Att-111

STATE OF NEW YORK
STATE OF CONNECTICUT
STATE OF MAINE
COMMONWEALTH OF MASSACHUSETTS
STATE OF NEW JERSEY
STATE OF RHODE ISLAND
STATE OF WASHINGTON

February 20, 2003

VIA CERTIFIED MAIL
RETURN RECEIPT REQUESTED

The Honorable Christine Todd Whitman
Administrator, Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Re: Notice of Intent to Sue Under Clean Air Act § 304(b)(2)

Dear Administrator Whitman:

Representing the States of New York, Connecticut, Maine, New Jersey, Rhode Island and Washington, and the Commonwealth of Massachusetts, we notify you, pursuant to section 304(b)(2) of the Act, 42 U.S.C. § 7604(b)(2), of our intent to sue EPA for its failure to review and, if appropriate, revise the New Source Performance Standard (NSPS) for fossil fuel fired electric generating units (EGUs or power plants) found at 40 CFR subpart Da. Pursuant to section 111(b)(1)(B) of the Act, 42 U.S.C. § 7411(b)(1)(B), EPA is required to "at least every 8 years, review and, if appropriate, revise such [NSPS] following the procedures required by this subsection." The information available to us indicates that EPA has not undertaken the required review of the efficacy of the subpart Da standards for at least two decades. Accordingly, EPA is in violation of its nondiscretionary duty to "review and, if appropriate, revise" subpart Da.

As explained below, we believe that EPA's review of the existing standard will reveal the need for significant revisions to the standard. The existing standards for sulfur dioxide and particulate matter fail to reflect the technological advances that have occurred in the past two decades as well as the current information regarding the environmental harm posed by those pollutants. In addition, we believe that subpart Da is inadequate in that it does not contain a standard for emissions of carbon dioxide, a pollutant that causes global warming with its attendant adverse health and environmental impacts. In this regard, recent information confirms that:

1. Carbon dioxide emissions from power plants in the United States are significant contributors to global warming;
2. Global warming and other aspects of climate change will significantly endanger public health and welfare; and
3. Demonstrated, effective technology exists to significantly reduce carbon dioxide emissions from electric utility generating systems.

Thus, power plant carbon dioxide emissions meet all the conditions set forth in the Act for inclusion within an NSPS. We therefore call on EPA to add limitations for carbon dioxide emissions when it revises subpart Da.

<u>EPA's Mandatory Duty to Review and, If Appropriate, Revise Subpart Da.</u>

Clean Air Act § 111(b)(1)(B) imposes on EPA a mandatory duty to review the continued efficacy of each existing NSPS every eight years:

> The Administrator shall, at least every 8 years, review and, if appropriate, revise such standards following the procedures required by this subsection for promulgation of such standards.

42 U.S.C. § 7411(b)(1)(B).

The word "shall" indicates a congressional demand that EPA undertake this review. When "a statute sets forth a bright-line rule for agency action ..., there is no room for debate – congress has prescribed a categorical mandate that deprives [the agency] of all discretion over the timing of its work." *American Lung Association v. Reilly*, 962 F. 2d 258, 263 (2d Cir. 1992). *See also NRDC v. Reilly*, 983 F.2d 259, 266 (D.C. Cir. 1992) (CAA § 202, which states that EPA *shall* promulgate onboard refueling vapor recovery standards, "most manifestly obligates" EPA to issue the standards); *State of New York v. Thomas*, 613 F. Supp. 1472, 1485 (D.D.C. 1985)("As reiterated by the United States Court of Appeals for the District of Columbia Circuit, when the Clean Air Act uses 'shall,' the normal inference is that the act is mandatory.").

<u>EPA is in Violation of its Mandatory Duty</u>

The NSPS for electricity generating units was published on June 11, 1979, 44 Federal Register 33613. Although there have been technical amendments since that date, none of these constitute the "review" mandated by the Clean Air Act. The only recent substantive modification to subpart Da was a modification to the nitrogen oxides limit undertaken pursuant to a Congressional direction contained in the 1990 Clean Air Act Amendments, rather than pursuant to EPA's duty to conduct 8 year reviews. *See Lignite Energy Council, et al. v. U.S. Environmental Protection Agency*, 198 F.3d 930 (D.C. Cir. 1999). Thus, EPA has not fulfilled its duty to review, every eight years, the existing rule.

The sole exception provided for in the statute applies only "if the Administrator determines that such review is not appropriate in light of readily available information on the efficacy of such standard." *Id.* Such a determination, if made, should have been based on an administrative record and made in accordance with applicable procedures of administrative law, including public notice and comment. In this case, there is no indication that EPA ever made the determination that such review was not appropriate, let alone a formal determination in accordance with administrative procedures; EPA simply never reviewed the standard.

The Existing Standard is in Need of Revision

Furthermore, the facial inadequacy of subpart Da establishes that EPA could not have made a determination that review was inappropriate. Section 111(b)(1)(B) provides:

> When implementation and enforcement of any requirement of this chapter indicate that emission limitations and percent reductions beyond those required by the standards promulgated under this section are achieved in practice, the Administrator shall, when revising the standards promulgated under this section, consider the emission limitations and percent reductions achieved in practice.

The following are a few notable ways in which subpart Da is substantially obsolete and inadequate:

- The sulfur dioxide standard for coal-fired power plants of 1.20 lbs/mmBtu is substantially in excess of levels that can be achieved through the use of established flue gas desulfurization systems. For example, the current standard is 800% greater than the emission rate of .150 lbs/mmBtu required by the recent consent decree that EPA entered into with PSEG. *United States and New Jersey v. PSEG Fossil LLC*, civ action no. 02-340 (JCL) D. N.J. (consent decree entered on July 26, 2002.).

- Similarly, current technologies for control of particulate emissions, such as precipitators and baghouse, can reduce particulate emissions to levels at least 50% below the current standard of .03 lb/mmBtu.

- In the years since subpart Da was initially promulgated, it has been established that carbon dioxide emissions cause global warming, resulting in significant harm to health and the environment. Not only do power plants contribute over 35% of carbon dioxide emissions in the United States, but their emissions are expected to increase by 35% over the next two decades. U.S. General Accounting Office, *AIR POLLUTION: Meeting Future Electricity Demand Will Increase Emissions of Some Harmful Substances*, GAO-03-49 (dated October 30, 2002) (*Future Demand*). Because technological developments have made it easier to reduce, control or capture carbon dioxide emissions from EGUs, a revised NSPS should contain limits on emissions of carbon dioxide from EGUs. Attached to this submission, for EPA's consideration in reviewing and revising subpart Da, is a summary of the scientific and technological basis for inclusion of standards for carbon dioxide emissions in a revised subpart Da.

Need for Prompt Action

Subpart Da is significantly obsolete to the extent that it does not reflect current information regarding the technological means for minimizing the emissions of these pollutants from newly constructed or modified power plants. Fossil fuel fired power plants are the largest sources of sulfur dioxide and carbon dioxide emissions in the United States, accounting for more than one-third of the nations' carbon dioxide emissions and two-thirds of the nation's sulfur dioxide emissions. See EPA, National Air Quality and Emissions Trend Report 1999, March 2001 (for sulfur dioxide). Application of demonstrated, commercially available technologies will significantly reduce the emissions of these pollutants from new and modified power plants. Given the significance and concentration of the utility sector, pollution reductions from these plants will be among the quickest and most cost-effective steps that can be taken to reduce these harmful emissions.

Prompt action is necessary in order to prevent the continued harm caused by these pollutants. Indeed, with regard to emissions of carbon dioxide, you told environmental leaders from around the world: "If we fail to take the steps necessary to address the very real concern of global climate change, we put our people, our economies, and our way of life at risk." G8 Environmental Ministerial Meeting, Working Session on Climate Change, Trieste, Italy (March 3, 2001). Review and revision of subpart Da provides you with an ideal opportunity to significantly reduce emissions of these harmful pollutants.

Conclusion

Accordingly, we intend to sue EPA for failure to comply with its mandatory duty to review and, if appropriate, revise subpart Da. In the event that you wish to settle this matter without the need for litigation, please contact the undersigned legal representatives of the States submitting this notice.

Sincerely,

ELIOT SPITZER
ATTORNEY GENERAL OF NEW YORK

By: [signature]
PETER LEHNER
J. JARED SNYDER
Assistant Attorneys General
The Capitol
Albany, NY 12224

RICHARD BLUMENTHAL
ATTORNEY GENERAL OF CONNECTICUT

By: Kimberly Massicotte (PL)
KIMBERLY MASSICOTTE
MATTHEW I. LEVINE
Assistant Attorneys General
P.O. Box 120
55 Elm Street
Hartford, CT 06141-0120

G. STEVEN ROWE
ATTORNEY GENERAL OF MAINE

By: Gerald Reid (PL)
GERALD D. REID
Assistant Attorney General
Department of the Attorney General
State House Station #6
Augusta, Maine 04333-0006

THOMAS F. REILLY
ATTORNEY GENERAL OF MASSACHUSETTS

By: James Milkey (PL)
JAMES R. MILKEY
Assistant Attorney General
Environmental Protection Division
200 Portland Street, 3rd Floor
Boston, Massachusetts 02114

PETER C. HARVEY
ACTING ATTORNEY GENERAL
OF NEW JERSEY

By: James Murphy (PL)
JAMES MURPHY
Deputy Attorney General
Richard J. Hughes Justice Complex
25 Market Street, P.O. Box 093
Trenton, New Jersey 08625-4503

PATRICK LYNCH
ATTORNEY GENERAL OF RHODE ISLAND

By: Tricia Jedele (PL)
TRICIA K. JEDELE
Assistant Attorney General
Department of Attorney General
150 South Main Street
Providence, Rhode Island

CHRISTINE O. GREGOIRE
ATTORNEY GENERAL OF WASHINGTON

By: Leslie Seffern (PL)
LESLIE SEFFERN
Assistant Attorney General
P.O.Box 40100
1125 Washington St., SE
Olympia, WA 98504-0100

ATTACHMENT

SUMMARY OF THE LEGAL AND TECHNICAL BASES FOR INCLUDING A STANDARD FOR EMISSIONS OF CARBON DIOXIDE IN A REVISED SUBPART Da.

The Clean Air Act sets forth specific criteria and procedures for issuance and revision of new source performance standards. When the EPA administrator determines that a category of sources "causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare," she "shall" include that category on a list of stationary sources. CAA § 111(b)(1)(A). Then, "[w]ithin one year after the inclusion of a category of stationary sources in [that] list ..., the Administrator shall publish proposed regulations, establishing federal standards of performance for new sources within such category." CAA § 111(b)(1)(B). Those criteria are met with respect to carbon dioxide emissions from power plants.

A. Carbon Dioxide is a Pollutant Subject to Regulation Under Section 111

Carbon dioxide clearly meets the statutory definition of "air pollutant," which CAA § 302(g) defines to include "any physical, chemical, [or] biological ... substance or matter which is emitted into or otherwise enters the ambient air." *See also* CAA §103(g) (dealing with research and referring to "carbon dioxide" as an "air pollutant").

While the plain meaning of the statute -- that carbon dioxide is a pollutant -- is clear and dispositive, it is also supported by administrative determinations. EPA has twice officially concluded that carbon dioxide is an "air pollutant." In 1998, the EPA General Counsel Jonathan Cannon set forth the legal analysis supporting the agency's conclusion that greenhouse gases, including carbon dioxide, are "air pollutants" subject to regulation, in response to a request from Congressman Tom DeLay. Memorandum of Jonathan Z. Cannon, General Counsel, to Carol M. Browner, Administrator, regarding *EPA's Authority to Regulate Pollutants Emitted by Electric Power Generation Sources*, dated April 10, 1998. In 1999, EPA General Counsel Gary Guzy confirmed and reiterated this position in testimony to Congress in which he presented EPA's "views as to the legal authority provided by the Clean Air Act to regulate emissions of carbon dioxide." *Testimony of Gary S. Guzy, General Counsel, U.S. EPA, Before a Joint Hearing of the Subcommittee on National Economic Growth, Natural Resources and Regulatory Affairs of the Committee on Government Reform and the Subcommittee on Energy and Environment of the Committee on Science*, U.S. House of Representatives, Oct. 6, 1999.

