the direction that NCER could provide. While ethanol technology has been around for years, there are new opportunities such as the conversion of biomass to ethanol. Since there are areas within this sector that are so new, such as ethanol production via the bacteria *Clostridium ljungdahlii*, NCER can have significant impact with funding directed to ethanol biomass production.

The production and use of cellulosic ethanol fits well with the existing portfolio of NCER. In the past four years NCER has funded several projects dealing with biofuels through the SBIR program and the P3 program. Since 2004, approximately 28% of all projects funded by P3 and SBIR have dealt with biofuels. These projects show that there is a trend of interest by NCER in the biofuel area, and the biofuel area that will grow the most within the next few years is cellulosic ethanol. Because the implementation of this technology will reduce GHG emission, it fits the EPA mission and is appropriate for NCER. NCER could possibly promote funding on the genetic engineering of *Clostridium thermocellum* so that it produces ethanol more efficiently (Genomics, 2007). This low level of development allows NCER to utilize their limited funding to make a significant difference in the area while possibly leading the sector in the appropriate direction for diffusion/utilization.

Bioreactors

One other technology used to produce cellulosic ethanol that could benefit from funding from NCER is bioreactors. The cellulose in the biomass feedstock needs to be converted to fermentable sugars for the alcohol transformation to be completed; one way this is done is through the use of microorganisms in bioreactors.

Bioreactors, systems designed to provide optimum conditions for specific microbial growth, have been used for years, however the process of producing cellulosic ethanol using bioreactors is a newly evolving sector (AgMRC, 2006). New methods to process the biomass for transformation to ethanol in bioreactors are being introduced frequently. For example, the University of Rochester is genetically engineering the *Clostridium ljungdahlii* bacteria so that the byproducts lactate and acetate aren't produced in the process (University of Rochester, 2007). Bioreactors, which have uses in climate change technologies ranging from algal hydrogen production to CO_2 sequestration, can be used to convert cellulosic plant material into ethanol including the emerging processes of cellulose saccharification and autohydrolysis (AgMRC, 2006).

Since these ethanol production methods are newly introduced, there is an opportunity for NCER funding to provide leadership in the direction of this technology. While some R&D has been conducted in this area, there is still much that needs to be done. The general area of biofuels was rated at a 4 for level of development, however this value was based on the level of development for the bioreactors used in the production of corn ethanol. Cellulosic bioreactors would be at a 2 if they were to be rated by themselves. Since other agencies are putting funding towards new cellulosic ethanol bioreactor development, it is also possible for NCER to guide funding provided by those other agencies. This is another trait that NCER finds desirable when considering funding possibilities. Research and development done on the production and use of cellulosic ethanol, the effects of the production and use of cellulosic ethanol, and bioreactor technology in cellulosic ethanol manufacturing processes all follow this trend.

Environmental Effects

One aspect that must be considered when discussing the production and use of cellulosic ethanol are other effects that will be caused by this process. If the production and use of cellulosic ethanol undergoes a substantial growth, there will be myriad effects that impinge on many systems including the water cycle due to irrigation and the level of nitrogen in the soil due to fertilization. Because of these numerous unknown effects, any research done in this area that leads to utilization has high potential for environmental impact. The planting of extra crops to fuel the increased biomass demand associated with increased production and use of cellulosic ethanol has the potential to disrupt the balance of the existing agricultural system. NCER is interested in climate change technology areas that have high potential for environmental impact, thus suggesting funding potentially important research in the effects caused by increased production and use of cellulosic ethanol.

Not much work on the environmental effects of cellulosic ethanol is being funded by other agencies. The USDA funded $22.5 million in biofuels and biomass in 2006 in fields such as inventory of carbon biomass, biomass research and development, and the carbon cycle. While greater detail is not provided by USDA, it is likely that the environmental effects of implementing cellulosic ethanol technology have been researched by USDA since this research is being conducted by the Natural Resource Conservation Service, the Agriculture Research Service, and the Forest Service.

5.2.6 Solar Energy

Solar technologies have the potential to be huge contributors to solving the world's energy problem in an environmentally responsible manner. Solar energy is a promising technology that can be applied across a broad range from small consumer uses to large commercial solar electric systems that can power, heat and light homes and businesses. Solar applications are already promoted via legislation and tax incentives such as a 30% tax credit for consumers who install solar water heating systems; such incentives are rare among climate change technologies. (EERE, 2007) Solar power can be harnessed in many different ways and can be used in many different applications. The four main ways to convert solar energy into electricity are Photovoltaics (PV), concentrated solar power (CSP), solar heating and solar lighting. All of these types of technologies provide forms of clean energy (zero GHG emissions).

Since the invention of the first photovoltaic cell, the efficiency and costs have been improving and devices reached 32.3% efficiency in 1999. (EERE, 2007) These technologies have advanced greatly and are currently in utilization and diffusion stages of their development. However the field is still going through intensive research and development is being conducted to improve the efficiency and lower the costs to make solar devices more attractive investments to the public and businesses. Significant breakthroughs for PVs are still necessary to propel them to widespread adoption. This is an aspect that makes this technology particularly attractive for NCER research funding. According to the CCTP, solar controlled windows, high performance and integrated homes which involve solar PV panels are categorized as near-term (present-20 years) technologies. However PVs for power production are categorized as a long-term technology. Fundamental solar innovations are needed to turn solar into a serious option for power production. If this can happen, solar PVs could be the closest thing to a "silver bullet" technology in the future. Although it is not in the EPA's goals specified by the CCTP, NCER should help support this fundamental research done by other agencies for technologies that will come to fruition in the mid (20-40 years) to long-term (40-60 years). This conclusion was confirmed after an interview with Frank Princiotta, a knowledgeable NRMRL employee.

Upon analysis of departments and agencies within the U.S. Government, the DOE was found to be investing 12% of their Office of EERE budget on solar energy in 2007. As part of the Advanced Energy Initiative (AEI), DOE created the Solar America Initiative (SAI), to be carried out by the EERE. The initiative "will accelerate the development of advanced photovoltaic materials with the goal of making it cost-competitive with other forms of renewable electricity by 2015" (EERE, 2007). These advanced photovoltaic technologies are on the cusp of the verification stage of development. The funding by DOE includes intramural and extramural research and development. The Solar Energy Technologies program is another EERE program that coordinates this research and development and promotes the technologies. But, as pointed out by a National Risk Management Research Laboratory (NRMRL) employee in an interview, Germany has most recently been doing much of the research world-wide on PVs and has been buying most of the rare materials needed for production and thus DOE is not contributing as much as the budget says they are.

Currently, solar energy has shown up in the NCER portfolio of climate change projects. Solar energy is mostly seen in P3 projects over the past few years. In several projects it has been part of a wedge approach to alternative energy (a method that uses different techniques to mitigate a problem, for example, using solar panels, biodiesel and more efficient appliances to lower the energy needs and emissions of a home). This approach is then applied to a community or specific area. These projects have shown practical retro-fit uses and breakthroughs in the technologies as well which make solar PVs a good candidate for NCER research funding. Solar PVs are also a good candidate because they show up in NCER's existing portfolio.

6. CONCLUSION

The goal of this project was to make recommendations to NCER on possible climate change technologies that they could fund for research and development. To achieve this objective many tasks were performed that assisted with giving these recommendations on climate change technologies. These tasks involved researching the background of climate change, climate change technologies, agencies that fund climate change technologies, and synthesizing this information to make logical recommendations. The literature review, results section, interviews, and analysis were completed in the process of making these recommendations.

The literature review contains background information on climate change and many of the different climate change technologies in existence. With this information, the project team was able to determine which technologies best help mitigate global climate change. The contributors to climate change are GHGs, the most prevalent one being CO_2. Research was performed on a broad spectrum of climate change technologies. These technologies were sorted into the following categories: GHG monitoring, efficiency and conservation, carbon capture and sequestration, low carbon fuels, and renewable energy and biofuels.

The project team compiled information on the level of funding provided by agencies such as the EPA, DOE, NASA, DOT, USAID, and USDA towards climate change technology research and development. These specific agencies were chosen using the Climate Change Technology Program (CCTP) as a guide. The CCTP strategic plan was established to implement the current administration's National Climate Change Technology Initiative (NCCTI), which focuses on supporting federal leadership on climate change technology research and development. The reason for distinguishing what agencies are funding was to identify technologies that have significant amounts of funding from these agencies going towards research and development. Interviews were conducted to aid in determining technologies that should be investigated, and help with what climate change technologies other people believed NCER could play a role in.

Some of these interviews were particularly helpful and the information obtained from them was further analyzed.

The analysis narrowed down the number of possible technologies that NCER could fund to six, using specified criteria. The criteria for the technologies were CO_2 factor, level of funding from various agencies, the level of development, the research needed, whether they fit into EPA's mission, and if they were a part of NCERs existing portfolio. The technologies chosen to be discussed in the recommendations chapter were post-combustion carbon capture, pre-combustion carbon capture, oxy-combustion carbon capture, geological carbon sequestration, cellulosic ethanol, and solar technology. These technologies were selected using the criteria developed and the criteria matrix. The criteria matrix allowed for a visual representation of all the technologies in their categories and made it easier to compare them with each other.

From the information gathered about various climate change technologies, using the techniques above, recommendations were given to NCER on what climate change technologies they could fund for research and development. NCER could also use the information in the report to make decisions on what technologies they think they could fund in the future based on breakthroughs in technologies, policy changes, and other events. The next chapter lists the technologies recommended to NCER and the reasons for their selection.

7. RECOMMENDATIONS

There are many different climate change technologies in existence throughout the world, and this extensive list had to be narrowed down to several to recommend that NCER fund, or play a role in some way or another. The climate change technologies chosen from this list are post-combustion carbon capture, oxy-combustion carbon capture, geological carbon sequestration, cellulosic energy production, and solar technology. However, suitable technologies that would be relevant to climate change that NCER could fund are not limited to climate change technologies. Fundamental or applied research on technologies that would enhance the performance of climate change technologies are another option. NCER is able to fund both these types of research via the Science To Achieve Results (STAR) program which focuses on fundamental research, and the Small Business Innovation Research (SBIR) program which performs applied research. Another program that NCER funds that could contribute towards climate change research is the People, Prosperity, and the Planet (P3) program since it deals with fundamental and applied research. The numbering of the following technologies does not represent their importance.

1. Post-Combustion Carbon Capture

Post-combustion carbon capture is recommended for several reasons including its potential to mitigate global warming, and the level of development. Post-combustion carbon capture technology uses CO_2 scrubbers in power plants to remove the majority of the CO_2 from the flue gas. This technology has great potential to mitigate global warming since CO_2 scrubbers can be retrofitted onto existing power plants, and some of these scrubbers are capable of removing 90% or more of the CO_2 from the flue gas. The captured CO_2 is deposited into geological reservoirs. Post-combustion carbon capture technologies are at the pilot stage of development. There are CO_2 scrubbers that function properly, and can remove large amounts of CO_2, but there are aspects to this technology which need to be greatly improved. An example of this is that CO_2 scrubbers will typically reduce the power generation of the plant by 30%. Although other agencies such as the DOE are funding this technology, it still needs fundamental and applied research and development to potentially achieve breakthroughs, and limit the efficiency drain on the power plants. Post-combustion carbon capture fits into EPA's goal of clean air and climate change, and it requires research that NCER funds, which is why it's a recommendation for NCER.

2. Oxy-Combustion

Oxygen-fuel combustion aids in GHG emissions reduction for existing coal power plants. Retro-fitting this technology is a huge benefit to existing coal plants, whereas construction of new plants is not cost efficient. As climate change becomes an increasingly important topic people will continue to point towards power plants, responsible for about one third of U.S. GHG emissions. Oxy-fuel combustion recycles the flue gas coming out of the power plant to co-fire with oxygen. This process can reduce the GHG emissions of flue gas by as much as 75%. Currently, oxy-fuel combustion cut emissions in half and does not have any negative environmental impacts. The benefit of this technology besides the direct GHG emissions reduction is the flue gas that does escape is CO_2 rich and allows for less expensive CO_2 scrubbers to be used for carbon sequestration. This technology could be researched by NCER because it is still new and currently is too expensive for power plants without incentives. Also, DOE and other departments in the U.S. government are not placing heavy emphasis on this technology so NCER would not be duplicating research. An important aspect of this technology is the cost of the pure oxygen needed to induce oxy-fuel combustion. Pure oxygen is expensive to produce and is one the main reasons the cost of oxy-fuel combustion systems are so high. A method to produce pure oxygen will greatly benefit this technology and could potentially be researched by NCER. Fundamental and applied research is required to advance oxy-fuel combustion. Oxy-fuel combustion can also reduce NO_x emissions, which falls under EPA's objectives as specified under the CCTP. Because fossil fuels seem to be unavoidable in the future, retrofitting and new technologies to move coal power plants towards near-zero emissions should be developed.

3. Geological Carbon Sequestration

Geological carbon sequestration is important because it has the potential to be a main contributor to CO_2 mitigation. Geological carbon sequestration is being funded by agencies such as the DOE. These agencies are funding research on whether or not CO_2 will leak from the underground reservoirs it's stored in, as well as the development of the technologies which inject the CO_2. Ground water contamination is an important aspect of geological carbon sequestration because these potential side effects must be studied in order to utilize this technology. Ground water could be contaminated due to geological carbon sequestration because CO_2 could leak into aquifers, or saline ground water could enter an aquifer as a result of being displaced by CO_2 injected into saline beds. Since the effects of ground water contamination are not being actively researched by the agencies involved with geologic sequestration such as the DOE, it presents an area in which NCER could play a role. Effects from studying ground water contamination as a result of geological carbon sequestration pertain to EPA's goal of clean and safe water. This research provides NCER with a funding niche in geological carbon sequestration.

4. Cellulosic Ethanol

The production and use of cellulosic ethanol has high potential for environmental impact. When cellulosic ethanol replaces a fuel derived from petroleum, the amount of GHGs emitted into the atmosphere is reduced, mitigating climate change. Cellulosic ethanol is at the pilot-scale level of development and must show some promise technically and economically to move to full-scale testing. This low level of development provides NCER the opportunity to play a leadership role in this technology area. Some aspects surrounding the production and use of cellulosic alcohol have been researched and developed extensively while others have had little work conducted in the area. While other agencies such as DOE and USDA work with biofuels such as cellulosic ethanol, many questions still need to be answered. One unknown in the use of cellulosic ethanol is the environmental effects caused by the increased production and use of cellulosic ethanol. Not much work is being conducted in this area by other government agencies, which is why not much is known about these effects. NCER could certainly guide the growth of the area of technology by applying funding resources here. Cellulosic ethanol fits both into NCER's existing technology profile because of the several biofuel projects funded within the last four years, and fits with the EPA's mission to protect human health and the environment. Since NCER wishes to conduct fundamental research, this area provides ample opportunity.

New bioreactor technology used for the production of cellulosic ethanol also needs further research and development. New processes for producing cellulosic ethanol, which require different bioreactor types, are being introduced to the biofuel community. New bacteria are being introduced to produce the enzymes that convert the cellulosic plant material into fermentable sugars, and different bacteria require different bioreactor designs. If a breakthrough occurred in a cellulosic ethanol production process that allowed this process to become more efficient or economic, it would impact climate change greatly. A new bacterium could be introduced that transforms the cellulose into fermentable sugars significantly more efficiently than currently used bacteria. Because of this potential for environmental impact, NCER should consider cellulosic bioreactor research and development as an option for funding. If a breakthrough occurred in this field that allowed for cellulosic ethanol production to move from commercial-test scale to diffusion/utilization, then a significant drop in GHG emissions would occur, mitigating climate change. Because of the low level of development in this section, NCER has the chance to obtain a leadership role in the area.

5. Solar Photovoltaics

Solar photovoltaics were recommended several reasons. Fundamental research and development in this area is needed in order for this technology to make a significant impact on climate change. The benefits of solar photovoltaics include solving part of the world's energy problem. Another benefit of solar energy is it has no negative environmental impacts. Solar technologies could be used for domestic energy and commercial energy production, two of the biggest contributors to worldwide GHG emissions. One of the reasons current photovoltaic technologies do not reach their full potential in the commercial market is due to low efficiencies. Other solar technologies such as solar heating and lighting are geared towards green houses, which this report doesn't cover. Concentrating solar power was not recommended to NCER because solar power plant facilities require a huge investment of land to operate and the technology does not look promising.

6. Advanced Processes and Materials

Research and development on technologies which would enhance climate change technologies is an area which NCER could fund, and is an additional recommendation. These technologies pertain to researching and developing higher temperature resistant materials, advanced oxygen separation, and many other technologies in various categories. Higher temperature resistant materials would allow boilers to run at a higher temperature, which would increase efficiency and lower the amount of fossil fuel required to run conventional fossil fuel power plants. Advanced oxygen separation has potential to impact climate change because pulverized coal power plants are able to have oxy-combustion carbon capture technologies retrofitted to them. Oxy-combustion can capture 50% or more of CO_2 and captures NO_x as well. However, oxy-combustion requires pure oxygen, and oxygen separation techniques are expensive. NCER has the potential to fund technologies such as these because breakthroughs from fundamental and applied research are needed. This technology research and development would be ideal for NCER to fund since it isn't being focused on by other agencies, and it requires the type of research NCER currently funds.

The technologies chosen for recommendations were post-combustion carbon capture, oxy-combustion carbon capture, geological carbon sequestration, cellulosic ethanol, solar photovoltaics, and advanced processes and materials. NCER can fund fundamental or applied research through the STAR and SBIR programs. Other criteria such as the level of development, and CO_2 avoidance factor contributed towards the selection of these six technologies. These six technologies have potential to greatly mitigate global warming, and NCER could assist in the advancement of these technologies through funding programs in these areas.

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Appendix

Appendix A1 – Sponsor Description

Environmental Protection Agency

The Environmental Protection Agency (EPA) develops and enforces regulations, offers funding, performs environmental research, sponsors voluntary partnerships and programs, and publishes information. Enforcing regulations ensures that standards set by the EPA are met. The EPA can issue penalties to make states reach the desired levels of environmental quality if such values are not being met.

The EPA was established as an independent agency. Unlike Departments, such as the Department of Education and Department of Transportation, the EPA is headed by an Administrator who is appointed by the President, but does not participate as a member of the Cabinet.

Created in 1970, the EPA was given a mission to protect human health and the environment in the United States. An increased public anxiety regarding environmental pollution led to the EPA opening on December 2nd in Washington D.C. The EPA was set up to perform national studies, and to monitor climate change. The EPA is also responsible for establishing environmental principals, and enforcing policies set up to guarantee that the environment is protected. The Environmental Protection Agency plays a part in many different environmental initiatives. For example, they regulate emissions from the automotive industry, harmful chemicals such as DDT, toxic waste and they also sponsor programs to increase recycling. One of the major accomplishments by the EPA was securing passage of the Clean Air Act Amendments of 1990. The act was originally passed in 1970 and it implemented a variety of programs that focus on:

- reducing outdoor, or ambient, concentrations of air pollutants that cause smog, haze, acid rain, and other problems
- reducing emissions of toxic air pollutants that are known to, or are suspected of, causing cancer or other serious health effects
- phasing out production and use of chemicals that destroy stratospheric ozone.

(EPA, 2007E)

In 1999, the EPA demonstrated that that the Clean Air Act benefits far outweighed its costs. Recently, as of 2005, the EPA has issued the Clean Air Interstate Rule that aims to “achieve the largest reduction in air pollution in more than a decade" (EPA, 2007E) and the Clean Air Mercury Rule which is the first-ever federal rule to “permanently cap and reduce mercury emissions from coal-fired power plants" (EPA, 2007E). Overall the Environmental Protection Agency takes part in many activities that”… have resulted in cleaner air, purer water, and better protected land.” The EPA is largely responsible for setting regulations, enforcing such regulations, and performing environmental research.