B. Power Plant Carbon Dioxide Emissions are Significant Contributors to Global Warming

As noted, CAA § 111 is triggered if a category of sources "causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." Power plant carbon dioxide emissions clearly cause or contribute significantly to global climate change.

First, the *U.S. Climate Action Report 2002*, U.S. Dept. of State, Washington, D.C., May 2002 (*Climate Action Report*) concludes that the dominant source of human-caused climate change is carbon dioxide (CO_2) emissions and that "the long lifetimes of greenhouse gases [such as CO_2] in the atmosphere and the momentum of the climate system are projected to *cause climate to continue to change* for more than a century." *Climate Action Report* at 82 (emphasis added). The *Climate Action Report* repeatedly notes that carbon dioxide emissions from the burning of fossil fuels, particularly in power plants (as well as industrial sources and vehicles), is most significant cause of global warming.

Second, a recent General Accounting Office report concluded that <u>CO_2 emissions from power plants are likely to increase by 35% by 2020</u> on the assumption that electricity use will increase 42% by 2020. U.S. General Accounting Office, *AIR POLLUTION: Meeting Future Electricity Demand Will Increase Emissions of Some Harmful Substances*, GAO-03-49 (dated October 30, 2002) (*Future Demand*). The Report noted that EPA data show that in 1999 "power plants were the single greatest industrial source of [carbon dioxide, mercury, nitrogen oxides and sulfur dioxide], emitting 35 percent of the nation's carbon dioxide," *Future Demand* at 1. If emissions from other sectors remain constant, the share of world-wide carbon dioxide emissions attributable to domestic power plants will approach 10%.

Thus, power plant carbon dioxide emissions clearly "cause or contribute significantly to" global warming.

C. <u>Global Warming Will Significantly Endanger Public Health and Welfare</u>

The Clean Air Act defines "welfare" broadly. Indeed, as set forth below, the range of harms caused by the changing global climate covers virtually the entire panoply of considerations within the meaning of "welfare."

> All language referring to effects on welfare includes, but is not limited to, effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being ....

CAA § 302(h).

As discussed in detail in Appendix A, particular consequences of global warming -- that <u>have</u> occurred and will occur -- include the following:

- The 1990s was the warmest decade, and 1998, 2001, and 2002 were the warmest years, recorded since 1861. World Meteorological Organization, 2002, *WMO Statement on the Status of the Global Climate in 2001*. This warming will increase. IPCC 2001 at 7. A warming of only 1-2 degrees in polar regions from below to above freezing will have major global impacts.

- Precipitation patterns have already changed and are expected to change more with dry areas becoming drier and more frequent storms. Worldwide economic losses due to weather events are doubling every 10 years and are expected to reach $150 billion/year within a decade. United Nations Environment Programme Finance Initiatives Climate Change Working group, *CEO Briefing: Climate Risks to Global Economy* (July 2002) at 2.

- Sea level has risen 10-25 cms over the last 100 years; significant acceleration of this rate of sea level rise is expected over the next 100 years. This would flood millions of acres of lowland in the United States and abroad, displace millions of people, and destroy coastal habitats. Expected increases in the frequency of severe storms would compound the impact. Fifty-three percent of the U.S. population lives within the coastal regions, the location of hundreds of billions of dollars in associated infrastructure. *Climate Change Science at 20.* These coastal habitats are considered to be responsible for about 30% of "ecosystem services" (such as fish production, nutrient recycling, weather stabilization) produced by the entire world and estimated conservatively to be worth (replacement cost, if it were feasible) over $10 trillion/year. R. Costanza et al., *The Value of the World's Ecosystem Services and Natural Capital,* 387 Nature 253, 259 (May 1997).

- Climate change may be much more abrupt than previously thought. Sudden and irreversible shifts in global climate patterns, although impossible to predict precisely, are "inevitable." For example, melting of Arctic and Greenland ice and subsequent reduction in the salinity of the surface water of the North Atlantic may result in the alteration of the Gulf Stream circulation patterns. National Research Council, *Abrupt Climate Change: Inevitable Surprises,* 2002, at 107-115, IPCC, *Climate Change 2001: Synthesis Report* (2001) at 14, 17. This would create massive and immediate climate changes.

- Many ecosystems in the United States are highly vulnerable to climate change. Alpine meadows in the Rocky Mountains and some barrier islands are likely to disappear entirely. Southeastern forests are likely to experience major shifts or breakup into a mosaic of grasslands, woodlands and forests. These changes "are likely to be costly or impossible to replace." *U.S. Climate Action Report-2002* (U.S. Department of State, May 2002 at 89).

- Serious impacts in New York, for example, include coastal erosion to Long Island's south shore; inundation of New York City infrastructure; New York City water supply changes; upstream movement of the Hudson River salt front, impacting the water supply of Poughkeepsie; saltwater intrusion into Long Island groundwater limiting that water supply; increases in exotic insects, pests and infectious diseases; increase in levels of ozone, a harmful air pollutant; loss of native species including trout and salmon. Increased water temperature due to global warming in Long Island Sound has already contributed to a large die-off of the American lobster. In New York City, temperature-related heat stress mortality, currently averaging 300 deaths per year, would increase 50-200% over the next century. *See generally* U.S. EPA. U.S. Environmental Protection Agency, *Climate Change and New York* (1997); U.S. Global Change Research Program, New England Regional Assessment Group. *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change; New England Regional Overview* (2001); Rosenzweig, C. and W.D. Solecki (Eds.), *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change - Metro East Coast.* Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States (2001).

- Impacts in the New England states include the heat-related illness and death described above as well as significant loss of shoreline and associated coastal wetlands. Information found on EPA's website documents that sea level along the East Coast is rising by 11 inches per century, and is likely to rise another 22 inches by 2100 in Massachusetts and Connecticut. Northeastern forests will also be damaged. For example, Maine's vast spruce-fir forests will be especially susceptible to insect infestations exacerbated by warming-induced changes in the timing of spring frosts.

These impacts of climate change -- itself the result of, in large part, carbon dioxide emissions from power plants and other sources – thus span the range of "welfare" and public health effects covered by the Act. These impacts clearly "endanger" public health and welfare.

Swift action is mandated because many of the impacts of global climate change are irreversible, at least on a human time scale. Indeed, carbon dioxide emissions and other human actions are making – and have already made – irrevocable changes to humanity's only habitat. The National Academy of Sciences has found that: "Despite the uncertainties, there is general agreement that the observed warming is real and particularly strong within the past 20 years." National Academy of Science, *Climate Change Science: An Analysis of Some Key Questions* (2001) at 3 (prepared in response to a request from President Bush to evaluate the level of uncertainty associated with the areas of science underlying climate change). (Relevant excerpts from all documents cited are attached in Appendix C.) The United Nations International Panel on Climate Change (IPCC) has concluded "with high confidence" that recent regional changes in temperatures have had discernible impacts on many physical and biological receptors.

These impacts are already occurring and will continue to exacerbate for a substantial period due to the long life of carbon dioxide in the atmosphere. The National Academy reported that it takes over 100 years to remove carbon dioxide from the atmosphere. *Climate Change Science*, at 3 & n.3. Thus, the greater and earlier the reduction in emissions, the smaller and slower the projected warming and the rise in sea levels. IPCC, *Climate Change 2001: Synthesis Report, 2001, at 19.* In other words, time is of the essence for effective response to the confirmed dangers of global climate change. *See Climate Change Science*, at 1 ("national policy decisions made now and in the longer-term future will influence the extent of any damage suffered by vulnerable human populations and ecosystems later in this century.").

D. Technology is Available to Significantly Reduce Carbon Dioxide Emissions from Electric Utility Generating Systems

While EPA need not set a NSPS for a category of sources if all other conditions are met if "it would not be appropriate in light of readily available information on the efficacy of such standard," CAA § 111(b)(1)(B), readily available information in fact demonstrates that there is technology available that can effectively and efficiently reduce carbon dioxide emissions from electric utility generating systems.

Under the CAA, a new source performance standard defined as:

> a standard for emissions of air pollutants which reflects the degree of emission limitation achievable through the application of the best system of emission reduction which (taking into account the cost of achieving such reduction and any non-air quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated.

CAA § 111(a)(1).

The technologies that can be mandated in an NSPS include "design, equipment, work practice or operational standards." CAA § 111(h)(1). *See generally State of New York v. Reilly*, 969 F.2d 1147 (D.C. Cir. 1992) (upholding in part and vacating in part on other grounds proposed NSPS for municipal incinerators that would have required operators to separate out certain batteries and other types of waste before incineration). Similarly, in the debates concerning the Clean Air Act Amendments of 1990, Congress noted that the stricter emission levels considered could be achieved through a variety of means, The Senate report notes that "[p]ollution can be reduced by (1) improving overall efficiency; (2) changing or cleansing fuels; (3) adopting alternative combustion technologies; (4) installing flue gas cleansing devices; or, (5) establishing end-use conservation programs." S. Rep. No. 228, 101st Cong., 1st Sess. at 291. Thus, EPA is not limited to end-of-pipe controls.

As noted in detail in Appendix B, there is technology available, much of which was not available in 1979 when the power plant NSPS was promulgated, to reduce CO_2 emissions. These include, among other things,

- Increasing generation efficiencies (thereby reducing CO_2 emissions/unit output)
- "End of pipe" capture of CO_2 at its sources
- Sequestration of captured CO_2 in a long-duration medium
- Generation mix changes offsetting CO_2 emissions (systemwide CO_2 reductions)
- Increased electrical use efficiency (reductions of CO_2 per service rendered)

Many of these technologies have been used on a wide variety of boilers and generation systems. Many have also already been mandated in the clean air or energy programs of states, local governments, or other countries. In addition, many technologies offer other air quality and non-air quality environmental and health benefits, and would improve our energy security. Thus, such technologies readily lend themselves to the promulgation of an NSPS for electricity utility steam generating units.

We emphasize that it is in the process of reviewing and revising the NSPS that EPA will establish appropriate technology-based limits. The review in Appendix B is simply illustrative to demonstrate that an EPA review of the existing NSPS is highly likely to identify technologies that meet the criteria of the Clean Air Act.

APPENDIX A

Global Climate Change: Human Health and Welfare Effects

February 2003

Introduction

Long term observations confirm that our climate is now changing at a relatively rapid rate. Global mean surface temperature of the earth has increased about 0.6°C per century since 1900; temperatures have increased three times faster since 1976. Atmospheric concentration of carbon dioxide (CO_2), the largest greenhouse gas contributor to global warming, has increased 31% since pre-industrial levels and is likely at the highest concentration in the last twenty million years (IPCC 2001a, p.44). Human activities are responsible for the increase (NRC 2001, p.3). Climate models predict that, assuming no major interventions to reduce continued growth of greenhouse gas emissions, temperatures in the US will rise approximately 5-9° F (3-5°C) on average in the next 100 years. The projected rate of warming is very likely to be without precedent during at least the last 10,000 years (IPCC 2001a, p.61). Greater than average temperature increases are expected to occur at higher latitudes; air temperatures in the Arctic have already increased as much as 5°C during the 20th century (IPCC 2001b, p.803). The 1990's appear to be the warmest decade and 1998, 2001 and 2002 the warmest years in the global instrumental record since it began in 1861 (WMO 2002, NASA 2002).