The EPA employs 17,000 people (more than the DOE) mainly composed of engineers, scientists, and policy analysts. Of the employees who do not fit the above categories, many are legal, public affairs, financial, information management and computer specialists. The headquarters for the EPA is located in Washington, D.C. The Agency is comprised of 10 regions that encompass the United States. The budget for the EPA’s administrative offices and sub-divisions was $7.3 billion in FY2007. Figure A1.1 shows the organizational chart of the EPA. Some departments the WPI project team is interested in are the Office of Air and Radiation (OAR) and the Office of Research and Development (ORD) branch. The group will be working under the National Center for Environmental Research (NCER).

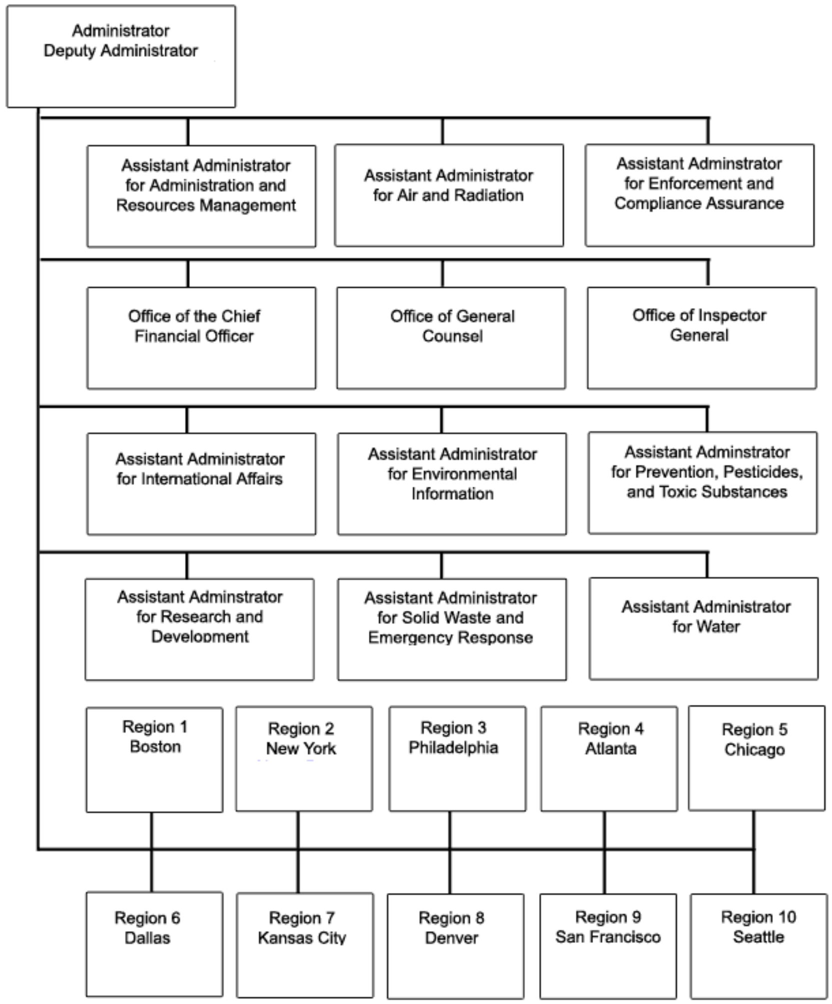


Figure A1.1: EPA Organizational Chart

Source: EPA, 2007E

Most of the scientific research done by the EPA is conducted within the ORD. The ORD seeks to develop solutions to current and future environmental problems. The ORD also gives technical support to help the EPA achieve its objectives. A branch within the ORD called NCER supports research performed by some of the nation's leading scientists. The NCER also helps the EPA achieve its goals by supporting cutting edge studies in exposure, effects, risk assessment, and risk management. Award competitions such as Science to Achieve Results (STAR) grants, the Small Business Innovation Research Program (SBIR), People, Prosperity and Planet (P3) grants, graduate and undergraduate fellowships, as well as numerous other research programs are carried out by NCER. The program encourages competitive research outside the EPA by granting approximately 140 research grants and graduate fellowships annually to the 3,000 to 3,500 applicants. These grants, along with the EPA's intramural research program, complement each other and help the EPA arrive at its goals. (EPA, 2007E)

The EPA composes a projected budget for every fiscal year. Each fiscal year runs from October to September. This budget helps determine the goals and objectives that the EPA is planning to work on during the upcoming fiscal year and spells out the funding that would be necessary to accomplish these goals and objectives. The budget created by the EPA is united with the budgets of the rest of the executive branch. This total budget is then sent to the Congress by the President. The Congress then determines how to accommodate those budgets by creating, altering, and, finally, passing bills which endorse the budgets into law. The budget report sent by the President is usually sent during the first quarter of the calendar year. The budget approved by Congress becomes the outline for the EPA's programs during the next fiscal year.

In the "Summary of the EPA's Budget" for fiscal year 2008, the EPA has ranked the following goals one through five respectively: clean air and global climate change, clean and safe water, land preservation and restoration, healthy communities and ecosystems, and compliance and environmental stewardship. In FY2007, the EPA spent approximately $930,000 of the allotted 7.3 billion dollars on goal one objectives for NCER. Even though clean air and global climate change remained as the primary goal for 2008, the funding is proposed to be cut by over $22,000 from 2007. Overall clean air and global climate change see the second smallest budget amongst the five goals seizing just 13% of the budget.

Financial assistance includes providing for research grants, and supporting environmental education projects. Using laboratories positioned around the country, the EPA can evaluate environmental conditions, and attempt to solve current problems while preparing for the future. The agency works with over 10,000 industries, businesses, non-profit organizations, and state and local government. They coordinate this work through their headquarters and various regional offices. Many of these 10,000 different businesses, non-profit organizations and industries work on over 40 voluntary pollution prevention programs and energy preservation efforts.

NCER funds three main extramural research programs that they would like us to analyze. These three main programs are the Collaborative Science & Technology Network for Sustainability (CNS), SBIR, and P3.

Collaborative Science & Technology Network for Sustainability (CNS)

The CNS, sometimes referred to as the CNS or the Network, is a branch of the EPA's Office of Research and Development (ORD). The CNS works by funding regional projects that work to solve problems that obstruct sustainability. If seeking funding for a project by the CNS, an applicant must submit a proposal along with the designated forms found at the EPA's NCER website within the specified "open" period.

All proposals should name an opportunity or problem that is associated with sustainability as well as explain how it pertains, long-term, to the mission of the EPA. Proposals must explain how engineering and science are used and include all data that has been collected or created. Proposals must predict short and long term success in terms of the environment, economy, and society and state how progress will be tracked. Proposals need to name all the parties who will be working with the project. Proposals also need to identify how approaches, lessons, and tools will be understood and used by other areas that could benefit from the technology or method. Resources such as water, atmosphere, land, energy, materials, and ecology should be looked at with a long term prospective in proposals. When those working for the Network review proposals, they look for 7 parts. These seven parts are: identification of a problem or opportunity; use of science; a definition of success and a measurement of progress; the qualifications of the project lead; collaborations; transferability; and a schedule and budget.

In 2004, $1.5 million was expected to be awarded to selected projects via six to ten awards. The projected amount of money granted per award was expected to range from $50,000 to $100,000 per year for up to three years. Continued funding for a project past the first year depends on availability of funds as well as satisfactory progress. By looking at a project's specifications we can learn things like how much money the EPA is spending on a problem, which gives some insight as to where the EPA's priorities are.

Small Business Innovation Research (SBIR)

The EPA is one of eleven federal agencies that have been involved with the SBIR program since 1982 after the Development Act was passed. The purpose of the Act was to build up the role of small businesses within federally funded research and development and to expand the national base for technical advancements. The definition of a SBIR small business is an independently owned and operated for-profit company with no more than 500 employees. The business's center of operations must be in the Unites States and the business must be owned by at least 51% U.S. citizens or lawfully admitted resident aliens. To date, the SBIR has not focused specifically on any climate change technology. SBIR funded projects have touched on areas such as biofuels, green homes, carbon sequestration and alternative energy (EPA, 2007E). The Agency intends for this program to conduct climate change technology research in the future (Richards, 2007).

The EPA funds SBIR projects using two phases. Phase I grants allow up to $70,000 and focus on the feasibility of the proposal that is being explored. The period of performance is generally six months for these projects. Using Phase I, the EPA is able to assess advanced high risk technologies and concepts to see if the company can conduct the research and whether sufficient progress has been made to qualify for Phase II funding and extended research.

Phase II funding extends up to $225,000 over 24 months. Contracts are exclusive to small businesses that have completed their Phase I contracts and have shown great promise in the technology or method. The funding is given through competitive awards based on successful results of Phase I and commercialization potential. The SBIR program is one of the EPA's main vehicles for technology innovation. The technologies and methods from these successful projects are an important part of the team's project. In 2005 EPA's SBIR program announced it would give out over $3 million to small businesses, focusing their efforts on five key environmental areas: control and monitoring of air emissions; pollution prevention; solid waste control; hazardous waste treatment; and homeland security. The team will be analyzing the limited climate change technologies and methods that have been researched through these grants. Today the EPA still has the same goals and funds around the same number of project proposals from year to year.

Looking at Phase II projects will give us a good understanding of the current status of the climate change technology, although if projects have not received Phase II funding, this does not imply that the technologies are any less significant. Phase II is specifically for technologies that are ready and developed enough to begin to commercialize for use in the business market. Creating an inventory of projects within the EPA and other departments such as DOT and DOE will help us see the holes in the research.

People, Prosperity, and the Planet (P3)

People, Prosperity, and the Planet (P3) is a program sponsored by the EPA and other various co-sponsors such as the National Council for Science and the Environment (NCSE), Environmental and Energy Study Institute (EESI), and the American Chemical Society Green Chemistry Institute's (GCI). It was established in 2004 by the EPA. This program focuses on student design teams that use their creations to benefit people, promote prosperity, and protect the planet.

The P3 awards are made to institutions of higher education located in the U.S. These institutions are able to apply for P3 grants that they can use to finance undergraduate or graduate student teams. There are many different categories of designs that are eligible for the P3 awards competition. These categories include water, built environment, agriculture, materials and chemicals, energy, and information technology. The competition contains two phases. The first phase consists of teams competing for $10,000 grants. The EPA sets aside approximately $550,000 to sponsor 55 groups. After a year of research the teams who received grants during Phase I attend the National Sustainable Design Expo to compete for an additional grant. Generally Phase II gives up to $75,000 additional to the 6 most deserving groups of the initial 55. With six groups receiving the 75,000 dollar award, the total amount EPA spends on P3 awards per year is $1,000,000.

To review the projects for Phase I, a panel made up of external peer reviewers looks at the projects using a set of criteria. The most important of these criteria are listed first, and the least important of these criteria are last. These criteria are:

- Relationship of Challenge to Sustainability
- People, Prosperity, and the Planet
- Challenge Definition, Innovation and Technical Merit, Measurable Results
- Integration of P3 Concepts as an Educational Tool

(EPA, 2007E)

Internal reviews are conducted on projects recommended by the peer review panel. These internal reviews are carried out by EPA experts, and they're purpose is to examine the head principal investigator of the project groups and perform a background check of they're performance on past projects. These EPA experts are experts in the various fields that the project deals with. For example, is the project deals with chemistry, they will use chemical experts. These EPA experts also determine how relevant the project is to what the EPA is currently researching. The external reviewers for Phase II are engineers, scientists, social scientists, economists, and various other professionals who can contribute knowledge to particular fields. This panel of judges also uses a set of criteria to select the best projects. In this set of criteria, certain aspects are more important than others. The most important of these criteria are listed first, and the least important are listed last. These criteria are:

- Relationship of Challenge to Sustainability (P3)
- Challenge Definition and Relationship to Phase I
- Innovation and Technical Merit
- Measurable Results (Outputs/Outcomes)
- Evaluation Method
- Demonstration Strategy
- Integration of P3 Concepts as an Educational Tool

(EPA, 2007E)

In 2005 seven groups were awarded Phase II funding, while six grants each were awarded in 2006 and 2007. Many of the projects recognized by the EPA that have been awarded Phase II grants pertain to the topic of climate change technology.

Appendix A2 – Minutes from Interviews

Interview Minutes with Darrell Winner

Meeting Date: 10/25/07
WPI Attendees: Charles Labbee, Nathaniel Law, and Ryan Shevlin
EPA Employee: Darrell Winner

1. The first thing we discussed was what Darrell does at the EPA
    a. Oversees global research at NCER
    b. Area of work deals with air environment more than aquatic environment
2. Gave us suggestions of some areas to research for the project
    a. CCSP – Climate Change Science Program
        i. Figure out what CCSP is doing, what is their progress, how EPA relates, and how NCER relates to that
    b. CCTP – Climate Change Technology Program
        i. Figure out what CCTP is doing, what is their progress, how EPA relates, and how NCER relates to that
    c. Other various agencies should be looked into as well
        i. DOE, DOT, NASA, NOAA
3. Asked him where he sees the future, and areas EPA might be interested in
    a. Believes Conservation is a big step
        i. Little things like policies for new light bulbs
        ii. An example is California uses 1/10 of nation wide average of coal by employing these little policies
    b. Would like alternative energy to be used more
        i. Solar Panels
        ii. Fuel cells
    c. Believes "Green Buildings" is something EPA might be into
4. Darrell suggested some people we should interview
    a. Ben DeAngelo – Works at CCTP
    b. Andy Miller – ORD risk management lab
        i. "self proclaimed king of renewable fuels"

Interview Minutes with Andy Miller

Interview Date (Via Phone): 10/31/07
WPI Attendees: Charles Labbee, Nathaniel Law, and Ryan Shevlin
NCER Attendees: April Richards
EPA (ORD) Employee: Andy Miller

1. The First thing discussed was a little background on Andy before the interview began
    a. Works for National Risk Management Research Lab, through ORD
    b. It is located in RTP, North Carolina
2. Introduced ourselves to Andy and reiterated the project we are working on
3. Asked Andy to give us some background information on himself
    a. Mechanical Engineer with a PHD
    b. Has worked for EPA for almost 17 years
    c. Mostly works with combustion related emissions for control of NOx and characterization for particulate matter.
        i. Combustion sources include power plants, industrial boiler, ect.
4. Asked what kind of work he is currently doing
    a. Heads a team researching biofuels in his lab, looking at environmental impacts of ethanol production using a sustainability perspective.
        i. Focused on corn based ethanol and soy based biodiesel
        ii. Believes future research could involve cellulosic ethanol production
5. Elaborated on what ORD is doing
    a. Hosting a pilot-scale CO_2 scrubbing technology (by RTI)
    b. Trying to understand what emissions are created from different conversion processes
    c. Not a whole lot of hands on work happening with mitigation technologies
    d. Most of the work deals with measuring emissions
    e. Lots of Bioenergy research
        i. Experiments that will help to characterize environmental impacts.
    f. Other technologies mentioned: oxy-fuel combustion retrofits, IGCC power plants which use pre-combustion (neither have been demonstrated full-scale)
6. Andy said that most of the control issues are dealt with by the DOE, EPA is researching impacts of technologies mostly
    a. DOE could research scrubbing technologies
    b. EPA would research impacts of scrubbing technology
        i. What happened to the residues, the rest of the flue gas, ect.
    c. The EPA will mostly be involved with technologies such as CO_2 scrubbing to the point of evaluation
        i. Part of the reason for this is most funding is going to the DOE.
    d. ORD is starting to evaluate how they can do experiments with Oxy-combustion and some scrubbing technologies

        i. These are good technologies to look at because they can be used to retrofit existing power plants and are quick fixes
        ii. The ORD must try to understand the environmental issues behind scrubbing and oxy-combustion.
    e. Monitoring within EPA
        i. For carbon output, typically measure CO_2 (+ other "stuff")
        ii. For large-scale assessment you can use prediction, 90% of CO_2 means complete combustion
7. Andy explained what the EPA is doing in regards to biofuels
    a. Biofuels are subject to weather, soil conditions and many other things that cannot be controlled.
    b. The EPA needs to understand environmental consequences beyond the emissions
        i. What going to happen to soil quality, will there be enough water, what will happen to the land, and many other things
    c. Groups of people starting to analyze some of this
        i. NRMRL lab in Oklahoma – Beginning to analyze ground and ecosystem issues
        ii. NRMRL lab in Cincinnati – Looking at agricultural run off issues
        iii. Region 7 with ORD research are scoping out the future of the Midwest and what the landscape will look like in 5 years, and how the air, soil, and water quality will be affected by biofuels
    d. Talked about corn-based ethanol
        i. Some advantages
            1. It does not require a significant change in infrastructure
            2. Much lower petroleum use
        ii. There are 3 reasons for ethanol policy wise
            1. Can be done now, Infrastructure does not require major change, and petroleum use could be reduced by 90 percent
            2. Rural economic development
            3. CO_2 quick fix
8. Andy made some predictions about what will be done and said what should be done
    a. If there is guaranteed economic return we will see cellulosic technology in the next 10 years
    b. Probably see more thermo chemical energy production than bio
        i. Biofuels must be thought of as solar energy conversion to liquid fuels. (1 Watt per m^2 for solar)
    c. We should be moving toward energy efficient societies
    d. Stated that the U.S. Department of Agriculture (USDA) said 1 billion tons of Biomass per year would be available. This will still only satisfy about 25-35% of the transportation market.
        i. Because of this we must take advantage of efficiency gains in homes, cars, ect.
9. Andy gave us one more little tidbit about climate change
    a. As climate change occurs, there are many different impacts it can cause.

        i. From Temperature Change, to air quality, to Rising sea levels, to health issues
   b. Different approaches for mitigating climate change will come about. Until now the approaches have been the same for the past 80 years.
        i. All these different approaches will raise tons of different environmental questions, and nobody knows what these changes will be at this point, or how to deal with them
        ii. Must consider these potential environmental impacts when writing our report/giving recommendations

10. Andy gave us some people that would be helpful to contact
    a. Rich Baldauf – Works with Office of Transportation and Air Quality (OTAQ) in OAR and ORD
    b. Brenda Groskinsky – Works in EPA Region 7, Analyzes possible impacts in the Midwest due to increased biofuel production and use
    c. Bob Wayland – Works with Office of Air Quality Planning & Standards (OAQPS) in OAR – works on advanced energy technology. Specifically looking at CO_2
    d. Jennifer Wang – Region 9. Works on a document that outlines using renewable energy at superfund sites
    e. MIT - report on the future of coal
        i. Herzog – Author of relevant reports
        ii. Hill – NAS
    f. Billion Ton Study (Biofuel,biomass) – USDA
    g. DOE – Carbon Sequestration Strategy

Interview minutes with Diana Bauer

Meeting Date: 10/31/07
WPI Attendees: Charles Labbee, Nathaniel Law, and Ryan Shevlin
NCER Attendees: April Richards
DOT Attendees: Diana Bauer

1. Diana: Currently on a temporary assignment with the DOT analyzing an array of programs within the DOT so they can make sense of programs that relate to climate change
2. 2 main areas
    a. Mitigation of emissions
        i. Transportation 28% of total US emissions
        ii. Over half of transportation emissions are passenger vehicles
        iii. 3 things considered with transportation emissions
            1. Fuels
            2. Vehicle miles traveled (traffic also needs to be considered)
            3. Vehicle technologies
    b. Energy often used for freight (accounts for 30% of GHG emissions in US)
    c. Infrastructure adaptation dealing with climate change
        i. How the ecosystem will react to, rising sea levels, warmer average temperatures, poorer air quality, etc.
3. DOE believes hydrogen from coal and carbon sequestration are the answer to addressing climate change
    a. DOE focuses on energy security
4. Topic switched to biofuels
    a. Diana said that biofuel production need to be spread out
        i. Can't place the weight of biofuels on the Midwest, biofuels need to be produced everywhere because they are very region specific
5. DOT – is a regulatory department with 3 main goals
    a. Safety
    b. Congestion
    c. Global Commerce
    d. Environmental Stewardship
6. DOT Mostly focused on
    a. Mitigation of emissions
    b. Transportation infrastructure
7. 3 options for transportation in future
    a. Biofuels
    b. Hydrogen (fuel cells)
        i. Metabolic production of hydrogen in the future
    c. Electric cars (hybrids)
        i. Electricity still from coal plants (con)
        ii. Batteries can use exotic and hazardous materials (con)

iii. Argument is that energy built up by power plants that supply sufficient electricity for peak hours or overnight where electricity use goes down. Cars could use excess off-peak production (pro)