Global climate change is likely to affect nearly all biological and physical processes on the planet. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that:

> [R]egional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Examples of observed changes include shrinkage of glaciers, thawing of permafrost, later freezing and earlier break-up of ice on rivers and lakes, lengthening of mid- to high-latitude growing seasons, poleward and altitudinal shifts of plant and animal ranges, declines of some plant and animal populations, and earlier flowering of trees, emergence of insects, and egg-laying in birds. (IPCC 2000b, p.3)

Current and potential impacts to the citizens and resources of the United States are staggering in breadth and scale. Additionally, EPA estimates the cost associated with a doubling of CO_2 in the atmosphere with regard to the effects, for example, on agriculture, energy consumption, sea level rise, health, forests, and water resources, is $351 billion per year in 1992 dollars; in 2002 dollars this equates to $453.6 billion per year (Titus 1992). The United States, United Nations and researchers around the world have conducted comprehensive analyses of the impacts of global warming and associated climate change. Many of these reports and associated findings are herein incorporated by reference in the Appendix C bibliography. Some of the most important findings on the effects of global warming are summarized below.

Dynamics of Climate Change

Sudden and/or unexpected climate change poses great challenges to our ability to adapt and can increase our vulnerability to significant impacts (NAST 2001, p.12). Anthropogenic greenhouse gas emissions may result in our earth's climate systems reaching threshold conditions that result in dramatic shifts in temperature, precipitation, storms and ocean circulation patterns. The National Research Council (2002) evaluated potential abrupt climate change and concluded:

> "... greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events ... and climate models typically underestimate the size, speed, and extent of those changes."

Scientists studying ice and sediment cores, tree rings and other proxies of past conditions have found evidence of sudden changes in climate throughout the paleoclimatic record (Broecker 1995). Previous abrupt climate change, however, occurred before the development of modern societies; adaptability of our current society to sudden and unexpected change would be exceedingly difficult. Two abrupt change scenarios currently under investigation by scientists include the following:

1) A rapid change in the circulation dynamics of the North Atlantic Gulf Stream (Hurrell et al. 2003; NRC 2002; Broecker 1997). Oceanographers theorize that an increase in fresh water inflows from Arctic meltwaters may cause the Gulf Stream to dive prematurely below the surface of the North Atlantic, resulting in a period of dramatic regional cooling of western Europe and North America.

2) A rapid decline of the perennial sea ice cover in the Arctic as confirmed by recent analysis of satellite data. Projected rates of future decline would lead to the complete disappearance of this sea ice cover before the end of this century (Comiso 2002). This would lead to dramatic changes in the Arctic climate system and associated impacts to its lands, biota and people (Kerr 2002). Abrupt change is not limited to physical systems; unpredictable effects on biological, economic and social systems as well are likely (NAST 2001, p.7).

Global climate change models predict significant variability in effects across the United States (IPCC 2001b, p.737). Large regional differences in temperature, precipitation and other effects of climate change will complicate adaptation strategies (NAST 2001, p.9). These effects, superimposed on current environmental problems (e.g. limited water supply, beach erosion, inland and coastal pollution) will further challenge our ability to respond (IPCC 2001b, p.739).

Human Health

Disturbances from global climate change to the physical and biological systems of the earth will significantly affect the health of its inhabitants. The IPCC has concluded that they expect negative impacts from climate change to outweigh any positive health impacts that may occur (IPCC 2001b, p.453). Direct health effects, such as impacts to the body from increased temperatures or hazards from increased severe storms, and indirect effects to physical, ecological and societal systems, such as increases in air pollution, infectious disease transmission, and impacts to food supply, are anticipated. In some instances, societal adaptations of the health care system and new or improved technologies may reduce some human health impacts, although likely at a high economic cost, but vulnerable populations and extreme climactic variation will preclude complete amelioration of effects.

Direct Temperature Effects. Increased surface air temperatures and increased frequency of heat waves associated with global climate change will increase the risk of mortality and morbidity, especially in older age groups and the urban poor (IPCC 2001b, p.453). For example:

- In the United States, the greatest number of heat-related illnesses and deaths in response to increased summer temperatures will likely occur in large urban centers, especially those in northeastern and Midwestern cities (Patz et al. 2000).
- In New York City, experts estimate that, because of global climate change, the number of days over 90° F could increase by two to seven times over the next century producing a 50% to 200% increase in heat stress-related mortality (EDF 1999).

In the report *Climate Change and New York* (U.S. EPA 1997), EPA concludes that "New York, with its irregular, intense heat waves, could be especially susceptible" to human health effects from higher temperatures and increased frequency of heat waves. Additionally, the report states "In New York City, one study projects that a 1°F warming could more than double heat-related deaths during a typical summer, from about 300 today to over 700 (although increased air conditioning use may not have been fully accounted for) ... The elderly, particularly those living alone, are at greatest risk."

Increased Air Pollution. Local and regional weather conditions influence air pollution in many ways including via pollutant transport and/or formation (IPCC 2001b, p.460). Warming and other climate changes could increase concentrations and exposure to ozone, airborne allergens, and fine particulate matter (NAST 2001, p.447). Ozone concentrations increase on hot, sunny days especially when stagnating circulation patterns accompany the higher temperatures (U.S. Department of State 2002). High ozone levels can aggravate existing respiratory diseases, including asthma, and decrease short term lung function. Studies at New York City hospitals demonstrate strong association between ozone exposure and increased incidence of asthma, hospital admissions and death (Rosenzweig and Solecki 2001). The Environmental Protection Agency (U.S. EPA 1997) concludes:

> A 4° F warming in New York City, with no other change in weather or emissions, would increase concentrations of ground-level ozone, a major component of smog, by 4%. Current ozone concentrations exceed the national health standards in many urban areas, especially New York City and Long Island.

Infectious Diseases. A warmer climate and other climate changes could expand the habitat favorable for the spread of infectious diseases, including diseases spread by insects (U.S. EPA 1997). Malaria, encephalitis, dengue fever, and other vector borne diseases could expand their range in an environment favorable to the proliferation of mosquitos and ticks (NAST 2001, p.450-452). Increased ocean temperatures could increase the frequency of toxic algal blooms along US coasts and increase the survival of viral pathogens that cause shellfish poisoning (NAST 2001, p.438). Recent warm winters in upstate New York, for example, have fostered an explosion of tick populations that transmit Lyme disease. In New Mexico, rodent populations and fleaborne plague incidence increased after unusual winter-spring precipitation patterns (Patz et al. 2000).

Storm Effects. Increases in the frequency and strength of severe storms will predictably result in an increase in deaths, injuries, toxic contamination, infectious diseases, and stress-related disorders, and other adverse health effects associated with social disruption, environmentally forced migration, and settlement in poorer urban areas (IPCC 2001b, p.453). Floods, heavy rain storms and ice storms not only directly affect human health and but also create conditions ripe for disease transmission. Sea level rise exacerbates the problem.

Water Resources

Clean, abundant water is central to the functioning of society. Worldwide, approximately one-third of the earth's population, 1.7 billion people, live in water-stressed countries and demand is growing rapidly (IPCC 2001b, p.8). The U.S. Global Change Research Program (NAST 2000, p.96) concludes that, because of global climate change, "Changes in the amount, timing, and distribution of rain, snowfall, and runoff are very probable, leading to changes in water availability as well as in competition for water resources. Changes are also likely in the timing, intensity, and duration of both floods and droughts, with related changes in water quality."

The retreat of mountain glaciers and expected decreases in winter snowpack, despite likely increases in the overall amount of precipitation, are expected to decrease water availability in many western states (IPCC 2001b, p.757). Seasonal shift in the amount and frequency of precipitation and runoff will affect water supply systems (NRC 2001, p.4). Increased storm flows will cause overflow discharges from wastewater treatment plants and combined sewer overflows polluting rivers and lakes. Many surface waters in the United States receive point and nonpoint discharges of pollutants. Drought or low flow conditions can limit pollutant assimilative capability of these receiving waters, and when combined with expected increases in surface water temperatures can significantly reduce water quality (U.S. EPA 1997). Additional examples of regional impacts include:

- Communities that rely on the gradual release of water from a winter snowpack, such as San Francisco, Boulder, and those in the Columbia River basin, will likely need to develop additional water supplies as precipitation is more likely to fall as rain rather than snow (Snyder et al. 2002). Serious water shortages could occur.

- Global climate models used by the IPCC predict increased temperatures, evaporation, and decreased flow into the Great Lakes, resulting in negative impacts to navigation, coldwater fisheries, drinking water supplies, and increased shoreline damage (IPCC 2001b, p.745).

- Heavily populated coastal floodplains, including those found along the Southeast, Gulf and mid-Atlantic, are highly susceptible to extensive flooding from heavy precipitation events and sea level. Subsequent contamination of water supply systems is possible.

- Sea level rise and decreased freshwater recharge would decrease the usability of coastal freshwater aquifers. Seawater intrusion is already a major issue in Florida, the Gulf Coast, southern California, Long Island, Cape Cod, and island communities (NAST 2001, p.423).

Coastal Zone and Marine Ecosystems/Sea Level Rise

Fifty three percent of the U.S. population lives on the 17% of land that comprises the coastal zone and these areas become more crowded every year (NAST 2000, p.108). Impacts from global climate change, including an increase in sea level and sea-surface temperature, decreases in sea-ice cover and changes in ocean circulation patterns, will dramatically affect many of these coastal inhabitants (IPCC 2001b, p.776). In most areas, developed or altered landscapes will block natural migration of coastal ecosystems in response to sea level rise (NAST 2001, p.464).

Mean global sea level has risen 1-2 mm per year since 1900 mostly due to thermal expansion and inflow from mountain glaciers; scientists expect it to accelerate in coming decades. The best estimate is that sea level rise will be an additional 19 inches (48 cm) by 2100, with an uncertainty range of 5 to 37 inches (13-95 cm) (NAST 2001, p.466-467). Sea level rise will lead to flooding of low-lying areas, loss of coastal wetlands, erosion of beaches, saltwater contamination of drinking water, and decreased longevity of low lying roads, causeways, and bridges (U.S. EPA 1997). In New York, Long Island's south shore, consisting of barrier islands, barrier spits, ponds, and sand beaches, could suffer extensive damage from sea level rise and coastal storms (U.S. EPA 1997). Loss of wetlands, integral to much of the coastal and marine food chain, would reduce food availability for coastal and marine wildlife and human consumers (Michener et al. 1997). Additional impacts include the following:

- Predicted climate change scenarios would alter temperature and flow regimes within coastal bays and estuaries, increasing vulnerability to non-native species and blooms of algae (NAST 2000, p.109).

- Changes in the distribution and migration patterns of marine and coastal fish, marine mammals and birds due to increasing ocean water temperatures will occur. For example, increased surface water temperature has likely already contributed to dramatic reductions of the lobster population in Long Island Sound and the winter flounder population off the New England Coast (NERAG 2001, p.66-67; NY Times 11/09/02).

- Coastal shorelines in areas with permafrost, found along many communities in Alaska, are being eroded and retreating inland due to rising sea level and a decreased stability of the ocean ice pack (NAST 2001, p.285)

- Coral reefs, extremely valuable resources for fisheries, recreation, tourism, and coastal protection, have experienced unprecedented declines in recent years (NAST 2000, p.111). Scientists believe rising atmospheric CO_2 reduces the alkalinity of the surrounding ocean water and therefore weakens the skeletal structure of the reefs. Additionally, an increase in ocean water temperatures can harm coral reef-building algae (NAST 2000, p.111-112).