8. NCER/EPA should influence the shift in energy
    a. Technologies should be as "green" as possible
        i. Focus on technologies that are outside the area of ones DOE would focus on
9. Diana talked about a large report that looks at cost of congestion (Urban Mobility Report)
    a. Uses techniques made in 1981
    b. She is helping improve this process
10. DOT does some extramural research
    a. Do not give grants but contract out
11. Sun Grant iniative
    a. Establishes/funds University centers that research biofuel production and environmental sustainability
12. DOT's budget might double over the next 5 years
13. Government shouldn't influence one specific energy source too much
    a. But it should look into biofuels more
14. DOE doesn't always consider all the environmental effects of actions/technologies
    a. DOE also has a strong bias towards coal and fossil fuels when making decisions
15. CNS is having a workshop next Friday morning on energy and climate change
    a. Darrell Winner will be one of the panelists
16. Contacts and other resources
    a. John Darics – EPA/OAR – GHG inventory
    b. Simon Mui – EPA/OAR – made a wedge analysis for transportation
    c. William Chernicoff – DOT – transportation technology (could be hard to track down)
17. Skip Laetner – Counsel for Energy Efficient Economy

Interview Minutes with Ben DeAngelo

Meeting Date: 11/2/07
WPI Attendees: Charles Labbee, Nathaniel Law, and Ryan Shevlin
OAR Attendees: Ben DeAngelo

1. Introduced ourselves
    a. Gave Ben background of why were here
2. Ben gave us some background information on himself
    a. He works in the Climate Change Division (CCD) through the Office of Atmospheric Programs (OAP) through the Office of Air and Radiation (OAR)
    b. Studied Geography
        i. Has his undergraduate and masters
            1. Common for employees in the CCD
    c. After Undergraduate Degree
        i. Began an internship at the Climate Institute -this institute helps facilitate workshops to produce reports on potential climate change impacts
        ii. Went to grad school at University of Toronto – his advisor was a carbon cycle monitor
            1. Degree was mix of earth science and environmental policy
    d. Working in D.C.
        i. Started off working with National Research Defense Council (NRDC).
        ii. Began working in EPA after that
            1. First job was regulatory work – regulating HFCs and phasing them out
            2. He was also the go to guy on a few paragraphs in the Kyoto protocol
    e. Been working on climate change for 10 years now
3. Chuck asked Ben why U.S. hasn't signed Kyoto protocol
    a. Ben said Bush gave a press release in 2001 with a list of reasons for why he didn't sign. He will email us that.
        i. The reasons he remembered was that it would hurt the U.S. economy,
        ii. Meeting the Kyoto protocol emissions standards would not have been easy, and
        iii. Bush also didn't like that fact that big emitters like India and China didn't have to ratify
    b. Since U.S. did not sign Kyoto protocol Bens department has used downtime to refine analyses, and models so when it comes back around they would be prepared
        i. His section of the EPA is largely responsible for climate change analysis
4. Ben spoke about the executive order the President issued

        a. This order stated that the EPA must start to regulate transportation emissions using the clean air act. This was because of the outcome of mass v. EPA
        b. His office is working with Office of Transportation and Air Quality (OTAQ) on this
        c. Bens main job is the endangerment finding
            i. Under the clean air act anytime something new is being regulated an endangerment finding must be created
                1. This endangerment finding must show evidence to prove what's being regulated is harmful
                2. The particular endangerment finding he's working on now focuses on transportation
                    a. Transportation sector is responsible for 6% of the worlds GHG emissions – this is as much or more than some countries

5. Ben spoke about some of the U.S.'s goals
    a. Currently the U.S. is responsible for about 20 percent of the worlds GHG emissions
    b. One goal is to reduce gasoline emission by 20% over 10 years
        i. This will be achieved with three methods
            1. Increasing CAFE standards –CAFE standards are the U.S.'s current Corporate Average Fuel Economy standards. They are the fuel efficiency standards set by an agency within the DOT
            2. Fuel Standards – increase alternative fuel use
            3. Green house gas standards for vehicles – grams of CO_2 per mile and similar rules. This is not in place yet, but it is being developed.
6. Ben gave us some insight as to what might be happening in the near future and what he believes should be happening
    a. He believes that a very likely scenario that will happen in Congress is that the Congress will direct the EPA to set up a nation wide program outside of the clean air act to address climate change.
    b. EPA should be looking at technological solutions in all sectors
        i. All technological solutions should be considered.
    c. Many people that were against carbon capture and storage and changing they're minds.
        i. This is because people are starting to realize ambitious goals of GHG reductions, such as those in California, wont be possible without capture and storage
7. Finally we asked Ben if he had any contacts that could help us with this project
    a. He said he would email us some names of people he believes could be helpful

Interview Minutes with Paul Shapiro

Interview Date: 11/14/07
WPI Attendees: Charles Labbee, Nathaniel Law, and Ryan Shevlin
NCER Attendees: April Richards
EPA (NCER) Employee: Paul Shapiro

1. Introduced ourselves to Paul
2. Ryan Asked Paul for some background on himself
    a. Paul works for NCER
    b. In the early 1990's there was a Global Change Mitigation Program, eventually money for technology research within this program was cut and the research was stopped.
        i. Paul was involved with this program. Since many technologies that our group has covered were not thought of back when Paul was involved with technology research he said he's not an expert.
3. Paul spoke briefly about new infrastructure for EPA
    a. A technology officer coordinates technology research across the agency
    b. Technology research has always been important, plays a big role in set up of infrastructure.
    c. With current situation there is less money, which makes coordinating technology research even more important. People working on technology would like to move forward with mitigation research
4. Paul suggested some areas we should look at, and some areas he believes would be good to focus on
    a. Should focus on what directions NCER can fund in moving technology forward to mitigate global warming
    b. Should look over the NACEPT report, www.epa.gov/etop. This website contains two reports.
        i. 1st report is technology development continuum
        ii. 2nd report is NACEPT report
    c. EPA has virtually no programs in commercialization aspect on continuum from first report
    d. EPA also has little or no contact with venture capital community, no knowledge of private sector money situation
    e. Paul talked about CCSP and CCTP
        i. CCSP – Collaborative Chairs/heads
        ii. CCTP – Someone from DOE is in charge
    f. Everything done within EPA must fit into these policies
        i. It would be helpful for the group to have thoughts on how NCER could relate to these policies with the little money they have
    g. Paul recommended we possibly focus in sequestration
        i. Environmental impacts could be important
        ii. Could possibly collaborate with DOE on sequestration efforts
    h. Paul also suggested looking at verification as a key step of commercialization and adopter of new technologies

        i. NCER could fund centers that ask for ways to promote verification for various technologies
        ii. Work in conjunction with other agencies
    i. Paul would like for NCER to be able to research more specific technologies rather than environmental impacts.
        i. Paul would like for NCER to be able to provide leadership in a technology
    j. Paul believes choosing one area to research and focus on could be a something the group could do
    k. On an ending not Paul stated the ORD/NCER need a climate change technology research strategy
5. Ryan asked if Paul has any useful contacts for us
    a. Frank Princiotta – NRMRL, thinking in terms of large scale technologies

Interview Minutes with Rachel Jakuba

Interview Date (In person): 11/16/07
WPI Attendees: Charles Labbee, Nathaniel Law, and Ryan Shevlin
NCER Attendees: April Richards
EPA (NCER) Employee: Rachel Jakuba

1. Chuck asked Rachel is she could tell us a little about herself
    a. She is at NCER as a science and technology fellow
    b. Her background is in Marine Sciences
    c. PHD on how open ocean nutrient trace metal will limit phytoplankton growth (Zinc, Cobalt, Phosphorous)
        i. Because of this she is very interested in iron fertilization. However, iron makes phytoplankton grow, unlike the metals she studied before
2. Chuck asked Rachel is she could go into more depth on iron fertilization
    a. Rachel explained iron is supplied to oceans through rivers, rain and sediment supplies the rivers with iron. Wind can also transport iron to the ocean
    b. Climos and Planktos are two U.S. companies interested in large scale iron fertilization
    c. The biggest complaint with iron fertilization is scientists don't know what will happen
        i. Algal blooms could be possible, and these blooms would create poisons. Not a severe problem since iron fertilization would take place in the middle of the ocean and far away from land
    d. Climos is planning on doing a 200 km2 commercial test. They plan to stay out at sea for 70 days to study whether or not the patch of phytoplankton sinks
3. Chuck asked Rachel what EPA's role with iron fertilization is
    a. EPA has some power over iron fertilization because it can be considered ocean dumping
        i. Phytoplankton could also deplete oxygen if there are big blooms in small water column areas
        ii. Companies argument to this is the ocean is really big and has deep water columns
4. Chuck asked Rachel what her stance is on iron fertilization
    a. She isn't sure if it makes sense
        i. Geologic carbon sequestration makes more sense to her
    b. She believes there is a chance it could work as a stop gap measure, and only do it for so long and then stop.
    c. The main problems with it in her opinion are:
        i. Not proven to work
        ii. It is not a long term option, and its hard to stop things once they are started

Interview Minutes with Russell Conklin

Interview Date (In person): 11/14/07
WPI Attendees: Nathaniel Law and Ryan Shevlin
NCER Attendees: April Richards
DOE Employee: Russ Conklin

1. After the group introduces themselves to Russ, Nate asks him to tell us about himself and what he does for DOE
2. April introduces the problem statement for the project next
3. Russ gives a brief overview of the Climate Change Technology Program (CCTP)
    a. He explains that this is one of Bush's initiatives
    b. Russ states that CCTP staffing doesn't do the actual research, they fund others to do research
    c. The CCTP budget for 2007 was $500,000
    d. The CCTP was asking for $1.1 million for FY 2008 budget
4. Russ tells that DOE focuses only on one greenhouse gas: CO_2
5. Then, Russ informs us that the CCTP Strategic Plan took 4 or 5 years to produce
6. Another Goal of the DOE is to update the Research and Development (RESEARCH AND DEVELOPMENT) portfolio
7. Russ notifies that a DOE staff goal is to achieve zero emissions
    a. Officially, DOE goals are related to energy intensity
8. Russ states that the U.S. has become more energy efficient
    a. Lower energy intensity
9. Russ tells that it is a challenge for the DOE to keep up with the most recent climate change technology and research
10. Next, Russ gives his opinions on climate change technology areas
    a. Nuclear needs to grow much bigger
    b. Coal carbon capture and storage needs to grow greatly as well
11. Russ informs the group that many different technologies are needed for a difference to be made in climate change
    a. This includes investments in many technology areas
12. Russ goes over a graph of the high view of the CCTP in the Strategic Plan
13. Russ tells us that the USDA is doing a lot of work with terrestrial sequestration
    a. This work was very small until recently
14. April, then, inquires about which areas can sequester the most CO_2
    a. Russ is not sure
15. Russ explains that there is a huge air particulate matter problem with the combustion of biofuels
16. Russ tells the group about Futuregen, a zero emissions coal plant that is being designed currently
17. Nate asks Russ is the DOE is focusing on geologic CO_2 storage or oceanic CO_2 storage
    a. Russ promptly responds that they are focusing on geologic storage

18. Russ informs the group about 2 CO_2 sequestration project that are ongoing
    a. One in the North Sea
    b. One that captures in North Dakota and stores in Canada
19. Russ tells us that knowing how to monitor GHGs is a huge issue
20. Russ moves on to tell the group that the DOE is trying to make existing power generation plants more efficient
21. Currently the U.S. has 103 operating nuclear power plants and the number will likely rise to 300 in the future
22. Russ informs us that the DOE is working with low wind speed turbines and large scale turbines (5 megawatt turbines)
    a. DOE is also looking as river turbines
        i. There could be much improvement in this area
23. Russ explains his view on solar energy
    a. The return of investment in terms of mitigation potential is not good enough
24. Russ tells that the DOE thinks that cellulosic ethanol is very important
    a. DOE is using land-use models to study effects of cellulosic ethanol production and use
25. Russ finally explains that solar energy storage is a big problem

Interview Minutes with Audrey Levine

Interview Date (In person): 11/26/07
WPI Attendees: Charles Labbee, Nathaniel Law, and Ryan Shevlin
NCER Attendees: April Richards
EPA (ORD) Employee: Audrey Levine

1. Meeting started off with introduction of WPI team and Audrey
    a. Audrey works on drinking water research in ORD
2. Climate Change
    a. She works answering the question, how will climate change affect the water?
        i. Temperature increase
            1. Easier to carry pathogens
            2. Could completely change the microbiology
3. Energy to make drinking water
    a. Most drinking water is from the surface
    b. There are becoming less and less sources of underground water
    c. Desalination process is expensive and not efficient
        i. ½ of the water processed is wasted
4. Geologic Carbon Sequestration (Band-Aid for climate change)
    a. Carbon captured from smoke stacks and plants is not pure, contains other pollutants
    b. There is a lot of pressure for EPA to make a ruling to permit geologic sequestration
        i. They plan to make a ruling by July of 2008
    c. Discussed briefly on cases of pumping waste into the ground
        i. Florida pumped waste water into aquifers and saw it seep back up on the shores
    d. Pumping it unknown and DOE needs to careful because CO_2 is acidic
    e. DOE has decreased their site testing from 20 or so to 3 major sites of Geologic Carbon Sequestration
        i. They are injecting pure CO_2 which has never been done
        ii. From this test they should extract valuable information
            1. How do you ensure the aquifers maintain integrity
            2. How do you monitor activity in the aquifers
    f. If CO_2 pollutes the drinking supply, how will we maintain safe drinking water?
        i. There are few water purification technologies for ground water
        ii. Would we have the technology to enable safe drinking water?
        iii. <u>Effects CO_2 leaks will have on water need to studied</u>
    g. If and when it is determined this is a promising method for mitigating climate change, proper models needs to be developed to evaluate potential sites
    h. In future, pollution control needs to be simplified
        i. Companies will want it cost effective and simple because environmental concerns are not high

i. By 2012 EPA plans to come up with regulation for geologic carbon sequestration
   i. Should this fall under clean water or clean air?
   ii. Are new categories needed?
j. By 2012 DOE plans to make geologic carbon sequestration fully commercialized
   i. No database of drilled wells which could be a big problem
k. Office of Air meeting next week on geologic carbon sequestration

5. Biofuels effecting the water
   a. Water demands to meet crop increase
      i. Fertilizer runoff will contaminate the water
      ii. Competition for water, crops and fuel
      iii. Increased biofuel production will create a lot of pressure on water resources
   b. Case in Iowa
      i. Intense corn harvesting resulted in high nitrogen concentration in rivers
         1. Needed to be diluted with ground water
            a. Placing greater strain on limited ground water supply
   c. Feedstocks
      i. Ones that require low quality water and require less water is crucial
         1. Saline water for crops would be optimal
      ii. Using the waste created by producing biofuels needs to be put to better use
6. Geologic Carbon Sequestration
   a. Possible by 2012
   b. An efficient use for carbon would be optimal
   c. Carbon in ground – not recommended
   d. Consequences need to be understood and researched
   e. Group should form solid questions and pathways for geologic carbon sequestration

Interview Minutes with Frank Princiotta

Interview Date (Via Phone): 11/30/07
WPI Attendees: Charles Labbee, Nathaniel Law and Ryan Shevlin
NCER Attendees: April Richards
EPA Employee: Frank Princiotta

1. Chuck Introduced us
    a. Described why were at NCER and what the project were doing is about
2. Chuck told Frank that we've looked into his report, and asked for Frank to give some background information
    a. Frank runs the Air Pollution and Prevention Control Division
        i. Currently working on development of CO2 scrubbers
    b. Is a chemical engineer with a background in nuclear power
    c. Has been working on global change for 15 years
3. Chuck asked about what Franks section of the EPA is doing with climate change technologies
    a. Frank stated that the EPA program is very modest
        i. Not focused extensively on mitigation
        ii. Mostly researching impact of global warming on air quality
        iii. Starting to look at adaptation since it might be to late to avoid substantial global warming
4. Chuck asked Frank about the effects climate change technologies will have on the environment, especially that of air and water
    a. Frank stated this topic needs a lot more work
        i. For example: Carbon capture methods will reduce efficiency, which means more coal will have to be mined, and that will have more effects
        ii. All of the new technologies have environmental problems that needs to be examined
5. Chuck asked Frank about carbon sequestration, and the role EPA could have
    a. Frank believes it is very legitimate role for EPA to study effects of carbon sequestration
    b. Frank believes carbon sequestration is a viable option for CO_2 mitigation, although many people are skeptical
6. Chuck asked Frank what he knows about CO_2 scrubbers
    a. Frank said that the DOE is currently funding his facility to test a CO_2 scrubber they have developed
    b. Franks facility is one of the only facilities capable of large scale testing of CO_2 scrubbers
    c. The scrubber Franks facility is working on is sodium carbonate which will react with CO_2 to create sodium bicarbonate, and CO_2 is eventually removed from the flue gas
        i. This scrubber will reduce power generation by about 30%, and its one of the best there is in that aspect. This scrubber will also take out 90% or more of CO_2 from the flue gas.

7. Chuck asked Frank about oxy-combustion
    a. Frank said it is expensive
        i. The problem with capturing carbon normally is its in a dilute stream, oxy-combustion makes the stream composed of mainly CO_2 and H_2O, so its easier to capture the CO_2
8. Chuck asked Frank about pre-combustion, or IGCC's
    a. Frank believes gasification isn't the answer, complex, not extremely reliable nor efficient
9. Chuck asked Frank of oxy-combustion and CO_2 scrubbers, which he prefers
    a. Frank believes its more economical to retrofit power plants with scrubbers, and not oxy-combustion
    b. Frank also said he believes all three capture technologies, post-combustion (scrubbers), oxy-combustion, and pre-combustion should be getting full attention.
10. Chuck asked Frank if he believes NCER could help with any of the three carbon capture methods
    a. Frank believes fundamental research on technology related issues is important
    b. Think about looking into technology and determining what the fundamental engineering questions that could benefit from fundamental or applied research are.
    c. This is research NCER could do since they give grant money to universities, and universities typically do this type of research
11. Chuck asked Frank what he thinks NCER could be doing
    a. Frank stated that there are two main categories
    b. Fundamental power generation technologies
        i. Photo-voltaic
        ii. Batteries
        iii. Cellulosic
        iv. These are examples of technologies that could greatly benefit from breakthroughs, and need fundamental research. NCER can fund this fundamental research to achieve these breakthroughs
    c. Technologies that will enable climate change technologies to be used
        i. High temperature material – run boilers at a higher, which will increase efficiency, which will mean less coal is needed
        ii. Advanced Oxygen separation
    d. These are two categories that have many technologies which could be researched, and NCER could contribute
12. April asked Frank about his efficiency recommendations section on his report
    a. Frank said to look at the IEA study, which is very important
    b. The appliances section is the "low hanging fruit", or the method that can be used immediately to mitigate emissions
    c. Probably wont be any breakthroughs, so it probably isn't a good area for us to be looking into
13. Chuck asked Frank about Biofuels

    a. Frank said there are a lot of people working in this area, and there is a lot of money going into this area
14. April asked Frank is he has a report we could cite
    a. Frank said he will send us a published paper that is just on power generation
    b. He will also send a copy of the paper we looked at once its approved
15. Finally Chuck asked Frank if it would be alright to use his name in the report
    a. Frank said that would be alright
    b. We said we will send him a copy of the minutes, and the sections where his name is used
    c. We will also send him a copy of the final report when it is complete

Appendix A3 – Analysis of Interviews

Andrew Miller Interview

An especially helpful interview was the one with Andrew Miller, who works for the National Risk Management Research Lab (NRMRL) through ORD. Andrew Miller is a mechanical engineer with a PHD, and has been working for EPA for nearly 17 years.