Urban areas along our coasts are at high risk from global climate change, particularly from impacts of sea level rise. Much of the infrastructure in our coastal communities is found at or below the current mean sea level. Wastewater treatment plants, water distribution systems, underground utilities, and other systems necessary for the functioning of cities are present at low elevations in relation to sea level. The impact of sea level rise and increased severe storm frequency on the New York City area, for example, exemplifies the devastating societal and economic impacts of global warming.

- Areas of lower Manhattan, Coney Island and Rockaway Beach would be at increased risk to severe flooding from Nor'easters and other storms (Gornitz et al. 2002).

- Most automobile, subway, and rail tunnel points of entry and all NYC airports are at elevations of three meters or less. Flood levels of only 0.3-0.6 m above those recently experienced during a 1992 storm could result in massive inundation (Gornitz et al. 2002).

- Over half a billion dollars has been spent in New York State, mostly on the south shore of Long Island, on beach replenishment projects. Sea level rise will require increased expenditures to maintain the beaches and might require the retreat of human population from the shoreline (Rosenzweig and Solecki 2001, p.37-38).

Terrestrial and Freshwater Ecosystems

Changes in temperature and precipitation will result in changes in animal and plant species composition and dominance. U.S. EPA (1997) estimates New York forests, known for the brilliant autumn foliage of their maples, eventually could give way to forests dominated by oaks, ash and pine; as much as 50-70% of the maple forests could disappear. The maple syrup industry would be lost. Reduced moisture in the forests due to drought and higher temperatures, combined with increased mortality to trees from disease and insect infestation, will increase the likelihood of severe forest fires. Fires will release even more CO_2 to the atmosphere. The recent killing of 80-90% of the spruce forests on the Alaskan Kenai Peninsula, over 2.3 million acres, by the spruce bark beetle previously limited by cold temperatures illustrates potential impacts (NAST 2001, p.285). Increased temperatures, altered precipitation cycles, combined with current stressors of acid rain and ozone pollution, will further strain the health of our Northern Forest stretching from New York to Maine.

Forest managers will have the difficult task of determining the appropriate tree species to plant for harvest in a changing, uncertain climate. Crops and wild plant species may initially experience increases in productivity due to CO_2 enrichment but a recent study predicts a subsequent decrease in plant reproductive capabilities (Jablonski et al. 2002). Small, unique ecosystems, such as alpine habitats in mountainous regions or mangrove swamps in coastal areas, are especially vulnerable to climate change. In the rainforest mountaintops of Costa Rica, scientists believe the golden toad has become extinct due to its inability to adapt to decreased moisture and increased temperatures due to global climate change (Still et al. 1999).

Distribution, population size, population density and behavior of wildlife have been and will continue to be affected by changes in climate and vegetation. Scientists report that they are now able to show with a high degree of confidence that climate change is altering living systems (Parmesan and Yohe 2002; Root et al. 2002). Animal species that have adapted to gradual changes in climate over the millennia probably cannot adapt to abrupt climatic changes (Root et al. 2002; WWF 2002a). In the polar regions, potential biologic and climatic impacts from the loss of the Arctic ice cover are staggering. Polar bears that only hunt on the ice in the Arctic, for instance, would not be able to eat during early ice-out conditions (WWF 2002b). Shockingly, a recent NASA study (Comisano 2002) suggests a high probability of complete disappearance of the perennial sea ice cover in the Arctic Ocean by the end of the century.

Barriers to migration found outside many of our wild areas, including our national parks, will prevent many animals from migrating with the changing climatic and biotic conditions. Habitats that may become climatically suitable for animal and plant species with future warming will be remote from current distributions, and beyond the dispersal capacity of many species (Walther et al. 2002). Cold-water fish habitats in rivers and lakes will suffer dramatic declines.

All of the brook trout fishery and most of the brown and rainbow trout fishery in New York are expected to be lost if a doubling of atmospheric CO_2 occurs (NERAG 2002, p.67; U.S. EPA 1997). Endangered plant and animal species, by definition highly stressed populations on the verge of extinction, will be lost due to their inability to adapt to the effects of climate change.

Appendix B

Potential Technologies for New Source Performance Standards for Control of Carbon Dioxide Emissions

February 2003

INTRODUCTION

Reliable and thoroughly demonstrated technologies that exist today can either avoid production of or capture and store CO_2.[1] Similarly, many new and traditional products and services and a substantial body of experience with them have been demonstrated to increase electricity use and supply efficiency, thereby reducing CO_2 created per unit of activity. These technologies and efficiency efforts, standing alone or operating in conjunction with each other, can reduce emissions, and therefore, the atmospheric concentrations of this gas; they fit into several basic categories depending on the role each plays in CO_2 control, namely capture, storage and displacement. Displacement and efficiency improvements reflect processes and policies that prevent new CO_2 from being created while capture and storage describe processes that gather, concentrate and/or hold CO_2 in long term storage media.

Control of CO_2 emissions from power plants is conceptually simple and based upon proven and reliable technology already used to create industrial and food grade CO_2 and dry ice, namely solvent extraction based upon MEA (monoethanolamine) or similar solvents. For application to existing fossil power plants, this technology would feature stack gas clean up (sulfur and particulate removal) and then introduction of the remaining gases to a solvent extraction step that separates the CO_2. Regeneration of the solvent releases the CO_2 and subsequent compressors increase the CO_2 pressure for pipeline or other transport means. Various enhancements and alternative fuel preparation designs can increase the concentration of CO_2 in the effluent and the efficiencies of power generation and CO_2 capture. Because air effluent conditions at conventional PC plants feature low pressures and CO_2 concentrations, however, the unit costs for CO_2 capture are higher than competing power generation methods.

While CO_2 capture and storage require substantial investment and operating costs, they are not prohibitive, especially if viewed against the presently externalized costs of climate change and the commodity value of CO_2 for industrial processes like food production and enhanced oil recovery operations. As one author points out, "If one can produce CO_2 for $25 per tonne from

---

[1] In general, this paper does not discuss technologies that curb production of or capture other greenhouse gases generated by various sectors such as methane (CH_4), black carbon particles or carbon monoxide (CO).

flue gas, is that expensive? Yes, if $10 per tonne CO_2 is available from natural reservoirs. No, if one has to pay typical commercial rates of $70-100 per tonne."[2]

This Appendix focuses attention on technologies only to the extent that they deal with electric power supply or demand,[3] and divides them into five categories:

A. Increased generation efficiency (displacing CO_2 emissions per unit output);
B. Separation and capture[4] of CO_2 at sources where it is generated, either at the "end of the pipe" or integrated within the energy production process;
C. Storage[5] of captured CO_2 in a long-duration medium;
D. Generation mix changes offsetting CO_2 emissions (systemwide CO_2 reductions);
E. Increased electrical use efficiency (DSM) (reductions of CO_2 per service rendered).

The Intergovernmental Panel on Climate Change (IPCC) has focused special attention of late on "issues associated with geological and oceanic carbon separation, capture and storage" of CO_2. An IPCC subgroup tasked with gathering and assessing information about these issues recently concluded that "Carbon dioxide capture and storage is an emerging technological option with a very high mitigation potential. It has been suggested that about half of the world cumulative emission to 2050 may be stored at costs comparable to other mitigation plans."[6]

---

[2] Herzog, Howard, MIT Energy Laboratory, "An Introduction to CO_2 Separation and Capture Technologies," August 1999 provided by author at page 2.

[3] Agriculture, forest destruction and fuel combustion for industry, transportation and energy production all generate a share of greenhouse gases, especially CO_2. Technologies and operational changes in these areas also can help reduce the amount of CO_2 in the atmosphere. This Appendix does not include discussion of such technologies although they could be considered as potential offsets for CO_2 produced at power plants.

[4] Capturing CO_2 refers to a process that separates and, where necessary for later storage, concentrates this gas in a short term storage device or condition.

[5] Sequestration refers to a process that facilitates long term storage or disposal of CO_2 in a soil or biomass medium. Sequestration is therefore distinguished from storage which refers to other ways of limiting escape of CO_2 to the atmosphere. An appropriate goal for secure storage should be a duration exceeding the period of peak fossil fuel exploitation generally projected to be within the present century.

[6] IPCC Working Group III, "Scoping Paper - IPCC Special Report on Carbon Dioxide Capture and Storage" at page 1, provided to Peter Skinner by Dr. Howard Herzog of Massachusetts Institute of Technology on February 3, 2003.

In the past, the IPCC has assessed the utility of CO_2 capture and storage/sequestration technologies in terms of some key option characteristics and metrics as adapted below.[7]

A. The science and technology of each approach;
B. The percent CO_2 removals that can be reliably extracted;
C. Permanence of and verifiability of removal, storage and sequestration options;
D. Implementation costs and time scale;
E. Associated impacts.

This Appendix presents information about each approach with respect to the basic metrics described above. These metrics are comparable to criteria identified in the federal Clean Air Act for selection of a new source performance standard:

> The term "standard of performance" means a standard for emissions of air pollutants which reflects the degree of emission limitation achievable through the application of the best system of emission reduction which (taking into account the cost of achieving such reduction and any non-air quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated."[8]

Some of the technologies described in this Appendix are better suited to construction of entirely new sources than the retrofitting of existing sources that fall within the NSPS requirements because of the modification or reconstruction provisions. On the other hand, many of the other technologies described below may be well suited for existing plants covered by the modification or reconstruction provisions of the Clean Air Act or a state plan under Clean Air Act section 111(d). For example, an existing plant can meet or exceed the emission reduction requirements of an NSPS by capturing and sequestering CO_2 or by adding clean generation capacity (i.e. wind or solar) to reduce overall CO_2 emission rates. EPA may also consider allowing existing sources to offset their emissions through demand side management programs.

---

[7] Adapted from Intergovernmental Panel on Climate Change (IPCC) "Fact-Sheet" metrics. For example, see IPCC Chapter 4, "Special Report on Land Use, Land-Use Change And Forestry," http://www.grida.no/climate/ipcc/land_use/243.htm, downloaded 12/12/02.

[8] Clean Air Act, § 111(a)(1), 42 U.S.C. § 7411(a)(1).

A. Power Generation Efficiency Improvements

1. Building More Efficient Power Plants. Substantial efficiency improvements and reductions of CO_2 can be obtained by requiring that new power plants utilize more efficient generation technologies that minimize the generation of CO_2 per unit of electricity produced. Major improvements in even the most basic power station design, the pulverized coal plant (PC), promise major efficiency increases. Citing a 1999 report, the IPCC observes that old coal plants average only 30% efficiency[9] and should be replaced as soon as possible.[10] They also note that employment of new materials and use of higher pressure "supercritical" Carnot cycles at PC plants may result in substantial increases in efficiency.[11] Even "new" PC plants have efficiencies well below potential efficiencies, largely because coal plants are capital intensive, but coal has been an inexpensive fuel. Regulation of CO_2 will change this economic balance, favoring increased efficiency.

As technology innovations and optimizaton increase energy production efficiencies of all types of combustion power plants, CO_2 emissions per kilowatthour decrease. An effective presentation of this phenomenon is illustrated as Figure 4 in Addendum 1 herein which is reproduced from a presentation made in June of 2002. This graph clearly shows that for both coal and gas systems, HHV efficiency increases over baseline values generate marked decreases in CO_2 emissions per unit of output. For instance, as advanced IGCC type facilities approach 50% HHV efficiency, CO_2 emissions drop by 30%. Similarly, as NGCC systems approach the

[9] This Appendix does not qualify stated combustion efficiencies as LHV or HHV, because most references do not provide that information. Entities in the United States often express power plant efficiencies in terms of high heating value (HHV) while Europeans use low heating value (LHV) calculations. The assumption about whether water evolved from combustion remains as vapor or liquid distinguished these values. Therefore, depending on various factors including the type of fuel, efficiency values expressed as HHV will differ by a few percentage points from those based upon LHV methods.

[10] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 235.

[11] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 238.

same efficiency, CO_2 emission drop by 60%.[12]

a. Natural Gas Turbine Combined Cycle Plants (NGCC). Natural gas fired combined cycle power plants offer a number of attractive benefits. In addition to avoidance of solid waste management challenges associated with PC fly ash or IGCC slag, these plants can yield substantial intrinsic efficiencies and low CO2 emissions. New high temperature gas turbines can push the efficiency of these plants to 60%.[13] The IPCC observes that "further improvements might allow" efficiency of these stations to rise to 70%.[14]

b. Integrated Gasification Combined Cycle (IGCC). IGCC is a demonstrated technology that offers a critical global warming mitigation benefit: higher electricity production efficiency. Worldwide there are 131 gasification projects in operation with a combined capacity equivalent to 23,750 MW of IGCC units.[15] An additional 31 projects are planned that would increase this capacity by more than 50 percent.[16] While many are used in refineries to produce hydrogen, starting with feedstocks like petroleum coke, IGCC plants which are used exclusively for electric power production are becoming more plentiful. Unlike conventional fossil fueled plants which use steam alone to spin the turbines, IGCC facilities rely on turbines spun by steam and combustion of synthetic gas created in a front end gasification reactor. A Texaco gasification scheme relies on feed of slurry of coal and water into a segmented and closed

---

[12] Clark, Paul (TransAlta Utilities Corp.), "New Electricity Technology," PowerPoint presention at ASRA Retreat at page 7, June 7, 2002, Ft. McMurray, Canada, downloaded February 13, 2003 from <http://www.aeri.ab.ca/sec/new_res/docs/ASRA_pres_clarke.pdf.>

[13] US DOE "World's Most Advanced Gas Turbine Now Ready to Cross Commercial Threshold," DOE Fossil Energy Techline, issued February 18, 2000, <www.netl.doe.gov/publications/press/2000/tl_gasturb.html> downloaded 12/12/02 at page 2.

[14] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 239.

[15] Simbeck, Dale, SFA Pacific Inc. Gasification Technology Update, presented to the European Gasification Conference, April 8-10, 2002. The total capacity is based on output of synthesis gas. Many of these projects produce chemicals in addition to or instead of electricity.

[16] Simbeck, Dale, SFA Pacific Inc. Gasification Technology Update, presented to the European Gasification Conference, April 8-10, 2002. The total capacity is based on output of synthesis gas. Many of these projects produce chemicals in addition to or instead of electricity.

gasification vessel[17] along with steam, oxygen and a flux. Others substitute air for oxygen. This gasification reaction produces a great deal of heat and a volatile gas (some call this "syngas") made up largely of hydrogen and carbon monoxide (CO) which is fed into a cascade of filters and purification steps that remove particulates and sulfur. Some experience with and tests of silicon carbide and alumina/mullite candle filters have demonstrated reliable syngas cleanup success.[18]

At this point, two basic processes are available to manage the syngas for power generation and/or production of chemicals, CO sour shift or non-shifted. The shift reaction dates back to the cokeworks era where "water gas" (produced by low pressure gasification) was "shifted" using an iron oxide catalyst [today, more efficient commercial catalysts are available] to hydrogen needed as the feed stock for the production of ammonia. The catalyzed exothermic shift reaction changes the CO and water into high concentration CO_2 and H_2. Another IGCC process does not use a sour shift reaction prior to the gas turbine and has found favor at Italian refineries and several Texaco facilities.[19] According to Texaco, eight of their IGCC plants in China rely on the sour shift reaction to produce hydrogen for ammonia production and a portion of the CO_2 for urea fertilizer.[20] The sour shift and CO_2 capture (at about 75% capture rate) process reduces the net efficiency by about 2% from the non-CO_2 capture IGCC configuration and the add-ons required for CO_2 capture increase the costs by a few percentage points.[21] Texaco argues, however, that recent analyses by SFA Pacific and Transalta have shown that "...coal gasification with CO_2 capture has advantages over a Pulverized Coal (PC) retrofit flue gas scrubber or O_2 combustion. PC retrofits reduce capacity and efficiency by about a third, whereas

---

[17] O'Keefe, Griffiths, Wainwright, "A Single IGCC Design for Variable CO2 Capture" at page 3 downloaded 12/16/02 <http://www.dti.gov.uk/cct/presentedsf.pdf>.

[18] Advanced Electric Power Generation, "Program Update 2000," Pinon Pine IGCC Power Project at page 5-101, downloaded 12/16/02 from <http://www.lanl.gov/projects/cctc/factsheets/updates/documents/advelecigcc_2000_all.pdf>.

[19] O'Keefe, Griffiths, Wainwright, "A Single IGCC Design for Variable CO2 Capture" at page 7 of 10 downloaded 12/16/02 <http://www.dti.gov.uk/cct/presentedsf.pdf>.

[20] Seabright, J., Lee, A. & Weissman, R. (Texaco) "Environmental Enterprise: Carbon Sequestration using Texaco Gasification Process," presentation at the First National Conference on Carbon Sequestration, in Washington, D.C., May 14-17, 2001 at page 8.

[21] O'Keefe, Griffiths, Wainwright, "A Single IGCC Design for Variable CO2 Capture" at page 4 of 10 downloaded 12/16/02 <http://www.dti.gov.uk/cct/presentedsf.pdf>.

coal IGCC increases both."[22] For a power plant IGCC, the only reason to feature a shift reaction is for CO_2 capture.

In any event, the syngas created by the reactor can be readily combusted and allowed to expand in a gas turbine (not unlike a jet engine), with or without the CO_2, which is attached to an electricity generator. The hot exhaust gases from the turbine and high pressure steam created downstream from the reactor are then fed into a heat recovery steam generator (HRSG). The steam raised in the HRSG is fed to a steam turbine which also generates electricity (hence the term, combined cycle).

Electrical efficiencies are substantially higher than conventional PC plants -- 38.5 - 40.5% vs. 36.0-37.5%,[23] thereby substantially reducing CO_2 emissions per unit of electrical output. US DOE predicts even higher efficiencies, stating that IGCC plants "could boost efficiencies by as much as 20% over conventional coal-burning plants, and improved versions might eventually double today's efficiencies."[24] "Coal gasification offers the prospect of boosting efficiencies to 45-50% in the short-term and potentially to nearly 60% with technological advancements."[25] Examples of plants that may achieve these higher efficiencies include the 99 megawatt Pinon Pine demonstration project to be built in Reno, Nevada. This facility will use a pressurized fluidized-bed gasifier with hot gas cleanup (HGCU) and has been designed to achieve an efficiency of 43.7%.[26] The IPCC observes that efficiencies of 50-55% may be achievable in the relatively near

---

[22] Seabright, J., Lee, A. & Weissman, R. (Texaco) "Environmental Enterprise: Carbon Sequestration using Texaco Gasification Process," Presentation at the First National Conference on Carbon Sequestration, in Washington, D.C., May 14-17, 2001 at page 8.

[23] O'Keefe, Luke F., and Sturm, Karl V., "Clean Coal Technology Options - A Comparison of IGCC vs. Pulverized Coal Boilers," Gasification Technologies 2002 Conference, San Francisco, CA, October 28, 2002 at slide 30.

[24] Office of Fossil Energy, USDOE, "Clean Coal Examples", (NO DATE), <http://www.fe.doe.gov/coal_power/cct/cct_examples.shtml> downloaded 12/16/02 at p. 3 of 4.

[25] Office of Fossil Energy, USDOE, "Gasification Technologies", (NO DATE), <http://www.fe.doe.gov/coal_power/gasification/index.shtml> downloaded 11/21/02 at p. 2 of 3.

[26] Advanced Electric Power Generation, "Program Update 2000," Pinon Pine IGCC Power Project at page 5-119 downloaded 12/16/02 from <http://www.lanl.gov/projects/cctc/factsheets/updates/documents/advelecigcc_2000_all.pdf>.

term and higher levels are foreseeable.[27]

Texaco reports that at facilities producing some 6,000 megawatts of output at four refineries and the Tampa Electric plant, its gasification process achieves efficiencies that result in substantial CO_2 reductions. According to Texaco, CO_2 emissions from a conventional PC plant amount to 2.26 pounds per kWh while their IGCC processes achieve 14% less, (1.95 lb/kWh).[28]

While the gasification reactor does create some solid byproducts including ash and slag, sulfur species can be easily captured to produce commercial grade sulfur instead of producing large amounts of SO_2 and flue gas desulfurization sludge from scrubbers. Because gasification takes place in a low nitrogen environment, NO_x emissions are low as well, in the range of 18 parts per million (ppm). Global Energy, builder of the Wabash facility IGCC system, boasts that this seven year old retrofit has achieved emission reductions in pounds per megawatt-hour from its original PC boiler system for SO2 of 97% (38.2 to 1.075), for NO_x of 92 % (9.3 to 0.75), for CO of 14% (0.64 to 0.55) and for PM-10 of 89% (0.85 to 0.09).[29] Emissions data from a recent paper delivered at US DOE Coal Conference[30] suggest that IGCC technology surpasses other modern coal combustion technologies by a wide margin for most air emission compounds of concern, as the table below adapted from Table 4 reproduced in Addendum 1 illustrates.

---

[27] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 239.

[28] Seabright, J., Lee, A. & Weissman, R. (Texaco) "Environmental Enterprise: Carbon Sequestration using Texaco Gasification Process," presentation at the First National Conference on Carbon Sequestration, in Washington, D.C., May 14-17, 2001 at slide 9 of 18.

[29] Amick, P., (Global Energy), "Reducing Multiple Air Emissions of Coal Based Power Generation," Presentation at the Gasification Technologies Public Policy Workshop in Washington, DC, October 1, 2002 at slide 21.

[30] Ratafia-Brown, J., Manfredo, L., Hoffmann, J., & Ramezan, M., "An Environmental Assessment of IGCC Power Systems," presented at US DOE NETL's Nineteenth Annual Pittsburgh Coal Conference, September 23-27, 2002, http://www.netl.doe.gov/coalpower/gasification/pubs/pdf/18.pdf downloaded 12/09/02 at page 3.

Emissions & Total Solids	PC Fired Plant w/ controls	Fluidized Bed Coal w/ Low NO_x & SNCR[31]	PFBC[32]	IGCC	Percent[33] improvement, IGCC vs. PC w/controls
CO_2 (lb/kWh)	2.0	1.92	1.76	1.76	12%
SO_2 (lb/MWh)	2.0	3.9	1.8	0.7	65%
NO_x (lb/MWh)	<1.6	1.0	1.7-2.6	0.8	50%
PM_{10} (lb/MWh)	<0.3	0.12	0.13-0.26	<0.14	53%
Total Solids (lb/MWh)	367 Ash & gypsum	494 Ash & Sp. Sorbent	450 Ash & Sp. Sorbent	175 Slag & Sulfur	52%

Coal gasification plants with syngas combustion turbines can be retrofitted to aging high emission coal plants, thereby avoiding some of the additional costs of new turbines, cooling systems and transformers etc. associated with a completely new facility.[34] A similar benefit is that other carbon rich fuels can be combusted in these reactors, including wood, petroleum coke and residues, and other combustible wastes. Most important for this analysis, however, is that IGCC type plants offer economically attractive conditions for CO_2 capture compared to PC plants.

---

[31] Selective non-catalytic reduction.

[32] Pressurized fluid bed combustion system.