Dr. Miller outlined the function and purpose of EPA's Office of Research Development, and described what his agency, which is through run through the ORD is working on. NRMRL is funding a pilot-scale CO_2 scrubbing technology, which is important information since post combustion capture is one of the possible technologies to recommend, and promises certain environmental benefits. Dr. Miller also explained that NRMRL is trying to understand what emissions are created from different conversion processes, which will help scientists to determine if other harmful emissions are being created due to the conversion processes. Another project that Dr. Miller is working on is bioenergy research. Research on this project involves characterizing the environmental impacts that bioenergy production could cause, and the possible risks as a result of these environmental impacts. Two more technologies being researched in ORD that Andy spoke about were oxy-fuel combustion retrofits, and IGCC power plants, which use pre-combustion. In terms of oxy-fuel combustion retrofitting technology and pre-combustion carbon capture technology, Dr. Miller's department is analyzing what the environmental issues behind these technologies are. The potential risks associated with these environmental impacts are also being analyzed. Both of these technologies are possibilities to recommend that NCER should research, so it is useful to know that other parts of the ORD are conducting research and that NCER could possibly collaborate with others departments in the ORD on technology research.

The group asked Andy if he could tell us what technologies, if any, the EPA is heavily researching. In general, Dr. Miller stated that control issues are dealt with by the DOE, and the EPA usually researched the impacts of technologies. He suggested that while DOE could research the scrubbing technologies themselves, the EPA could research the impacts of scrubbing technologies, such as what happens to the residues and the rest of the flue gas. To get some input from Dr. Miller about possible technologies to research, not just environmental impacts, he was questioned about the potential impact for biofuels. Dr. Miller stated that he believes if there is a guaranteed economic return, cellulosic technology will be developed sometime in the next ten years. On top of the economic returns influencing the development of cellulosic technology, ethanol fuel makes sense for three main reasons: Ethanol can now be mass produced with existing technologies, although it is inefficient; expanded use of ethanol as a fuel would not require any major infrastructure change; and ethanol would foster rural economic development. As an added bonus, ethanol is a CO_2 quick fix.

This interview assisted in identifying certain technologies that needed to be analyzed for further research, but it didn't necessarily help to determine technologies to recommend. Some of the technologies looked into were pre-combustion and oxy-combustion technologies, and biofuel technologies such as cellulosic.

Audrey Levine

An interview with Audrey Levine, an employee of ORD, with a specialization in water quality, focused on important water quality and supply concerns associated with biofuels and geologic sequestration. Dr. Levine works on research involving the effect of climate change to drinking water supply and quality.

Several research questions were raised involving both climate change technologies. Dr. Levine also pointed out that most of the effects on water quality and supply cannot be yet be studied because they have not been indentified. This type of research is not only appropriate for NCER but in dire need because of DOE's accelerated plans for geologic carbon sequestration and biofuels.

Geologic carbon sequestration is an underdeveloped and wildly unknown process. The biggest unknown is how long the carbon will stay underground. If carbon seeps back up through the earth, it could affect ground water in unforeseen ways. Ground water is one the greatest concerns because it is the main source of drinking water and is generally untreated. If concentrated amounts of CO_2 and other elements brought to the surface with the CO_2 are exposed to the ground water supply, new technologies and methods will then have to be adopted to treat the water, which could be expensive and disastrous. She referenced an example is Florida where waste water was pumped into "self-contained" underground aquifers from which the waste water was later found re-surfacing on the shores. It is unknown how sequestered carbon and other elements could travel through the ground to pollute the drinking water supply, and what types of technologies will be needed to keep the drinking water supply safe. This is important because desalination of sea and ocean water is a costly process and still needs research and development to become more efficient.

Biofuels, unlike geologic sequestration, will definitely affect the water supply. Increased crop growth requires increased water to be used. This is a serious issue because, as population continues to increase, the U.S. the availability of water becomes scarce which is why water supply is predicted to become a huge issue in the 21^{st} century. Another issue with increasing harvesting for biofuels is the fertilization required to grow feedstocks (switchgrass, perennial grasses, and woodchips). In Iowa, scientists are already starting to see high concentrations of nitrogen (main component in fertilizer) in nearby rivers. In response, cities and towns have had to dilute the water with pure ground water, placing a greater strain on the drinking water supply. Dr. Levine also emphasized the importance of choosing feedstocks for ethanol production that require less treatment (water and fertilizer). This would place less strain on the water supply and will not pollute the surface water.

At the end of the interview Dr. Levine spoke on the DOE's geologic carbon sequestration. They planned originally to have around 26 test sites but have recently announced a new strategy of three large scale test sites. This testing will, according to the DOE, lead to a commercialized sequestration technology by 2012. This is relevant to the EPA because, by 2012, they plan to formulate a regulation for this technology. Since the effects of geologic sequestration of carbon are unknown at this point, intensive research is necessary to meet this deadline.

Audrey Levine brought up many important research questions dealing with the effects of biofuels and geological sequestration on the water supply and quality that are appropriate for NCER research funding.

Russell Conklin

An interview with Russell Conklin, a policy analyst with the DOE's Office of Climate Change Policy and Technology, focused on DOE's involvement in the CCTP and with climate change technologies. There was also discussion of important climate change technologies that should be researched.

Shortly after the interview began, Dr. Conklin explained the DOE's involvement with the Climate Change Technology Program (CCTP) and what areas of climate change technology the DOE is involved with. This helped the group understand how the CCTP works which aided in the process of writing up the results. The CCTP is important because it combines the work done by our nation's government agencies on climate change into one central program. When making the recommendations to NCER, as dictated by the project scope, it is vital to consider climate change research and development promoted by other agencies. This is necessary because, if NCER wants to make an impact on the mitigation of climate change, it has to use the relatively small amount of funding they have available for climate change research and development on areas that haven't been researched and developed in great depth or areas that currently have a great deal of funding already being put towards that area's research and development. For example, the DOE put nearly $150 million towards solar energy in 2007, so it would not be wise for NCER to put any of its approximate total budget of $65 million in 2007 towards research and development in that field (DOE, 2007a). The interview help clarify that DOE funding for climate change research and development is allocated, was such an aid to completion of project objective three (recommendations).

Another reason why this interview was helpful was that Dr. Conklin knew a considerable amount about climate change technologies. He understood a good deal on the vast scope of climate change technologies. When quizzed further about specific areas, Dr. Conklin revealed that he believes that cellulosic ethanol will be important in the future of our nation. This led Russ to suggest that maybe the group should recommend basic research and development on the production and use of cellulosic ethanol as well as research and development on the widespread effects that will be caused by the production and use of cellulosic ethanol. The group already had cellulosic ethanol in mind as a topic for funding for NCER, and this comment on bolstered that option. Dr. Conklin also mentioned in the interview that there is a big air particulate matter problem with the combustion of biofuels. Since, biofuels were another possible basic topic of future focus by NCER; this option was solidified with this comment.

Frank Princiotta

Although the interview with Frank Princiotta occurred late into the term it was extremely beneficial. Mr. Princiotta runs the Air Pollution and Prevention Control Division through EPA. This interview was beneficial because Mr. Princiotta is knowledgeable about many different technologies and was able to give advice on what research and development he believes would be appropriate for NCER.

Mr. Princiotta was able to describe many different technologies and what he believes their importance is, and what research and development he believes needs to be done in order to improve, or employ these technologies. Some of the technologies discussed were carbon sequestration, post-combustion, oxy-combustion, and pre-combustion carbon capture technologies, as well as technologies he believes could be researched in order support or employ climate change technologies.

Mr. Princiotta stated that he thinks it is legitimate for the EPA to have a role in studying the effects of carbon sequestration, and he also believes carbon sequestration is a viable mitigation technology. The NRMRL facility he works at is testing pre-combustion carbon capture technology by performing research and development on CO_2 scrubbers. This is one of the only facilities capable of large scale testing of CO_2 scrubbers. He also stated that he believes it is more economical to retrofit power plants with scrubbers instead of oxy-combustion. The problem with oxy-combustion is that it is expensive, and it's easier to retrofit plants with scrubbers, and the problem with pre-combustion is that it's complex, not reliable, and it's inefficient. Although Mr. Princiotta believes post-combustion is the best option, he thinks that all three carbon capture technologies should be getting full attention. One additional important piece of information that was discussed in this interview was the two areas of research and development on technology that he believes NCER could play a role in.

One of these areas is that Mr. Princiotta believes fundamental research on technology related issues. He believes NCER could contribute in this area because certain technologies require fundamental or applied research to achieve breakthroughs, and universities, which NCER funds, generally perform this type of research. The second area that NCER could assist with is technologies that will enable climate change technologies to be used. Examples of these types of technologies are high temperature materials, and advanced oxygen separation. The reason that research and development would be beneficial on these types of technologies is because if high temperature materials were developed than that would allow boilers to be run at higher temperatures, which would increase the efficiency, which would mean less coal is needed in the power plants.

This interview helped the group to determine which technologies NCER could play a role in and perform research and development. Frank was able to give us ideas that we didn't have before the interview on areas of technology NCER could perform research and development on, and he was able to confirm that some of the areas we believed NCER could play in a role in would, and should be able too.