[33] The percent improvement here contrasts emissions from the IGCC compared to the reference PC plant with all controls. Data taken from Ratafia-Brown, J., Manfredo, L., Hoffmann, J., & Ramezan, M., "An Environmental Assessment of IGCC Power Systems," presented at US DOE NETL's Nineteenth Annual Pittsburgh Coal Conference, September 23-27, 2002, http://www.netl.doe.gov/coalpower/gasification/pubs/pdf/18.pdf downloaded 12/09/02 at page 3.

[34] Designed and built by a consortium of companies including Dow/Destech, NGC/Dynegy and Global Energy, the Wabash River plant is a good example of repowering/retrofitting. The boiler 90 megawatt Unit 1 was repowered with a 265 megwatt IGCC plant and made operational in 1995. *See* Amick, P., (Global Energy), "Reducing Multiple Air Emissions of Coal Based Power Generation," Presentation at the Gasification Technologies Public Policy Workshop in Washington, DC, October 1, 2002 at slide 2 *et seq.*

c. Pressurized Fluid Bed Combustion. PFBCs feature a boiler based upon a bubbling bed of combusting coal. Small capacity designs are already in operation and a 350 megawatt plant in Japan should be operating soon. Power plants based upon this design are expected to reach efficiencies in excess of 40%.[35]

d. New Pulverized Coal Plants. Newer designs of direct combustion pulverized coal promises efficiencies as high as 44%.[36] Subcritical, supercritical and ultra-supercritical cycles (steam pressures as high as 4,500 psig) may be able to achieve heat rates as low as 8,251 Btu/kWh.[37] The IPCC observes that in the "longer term," world average PC power station efficiency which stands at about 30% now "has the potential" to rise to 60%.[38] The newer designs still require installation of expensive end of pipe controls for today's criteria pollutants and generate large amounts of difficult to manage solid waste products. As a result, newer IGCC designs are obviously preferable options to even the newest designs for conventional PC plants.

2. Efficiency Improvements at Existing Power Plants. The logical place first to reduce CO_2 production is to increase the efficiency of electricity production, *i.e.* the amount of electricity per unit of fuel, especially at coal plants. Power plant equipment and system upgrades as well as general maintenance of existing machinery and parts provide for an incremental approach to increasing the plant's overall efficiency, meaning a reduction in the heat rate (the amount of energy needed to create a unit of electricity). Incremental improvements have been gained at many stations in the last decade through optimization and relatively small equipment upgrades.

Performing a preliminary energy audit by initiating meetings with management and personnel and inspecting the plant for potential problems such as leaks and malfunctioning

---

[35] Bonk, D., & Freir, M., (US DOE) and Buchanan, et al. (Parsons Power) "Assessment of Opportunities for Advanced Technology Repowering," page 3, Proceedings of the Advance Coal Based and Environmental Systems Conference, Pittsburgh, PA, July 22-24, 1997.

[36] Lester, E. "Minimization of Global Climate Change Using Clean Coal Technology," American Institute of Chemical Engineers, August 1998, p.5 and Sinclair Knight Merz Pty. Ltd., "Integrating Consultancy - - Efficiency Standards for Power Generation," Australian Greenhouse Office, January 2000, page 6.

[37] US DOE, Office of Fossil Energy, "Market Based Advance Coal Power Systems," Section 3 – Pulverized Coal-Fired Plants, May 1999, DOE/FE-0400, p. 3.1-5, 3.2-2, and 3.3-2.

[38] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 235.

equipment acts as a starting point for identifying the different approaches through which efficiency can be improved. In conjunction with US DOE, Wisconsin Electric Power (WEPCO) upgraded three of its power plants using a variety of operational and equipment changes such as the ones described below during the 1990-1994 period and thereby achieved efficiency increases of 2.3 - 4.1%. Installation of variable speed drives and cooling tower upgrades garnered some of the greatest improvements for WEPCO. The company expected an additional 0.5% improvement from additional actions in the 1995-2000 period.[39]

a. Equipment upgrades. Upgrades can include improvements to the boiler, turbine and control system of a power plant. Adding extra air heater surface[40] or improving the soot blowing in the boiler allows for increased heat absorption.[41] Examples of turbine improvements includes installing high efficiency turbine blades which allow for increased power generation and an efficiency improvement of 0.98%.[42] Fuel consumption reduction can occur with improvements to feedwater heater material within a turbine system, leading to an increase in efficiency of between 1% and 5%.[43] Upgrading the software of the control system that monitors and fine tunes combustion can improve efficiency between 0.3% to 3%. NeuSIGHT, ULTRAMAX and GNOCIS computer programs optimize fuel to air ratios and other boiler settings to achieve maximum combustion within a plant.[44] At the 500 megawatt Hammond Plant in Georgia, for

---

[39] Perrin Associates, "Review of Potential Efficiency Improvements at Coal-Fired Power Plants," April 17, 2001, at page 4.

[40] USEPA, "Review of Potential Efficiency Improvements at Coal-Fired Power Plants", 04/17/01, <http://www.epa.gov/airmarkets/fednox/126noda/heatrate_rpt_april17.pdf> downloaded 11/22/02 at page 3.

[41] Sargent & Lundy LLC, "Plant Performance Improvement - Integrated Technical Assessment & Implementation," <http://www.sargentlundy.com/fossil/plant.asp> downloaded 12/16/02 at page 2 of 4.

[42] USEPA, "Review of Potential Efficiency Improvements at Coal-Fired Power Plants", 04/17/01, <http://www.epa.gov/airmarkets/fednox/126noda/heatrate_rpt_april17.pdf> downloaded 12/16/02 at page 3.

[43] Sargent & Lundy LLC, "Plant Performance Improvement - Integrated Technical Assessment & Implementation", (NO DATE), <http://www.sargentlundy.com/fossil/plant.asp> downloaded 12/16/02 at page 2 of 4.

[44] USEPA, "Review of Potential Efficiency Improvements at Coal-Fired Power Plants", 04/17/01, <http://www.epa.gov/airmarkets/fednox/126noda/heatrate_rpt_april17.pdf> downloaded 12/16/02 at page 5.

example, an operating GNOCIS artificial intelligence optimization program achieved a 0.5% efficiency increase.[45]

b. Parts and equipment maintenance. Maintenance, along with other actions that restore a plant to design conditions, is an economical as well as practical method for improving plant efficiency. Valve overhauls and the replacement of other plant components such as turbines, pumps, and feedwater heaters can lead to efficiency improvements as high as 0.5%.[46] Reducing steam leakage, refurbishing and/or reinstating out of service feed heaters can improve plant efficiency between 0.46% and 1.97%.[47]

c. Repowering. Many aging power plants have inefficient and unreliable boilers and/or ineffective emission control systems but also have satisfactory intrinsic infrastructure at the site, including turbine-generators, cooling systems, transmission and transformer equipment. Of the 10,310 plus fossil power generating facilities in the U.S., more than 2,115 of them (239 gigawatts or 36% of capacity) are more than 30 years old.[48] Retrofitting the existing infrastructure with modern combined cycle systems discussed earlier (*e.g.* IGCC or NGCC) offers great promise for cost-effective efficiency upgrading and improved emission control.

1. Gas Turbine Add-on. A less expensive improvement would be integration of a gas turbine with an existing boiler and use of the exhaust from it to heat feed water or replace primary air to the boiler (hot windbox repowering). According to US DOE, this add-on could increase total generation capacity by 25 to 30% and generation efficiency by 5- 15%.[49] The Advanced Cheng Cycle which captures waste heat to generate steam and inject it back into simple

---

[45] US DOE, "Pollution Controls for Power Plants," <www.fossil.energy.gov/coal_power/existingplants/index.shtml> downloaded 12/02/02 at p. 3.

[46] Sargent & Lundy LLC, "Plant Performance Improvement - Integrated Technical Assessment & Implementation", (NO DATE), <http://www.sargentlundy.com/fossil/plant.asp> downloaded 12/16/02 at page 2 of 4.

[47] USEPA, "Review of Potential Efficiency Improvements at Coal-Fired Power Plants", 04/17/01, <http://www.epa.gov/airmarkets/fednox/126noda/heatrate_rpt_april17.pdf> downloaded 12/16/02 at page 3.

[48] Wang, S., Jones, S., Hurt, J., Poojara, J., & Slettehaugh, R. (Black & Veatch), "Identifying Winning Repowering Opportunities," at page 1.

[49] US DOE, "Pollution Controls for Power Plants," <www.fossil.energy.gov/coal_power/existingplants/index.shtml> downloaded 12/02/02 at p. 4.

cycle combustion gas turbines can increase power and efficiency by 80% and 40% respectively.[50]

2. Natural Gas Switching. Combustion processes based on natural gas generally have higher raw efficiencies both with and without CO_2 separation when compared to coal. As a result, burning natural gas also produces less CO_2 than does a coal-fired plant, per unit of electricity output.[51] Mining, transporting and then burning coal lead to emissions of CO_2, black carbon particles, methane (CH_4), carbon monoxide (CO), nitrogen oxides (NO_x) and sulfur dioxide, (SO_2). These compounds all exacerbate global warming to different degrees, in different ways, and along different time scales.

Assessment of the benefits of natural gas switching starts with analysis of the stoichiometry of gas and coal combustion. This analysis results in values for pounds of CO_2 per million Btu of 31.25 for gas and 60 for coal, almost twice as much for coal. This benefit is increased further by the higher thermal efficiency of natural gas combined cycle turbines (NGCCs) compared to "modern" coal fired power plants. When this advantage is coupled with the inherent CO_2 benefits of coal, the NGCC emits 31% of the CO_2 emitted by modern coal plants (a reduction of nearly 70%).[52]

Switching selected coal plants to natural gas will slow the pace of global warming over the long term. A US DOE-funded study by Jain, *et al.* demonstrates that while global warming benefits of natural gas substitution is not always positive, this mechanism was found to "enhance the potential for this strategy to reduce the net climate impacts of fossil fuels on climate, regardless of the uncertainties involved."[53] Basing their analysis on exercise of the "Integrated

---

[50] Wang, S., Jones, S., Hurt, J., Poojara, J., & Slettehaugh, R. (Black & Veatch), "Identifying Winning Repowering Opportunities," at page 4 downloaded 12/16/02 from <http://www.conae.gob.mx/work/secciones/392/imagenes/Identyfing.pdf>

[51] Lyngfelt, A. & Leckner, B. "Technologies for CO_2 Separation," Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, October 22, 1999, Goteborg, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

[52] "Applications of Technology," dated October 7, 2002 at pages 9-11, downloaded from MIT February 14, 2003 from <http://web.mit.edu/1.149/www/fall2002/handouts/lecture10/slides.pdf>

[53] Hayhoe, K., Kheshgi, H.S., Jain, A.K., & Wuebbles, D.J., "Substitution of Natural Gas for Coal: Climatic Effects of Utility Sector Emissions," Journal of Climate Change, 54: 107-139, July 2002 at page 125.

Science Assessment Model,"[54] the authors show that electricity generated by high efficiency natural gas turbines takes advantage of natural gas' lower carbon content and creates less methane and emits less black carbon, particularly when impacts of mining and transportation are considered. Coal's dubious benefit[55] of emitting sulfur dioxide, which transforms in the clouds to sulfate aerosols that tend to cool the Earth's surface, is relatively short-lived (in the 30-year time horizon). The benefit of switching from coal to gas can be maximized by converting the most antiquated coal plants furthest from mines to state of the art natural gas turbine facilities.

These efficiency improvements can be accomplished quickly and at relatively low cost, and will pay for themselves in a short time. Because the improvements will also reduce emissions of all pollutants, they should not trigger new source review permitting obligations.

B. Capture of Power Plant Produced Carbon Dioxide

Storage, discussed later, requires capture[56] of CO_2 from flue gases. Cost effective transport and injection schemes all require concentrated CO_2 for subsequent sequestration in geologic or ocean media.[57] Capturing CO_2 is a two-phase undertaking. First, the gas must be separated from cleansed flue gases (it can also be separated before combustion from the syngas resulting from coal gasification) and then conditioned for storage or transport to sequestration destinations by compressors and dehydrators. The separation technologies described below are generally available and have been practiced for CO_2 separation and conditioning for decades, except for emerging oxygen combustion or IGCC paths where CO_2 capture still needs to be demonstrated. A technology review in 1999 identified at least a dozen commercial power plant based CO_2 separation and capture plants worldwide which had operated or were operating. These

---

[54] This model has been used by the UN's Intergovernmental Panel on Climate Change (IPCC) to assess the impacts of more than 40 gases associated with the global warming phenomenon.

[55] SO_2 has adverse health effects and causes acid rain, which damages agriculture, forests, and ecosystems and leads to other conditions that frustrate achievement of regional air quality goals.

[56] Capture refers to a process that separates and compresses CO2 (pressures greater than 100 psia) for subsequent transport and storage.

[57] Anand B. Rao and Edward S. Rubin, "A Technical, Economic, and Environmental Assessment of Amine-Based CO_2 Capture Technology for Power Plant Greenhouse Gas Control," Environmental Science and Technology 36,4467-4476, 2002.

plants featured capacities as large as 1,200 tons/day of CO_2 and were designed and operated for a variety of purposes including enhanced oil recovery (EOR), food-grade products, and urea production.[58] Another example is the Great Plains Synfuel Plant near Beulah, North Dakota that gasifies coal producing syngas and nearly 7 million standard cubic meters of CO_2, a large amount of which is shipped through a 325 kilometer pipeline for injection into an EOR field.[59]

1. CO_2 Recovery from power plant combustion gases. In the simplest terms, stack gas CO_2 recovery systems begin with particulate removal and cooling steps (that condition the effluent for subsequent steps). A large centrifugal fan next pressurizes the gas. In coal plants, sulfur compounds are also removed. From there, the gas enters a step that separates CO_2 from the rest of the effluent gases.[60] The more concentrated the CO_2 is in the incoming gas stream, the more efficient this step becomes per unit of CO_2 captured. Citing several sources, the IPCC observes that gas turbine (NGCC) emissions contain CO_2 at 4% and PC plants at 14% while IGCC plants offer pre-combustion syngas CO_2 concentrations that are much higher. Using pure oxygen instead of air in PC systems to combust coal, oil or gas can raise CO_2 concentrations to 90%.[61] The overall costs of gasification schemes presently are higher than NGCC and PC plants but modularization and experience may generate major cost reductions. Separation methods include the following:

---

[58] Herzog, Howard, MIT Energy Laboratory, "An Introduction to CO_2 Separation and Capture Technologies," August 1999 available from author at page 1 and Table 1.

[59] Herzog, Howard and Golomb, Dan, "Carbon Capture and Storage from Fossil Fuel Use," contribution to Encyclopedia of Energy, to be published 2004, at page 4. This submission is available from the authors at Massachusetts Institute of Technology.

[60] According to SRI Consulting, "Process Economics Program Report 180 - Carbon Dioxide Separation," December 1987 (downloaded 12/02/02), two solvent extraction processes represent "virtually all commercial" applications used for CO_2 capture: a) reversible chemical reactions involving aqueous monoethanolamine (MEA) or potassium carbonate and b) absorption on physical solvents involving methanol or dimethyl ethers. Hybrid mixes of these two methods have been practiced as well. Today, commercial grade solid and liquid CO_2 production almost entirely comes as a byproduct of other chemical processes. As demand has increased for lower grade gaseous CO_2 for oil field stimulation, economically acceptable technology has evolved for capture of CO_2 from natural gas power plant flue gases. Power engineers can now draw on the substantial body of experience in this field for greenhouse gas controls.

[61] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at pages 249-250.

a. <u>MEA Absorption and Stripping.</u> Absorptive scrubbing with amine solutions "scrubs" CO_2 from flue gases by passing the exhaust through a chemical medium that has a particular affinity for the gas (typically monoethanolamine (MEA)). While the combustion process itself is not affected, absorption itself consumes energy, thereby lowering the efficiency of the power production system.[62] This is the most common demonstrated process for capture of CO_2. MEA absorption has been the preferred extraction method to produce industrial and food grade CO_2 and dry ice for over 60 years.[63] The International Test Center for Capture (ITC) operated a CO_2 extraction pilot plant in the fall of 2000 (and has been in operation since) to test and demonstrate the potential of various CO_2 capture technologies. Results of a 35-day study using an MEA-based solvent for CO_2 removal show that this process is capable of removing 75-90% of CO_2.[64] Other good examples are plants in Trona, California and in Bellingham, Massachusetts.[65]

According to staff at a leading industrial gas manufacturing company, chemical absorption currently represents the "most cost-effective means of directly obtaining high purity (>99%) CO_2 vapor from flue gases in a single step."[66] A typical process features 1) a flue gas cooler, 2) an

---

[62] Lyngfelt, A. & Leckner, B.,"Technologies for CO_2 Separation," presented at the Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, October 22, 1999 at page 16, Goteborg, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

[63] Herzog, Howard, MIT Energy Laboratory, "An Introduction to CO_2 Separation and Capture Technologies," August 1999 available from author at page 1.

[64] Wilson, M., Tontiwachwuthikul, P., Chakma, A., Idem, R., Vaewab, A., Aroonwilas, A., Gelowitz, D., Barrie, J., and Martin, C. "Test results from a CO_2 extraction pilot plant at Boundary Dam coal-fired power station," at page 6, downloaded February 7, 2003, http://www.rite.or.jp/GHGT6/pdf/A4-3.pdf

[65] Herzog, Howard, MIT Energy Laboratory, "An Introduction to CO_2 Separation and Capture Technologies," August 1999 available from author at Table 1.

[66] Chakravarti, S., Gupta, A., Hunek, B., "Advanced Technology for the Capture of Carbon Dioxide from Flue Gases," First National Conference on Carbon Sequestration, May 15-17, 2001 at page 2 *et seq.* The IEA Greenhouse Gas R&D Programme [see "Carbon Dioxide Capture from Power Stations - Conclusions," <http://www.ieagreen.org.uk/> downloaded 12/02/02, page 1] concludes that for IGCC plants, the Selexol process (high pressure dimethylether or polyethylene glycol absorption) is the best approach in the short term although refinements to membrane separation may make that process the preferred alternative in the future. There are other absorption processes, such as one based on DEA and not potassium carbonate. IEA Greenhouse Gas R&D Programme, "Carbon Dioxide Capture from Power

absorber using a methyldiethanolamine (MDEA) mixed with smaller amounts of faster reacting chemicals including diethanolamine (DEA) and piperazine, 3) a heat exchanger/CO_2 stripper combination to remove the CO_2 from the solvents and 4) reboiler, reclaimer and reflux drum peripherals to recondition the solvent and condition the CO_2 prior to dehydration and compression.

b. Membranes and Cryogenics. Commercial scale use of gas separation membrane technology is being explored for enhanced oil recovery (EOR) applications where gases with high pressures and CO_2 concentrations are available. In conjunction with solvent extraction processes, the membrane assists separation of CO_2 at near atmospheric pressure for later compression for storage purposes. If high purity CO_2 is a desired end product, cryogenic compression is a candidate process.[67]

2. Post-Capture Compression and Transport. Capture of CO_2 separated from power plant effluent has been practiced for decades using simple solvent extraction processes. These applications have generated the large volumes of CO_2 needed for commercial products and industrial purposes such as injection into oil fields for enhanced oil recovery activities, an early example of which was a plant in Lubbock, Texas, which could produce 400,000 tonnes of CO_2 per year. Injection pressures of 1500 psia are common requirements.[68] Numerous pipelines to transfer dehydrated CO_2 have been built to facilitate transfer from power or synfuels plants to the oil fields.[69] To facilitate transport and use in various processes, industrial operations use commonly available compression systems to pressurize this gas.

3. Combustion Systems that Concentrate CO_2 to Facilitate Capture. To facilitate storage, CO_2 must be separated from flue gases. If it is not, the storage will be much more expensive due to handling difficulties associated with larger volumes and because of the presence

---

Stations - Design and Chemistry," <http://www.ieagreen.org.uk/> downloaded 12/02/02, page 1.

[67] Smith, L.A., Gupta, N., Saas, B.M., Bubenik, T.A., et al., "Engineering and Economic Assessment of Carbon Dioxide Sequestration in Saline Formations," Journal of Energy and Environmental Research, Volume 2, at pages 5-22, February 2002; IEA Greenhouse Gas R&D Programme, "Carbon Dioxide Capture from Power Stations - Cryogenic Technologies," <http://www.ieagreen.org.uk/> downloaded 12/02/02, page 1.

[68] Chakravarti, S., Gupta, A., Hunek, B., "Advanced Technology for the Capture of Carbon Dioxide from Flue Gases," First National Conference on Carbon Sequestration, May 15-17, 2001 at page 2 *et seq.*

[69] Lyngfelt, A., "An Introduction to CO_2 Capture and Storage," at page ix, Goteborg, October 26, 2001, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

of other gases like oxygen, nitrogen and combustion products (SO_2, NO_x, H_2S, etc.). It is much more economical to separate CO_2 early in the system and then just compress that gas alone. In addition, these other gases may impede chemical and physical processes associated with subsequent compression, dehydration and storage.

Several generating technology modifications achieve flue gases of higher CO_2 concentration, mostly using oxygen gas instead of air during fuel combustion or gasifying the fuel with oxygen in the early stages of power production. Of particular interest, most of the combustion process modifications listed below can be retrofitted at existing plants. Several technologies stand out, namely integrated combined cycle front end gasification (IGCC), oxyfuel firing, chemical looping combustion and the carbon monoxide sour shift process.

a. Integrated Gasification Combined Cycle (IGCC). As explained above, IGCC offers several critical global warming mitigation and other environmental benefits - higher efficiencies, much lower emissions, less waste, commercial grade sulfur. In addition, IGCC creates a pre-combustion gas that features much more concentrated CO_2 at high pressures, which can be captured more efficiently and cheaply. The catalyzed exothermic shift reaction for gasification changes CO and water into high concentration CO_2 and H_2 (hydrogen becomes the key combustible fuel for succeeding power steps). Natural gas combined cycle plants (NGCC) produce emissions with only 3% CO_2 whereas PC plants have a higher flue gas content of 13%.[70] IGCC plants, however, produce a pressurized syngas made up of 40% CO_2.[71] Because higher pressures and concentrations help facilitate absorption steps, the cost of CO_2 capture at IGCC plants is about half the unit cost of competitive pulverized coal plants.[72]

Research into IGCC system enhancements is a substantial area of interest now. Staff of Texaco and General Electric Power Systems have presented an IGCC concept using currently available technology with an option for CO_2 removal through some minor modifications. They estimate a $5 to $10 million cost for the equipment modifications to capture CO_2 from an 850

---

[70] David, J. & Herzog, H., "The Cost of Carbon Capture," (MIT) at page 2. <http://sequestration.mit.edu/pdf/David_and_Herzog.pdf> downloaded 12/13/02.

[71] Gambini, M. & Vellini, M., "CO_2 Abatement from Fossil Fuel Power Plants by Exhaust Gas Treatment," IJPGC2000-15056, paper delivered July 23-26, 2000 in Miami Beach, FL, at page 2.