Appendix A4 – Table of CCTP Funding

Table A4.1: CCTP Funding Landscape

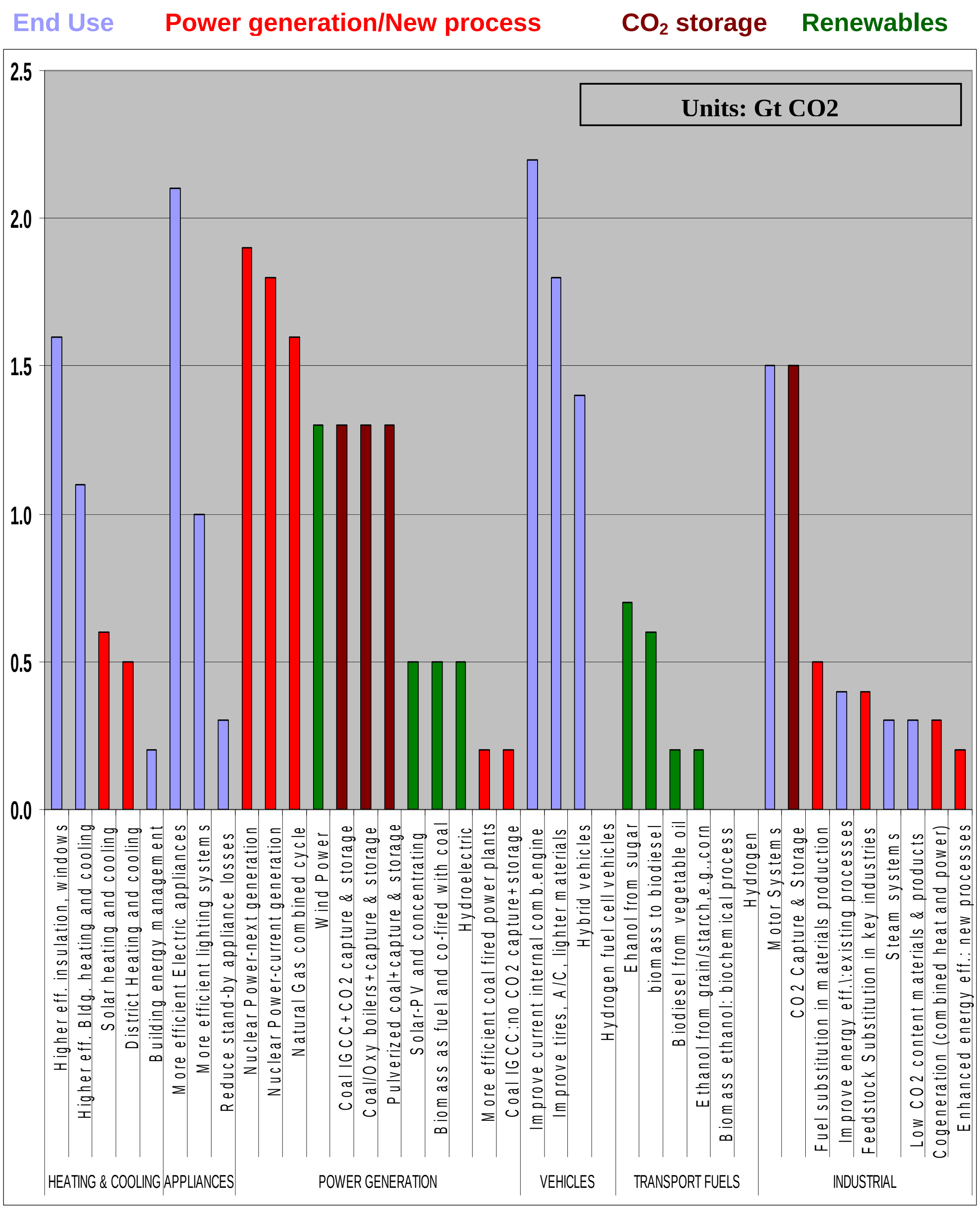
	Funding in $ millions	
Department and Account(s)	**FY 2006 Enacted**	**FY 2007 Request**
Department of Agriculture		
Natural Resources Conservation Service (NRCS)		
Biomass R&D	12	12
Carbon Cycle	0.5	0.5
Forest Service R&D – inventories of carbon biomass	0.5	0.5
Agricultural Research Service – Bioenergy Research	2.4	2.4
Cooperative State Research, Education and Extension Service (CRSEES) -Biofuels/Biomass Research; formula funds, National Research Initiative	4.7	3.4
Forest Service – Biofuels/Biomass, Forest and Rangeland Research	2.4	2.8
Rural Business Service – Renewable Energy Program and Value Added Producer Grants	25.3	12.7
Subtotal - USDA	**47.8**	**34.3**
Department of Commerce - ITA		
International Trade Administration (ITA) - Asia Pacific Partnership	0	2
Subtotal - DOC/ITA	**0**	**2**
Department of Commerce - NIST		
National Institute of Standards and Technology (NIST) - Scientific and Technological Research and Services	7.2	7.2
Industrial Technical Services – Advanced Technology Program	10.3	0
Subtotal - DOC/NIST	**17.5**	**7.2**
Department of Defense		
Army	36.5	5.5
Navy	23.4	6.9
Air Force	0	0
Defense Advanced Research Projects Agency (DARPA)	7.1	3
R&D, Office of Secretary of Defense	3.6	0
Subtotal - DOD	**70.6**	**15.4**
Department of Energy		
Energy Efficiency and Renewable Energy (EERE)	1,174	1,176.30
Fossil Energy	404.5	419.1
Nuclear Energy	332.5	463.3
Science	422.6	551.4
Electricity Delivery and Energy Reliability	73	100.3

Climate Change Technology Program	0	1
Subtotal - DOE	**2406.5**	**2,711.40**
Department of Interior		
US Geological Survey – Surveys, Investigations and Research - Geology Discipline, Energy Program	0	0
Subtotal - DOI	**0**	**0**
Department of Transportation		
Office of the Secretary for Technology – Transportation, Policy, R&D	0	0
National Highway Traffic Safety Admin	0.9	0.9
Research and Innovative Technology Admin	0.5	0.5
Subtotal - DOT	**1.4**	**1.4**
Environmental Protection Agency		
Environmental Programs and Management	90	91.9
Science and Technology	18.6	12.5
Subtotal - EPA	**108.6**	**104.4**
National Aeronautics and Space Administration		
Exploration, Science & Aeronautics	104.4	85.8
Subtotal - NASA	**104.4**	**85.8**
National Science Foundation		
Research and Related Activities	17.7	18.6
Subtotal - NSF	**17.7**	**18.6**
TOTAL - CCTP	**2,774.40**	**2,980.40**
Activities Associated with CCTP		
United States Agency for International Development		
Energy Technology Development	92	57.3
Carbon Capture and Sequestration Measures	80.3	71.7
Subtotal - USAID	**172.3**	**129**
TOTAL - CCTP & Associated Activities	**2946.7**	**3109.4**

Source: CCTP, 2006

Appendix A5 – CO_2 Avoidance Factor Criteria

Figure A5.1: Technologies needed to meet 32 Gt CO_2 IEA ACT Map Scenario Avoidance Goal



Source: Private communication with Frank Princiotta, 2007

"Figure A5.1 summarizes the results of the IEA analysis by identifying technologies contributing to the CO_2 avoidance of the ACT Map scenario to 2050. The sum of all the bars yields the 32 Gt avoidance goal. The figure illustrates the projected avoidance by technology in the key energy sectors color coded into the following categories: End Use, Power Generation, CO_2 Storage and Renewables. As can be seen, a diverse array of technologies in all key energy sectors will be needed if the 32 Gt avoidance goal is to be met at 2050. Of particular importance are end use technologies, in the building and transport sectors; power generation; and carbon storage technologies, in the power generation and industrial sectors." (Frank Princiotta, 2007). The 32 Gt avoidance goal is a projected result of the International Energy Agency's scenario which proposes to mitigate 32 Giga tons of CO_2 in 2050.

This Figure A5.1 was used to determine the CO_2 avoidance criterion in the criteria matrix for the technologies. If the technology on the graph was between 0.0 and 0.5 Gt of CO_2 mitigated it received a 1 for the potential CO_2 avoidance factor on the criteria matrix. For a technology between 0.5 and 1.0 Gt of CO_2 mitigated it was given a 2 on the criteria matrix and so on and so forth until a technology between 2.0 and 2.5 Gt of CO_2 mitigated on this graph would obtain a 5 on the criteria matrix.

Appendix A6 – Technologies for Goal #1(CCTP): Reduce Emissions from End Use and Infrastructure

	NEAR-TERM	MID-TERM	LONG-TERM
Transportation	• Hybrid & Plug-In Hybrid Electric Vehicles • Clean Diesel Vehicles • Alternative and Fuel-Flexible Vehicles • Improved Batteries, Energy Storage • Power Electronics • Engineered Urban Designs • Reduction of Vehicle Miles Traveled • Improved Air Space Operations	• Fuel Cell Vehicles and H_2 Fuels • Efficient, Clean Heavy Trucks • Cellulosic Ethanol Vehicles • Intelligent Transport Systems • Integrated Regional Planning • Low-Emission Aircraft • Intercity Transport Systems	• Zero-Emission Vehicle Systems • Optimized Multi-Modal Intercity & Freight Transport • Widespread Use of Engineered Urban Designs & Regional Planning • Very Low Aviation Emissions (all GHGs)
Buildings	• High-Performance, Integrated Homes • Energy-Efficient Building Materials • High-Efficiency Appliances • Solar Control Windows	• "Smart" Buildings • Solid-State Lighting • Ultra-Efficient HVACR • Intelligent Building Systems • Neural Net Building Controls	• Energy Managed Communities • Low-Power Sensors with Wireless Communications
Industry	• Improved Processes in Energy-Intensive Industries • High-Efficiency Boilers and Combustion Systems • Greater Waste Heat Utilization • Improved Recyclability and Greater Use of Byproducts • Bio-Based Feedstocks	• Transformational Technologies for Energy-Intensive Industries • C&CO_2 Managed Industries • Superconducting Electric Motors • Efficient Thermoelectric Systems • Advanced Separation Technologies • Low-Emission Cement Alternatives • Water and Energy System Optimization	• Integration of Industrial Heat, Power, Processes and Techniques • High-Efficiency, All-Electric Manufacturing • Widespread Use of Bio-Feedstocks • Closed-Cycle Products & Materials
Electric Grid & Infrastructure	• Distributed Generation • Smart Metering & Controls for Peak Shaving • Long-Distance DC Transmission • High-Temperature Superconductivity Demonstrations • Power Electronics • Composite Conductor Cables	• Energy Storage for Load Leveling • Neural Net Grid Systems • Advanced Controls and Power Electronics	• Superconducting Transmission and Equipment • Standardized Power Electronics • Wireless Transmission

Figure A6.1: Technologies for Goal #1(CCTP): Reduce Emissions from End Use and Infrastructure

Source: CCTP Strategic Plan, 2006