[72] O'Keefe, L.F. & Sturm, K.V., "Clean Coal Technology Options - A Comparison of IGCC vs. Pulverized Coal Boilers," a presentation at the Gasification Technologies 2002 Conference, October 28, 2002 at slide 37; See also David & Herzog (MIT) "The Cost of Carbon Capture," <http://sequestration.mit.edu/pdf/David_and_Herzog.pdf> downloaded 12/13/02.

MW plant and expect a 75% capture rate.[73] Mitsubishi/Kansai have developed new improved absorbents that they report will reduce up to 30% of the parasitic energy demands of the conventional MEA process and achieve an 80-90% reduction of wastes from it too.[74] Researchers at Alstom Power expect the following CO_2 capture rates from gas turbine (GT) powered plants: 85-95% from a GT system with tail-end CO_2 capture; 85-95% from a hydrogen GT system with fuel decarbonization; 100% for an oxy-fuel GT system; and 100% from a membrane-based GT system.[75] Another author's simulation showed that at a 90% removal rate of CO_2, combined cycle plant efficiency was 47.7%. The corresponding NGCC plant efficiency without CO_2 capture was 58.4%.[76] (Our earlier comment about the distinction between LHV and HHV efficiency values should be considered here.)

b. Pre-Combustion: Oxyfuel with flue gas recycle (Combustion in O_2/CO_2 atmospheres). Coal fired boilers could be designed or retro-fitted with oxygen firing equipment (as opposed to air).[77] Combustion with oxygen produces an exhaust with high CO_2 concentration suitable for more cost-effective capture and subsequent storage. Parasitic power requirements for the coolers, air separation unit for oxygen manufacture, gas clean-up devices and fans would be substantial. More experience with O_2/CO_2 combustion and equipment development would be

---

[73] However, this capture results in a 2% loss of efficiency resulting in a 3% decrease in net energy output. See O'Keefe, L.F., Weissman, R.C., De Puy, R.A., (Texaco Power and Gasification); Griffiths, J., East, N., (The Jacobs Consultancy); Wainwright, J. (General Electric Power Systems), "A Single IGCC Design for Variable CO_2 Capture" at pages 2 and 12 downloaded February 7, 2002 from <www.jacobsconsultancy.com>.

[74] Svendsen, H.F., Hoff, K.A., Poplsteinova, J. and da Silva, E.F., "Absorption as a Method for CO_2 Capture" presented at the Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, October 22, 1999 at page 16, Goteborg, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

[75] Griffin, T., Bell, A., Marion, J.L. and ya Nsakala, N., "CO_2 Control Technologies: Alstom Power Approach" downloaded 12/16/02 <http://www.rite.or.jp/GHGT6/pdf/L3-2.pdf> at Table 1, page 3.

[76] Kvamsdal, H.M., Ertesvag, I.S., Bolland, O. and Tolstad, T., "Combined Cycle with CO_2 Capture Based on the Pre-Combustion Method," page 32, paper presented at the Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, Goteborg, October 26, 2001, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

[77] Stromberg, Lars, "Combustion in a CO_2/O_2 Mixture for a CO_2 Emission Free Process," Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, October 22, 1999, Goteborg, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

needed to adapt gas turbines to the different properties of this gas mixture.[78] NO_x emissions can be minimized because relatively pure oxygen, rather than nitrogen-laden air, is used as the principle oxygen source.

Researchers at the University of Waterloo and the CANMET Energy Technology Centre in Canada have used a commercial process simulation package (HYSYS) to compare O_2/CO_2 recycle combustion with amine scrubbing at a natural gas-fired power plant. Results of the simulation show that it is possible to remove 66% and 58% of CO_2 using O_2/CO_2 recycle combustion and amine scrubbing respectively. While the authors indicate that final conclusions cannot be made until each process is fully optimized and capital costs are considered,[79] general consensus in field is building that O_2/CO_2 recycle and MEA are fairly close in unit costs.[80]

c. Chemical-looping combustion (CLC). This combustion technology uses metal oxide as an oxygen carrier to transfer oxygen for fuel combustion. Since there is no direct contact between the combustion air and the fuel, CO_2 and water (the products of combustion) are kept separate from the rest of the flue gases.[81] Once again, NO_x emissions will be minimized. Developmental challenges face this process before it can be considered a commercial process.[82]

4. Power Generation Impacts of CO_2 Capture. The economics of fossil fuel power systems change markedly when CO_2 is integrated into system operations. Numerous analyses of fossil fuel cycle operations and capital costs conclude that IGCC plants are the most compatible with CO_2 capture technology, thereby substantially reducing the incremental costs associated with

---

[78] Lyngfelt, A. & Leckner, B., "Technologies for CO_2 Separation" Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, October 22, 1999, Goteborg, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

[79] Singh, D.J., Croiset, E., Douglas, P.L., and Douglas, M.A. "CO_2 Capture Options for an Existing Coal Fired Power Plant: O_2/CO_2 Recycle Combustion vs. Amine Scrubbing."

[80] Commentary, February 5, 2003, Dr. Howard Herzog at Massachusetts Institute of Technology.

[81] Mattisson, T., & Lyngfelt, A., "Applications of Chemical-looping Combustion with Capture of CO_2." Nordic Minisymposium on Carbon Dioxide Capture and Storage, Goteborg, October 26, 2001, <http://entek.chalmers.se/~anly/symp/symp2001.html>.

[82] Personal commentary with P. Skinner, New York Attorney General, February 5, 2003 with Dr. Howard Herzog at Massachusetts Institute of Technology.

this function.[83] Another holistic cost analysis concludes that IGCC and NGCC are the most cost effective methods to achieve 90% reduction of CO_2.[84] If one also considers emissions of other criteria pollutants and waste products such as fly ash and flue gas desulphurization sludge, IGCC and NGCC plants appear to trump even the newest generation of PC plants.

C. Carbon Dioxide Storage and Sequestration

Four basic reservoirs exist to store or sequester[85] CO_2: oceans (by far the largest of the four); geologic strata; terrestrial reservoirs; and the atmosphere. This last sink is by far the smallest[86] but the one which appears to have changed the most due to anthropogenic additions created by fossil fuel use.

1. Geologic Approaches. CO_2 captured from combustion emissions can be sequestered in geologic media using a number of different approaches. These include oil and gas reserves, coal seams, and deep saline reservoirs.

a. Oil and Gas Reserves. Many oil fields around the world, especially in the U.S.,[87] have already given up their easily accessible oil reserves. The balance of the residuum must be induced to travel to withdrawal wells using various stimulation techniques. One widely exercised enhanced oil recovery (EOR) method relies upon injection of compressed CO_2 into underground

---

[83] DeLallo, M., Buchanan, T., White, J., (Parsons Energy & Chemical Group Inc.) Holt, N., (EPRI), Wolk, R., (Wolk Integrated Technical Services), "Evaluation of Innovative Fossil Cycles Incorporating CO_2 Removal," paper delivered at the 2000 Gasification Technologies Conference, October 8-11, 2000, at Table 6 and Figure 1.

[84] David, J. & Herzog, H., "The Cost of Carbon Capture," (MIT), <http://sequestration.mit.edu/pdf/David_and_Herzog.pdf> downloaded 12/13/02. at page 3.

[85] Sequestration refers to a process that facilitates long term storage or disposal of CO_2 in a soil or biomass medium.

[86] IEA Greenhouse Gas R&D Programme, "Ocean Storage of CO_2," http://www.ieagreen.org.uk/ downloaded 12/02/02, Introduction at page 1.

[87] The Permian Basin in western Texas is presently the sink for most of the CO_2 created in the U.S. for enhance oil recovery purposes. Pipelines carry pressurized high purity CO_2 to the well fields. See Stevens, S., Eppink, J. " CO_2 Utilization for Enhanced Oil and Gas Production," October 9, 2001, Gasification Technologies 2001, conference presentation at slide 7 *et seq.*

oil reservoirs. The CO_2 helps to mobilize through displacement of and mixing with the non-flowing oil in the formation and push it to adjacent wells in the same production zone. When the gas emerges with the mobilized oil, it is separated and re-injected along with new gas continuously until as much enhanced oil has been produced as possible.[88] At the Rangely Field in Colorado, a study found that over time, injection of 1,167 billion cubic feet (bcf) yielded storage of 472 bcf. (40.4%). The authors estimate that less than 2% of the sequestered CO_2 is lost from other production wells perforating the zone and cap rock leaks.[89] The integrity of the CO_2 that remains in the reservoir is very high, as long as the original pressure of the reservoir is not exceeded.[90]

Millennium Energy Inc. (MEI) owns an interest in a mature CO_2 flood of an oil reservoir in west Texas, started in 1983, which now adds 10 million cubic feet per day (cfpd) of new CO_2 (piped in from New Mexico) to 30 million cubic feet per day of CO_2 being recycled from the enhanced oil production. That represents 40 million cubic feet of CO_2, weighing over 2,000 tons, handled every day.[91] The IEA Weyburn CO_2 monitoring and storage project in Saskatchewan, Canada practices EOR as well. They purchase CO_2 from Dakota Gasification Company's synthetic fuel plant in Beulah, ND, which is transported to the Weyburn unit through a 325-kilometer pipeline.[92]

Fully depleted oil and gas fields offer another attractive CO_2 disposal site. Since such zones sequestered their oil and gas contents for millennia, CO_2 disposed of there should remain in place for a similar duration. One source provides a worldwide capacity estimate of as much as

---

[88] Millenium Energy, Inc., "Enhanced Oil Recovery (EOR)" downloaded 12/16/02 from <http://www.millenniumenergyinc.com/eor.shtml>.

[89] Stevens, S., Eppink, J., " CO_2 Utilization for Enhanced Oil and Gas Production," October 9, 2001, Gasification Technologies 2001 conference presentation at slide 11.

[90]Office of Fossil Energy, USDOE, "Carbon Sequestration -Geologic Approaches", (NO DATE), <http://www.fe.doe.gov/coal_power/sequestration/sequestration_geologic.shtml> downloaded 12/16/02 at page 1 of 2.

[91]Millennium Energy Inc., "Enhanced Oil Recovery (EOR), <http://www.millenniumenergyinc.com/eor.shtml> downloaded 12/16/02 at page 2 of 2.

[92] Moberg, R., Stewart, D.B. and D. Stachniak, D., "The IEA Weyburn CO_2 Monitoring and Storage Project," <http://www.rite.or.jp/GHGT6/>.

200 gigaton of CO_2.[93]

b. Coal Bed Methane. Methane gas (loosely adsorbed in coal) is present in large amounts in coal beds. Methane can be displaced from coal beds with water flooding. An alternative approach is to pump CO_2 into the same beds and since CO_2 is preferentially adsorbed onto coal (as much as two times),[94] the methane is displaced. Since many coal power plants are located near coal beds, these plants could not only provide convenient sources of CO_2, thus reducing transportation and parasitic energy costs, but also burn the methane driven out for power production. A pilot project of CO_2-assisted Coal Bed Methane (CBM) production in San Juan Basin has been underway since 1996: it injects 4 million cubic feet/day of CO_2 in nine injection wells[95] with over 2.5 billion cubic feet of CO_2 having been injected so far. Coal basins in Australia, Russia, China, India and Indonesia offer sizeable CBM opportunities as well.[96] While EOR is a well understood and widely practiced procedure, enhanced coal bed methane recovery via CO_2 flooding is still in the developmental stage.

c. Saline Formations. Deep salt formations offer attractive long term storage sites for compressed CO_2 . CO_2 must be injected below 800 meters to preserve it in a dense phase, the specific gravity of CO_2. Since that density is sadly lower than the brine found at that depth, the injected CO_2 will tend to rise and create the risk of out leakage. Consequently, only formations with impermeable caps or geologic traps are candidate sites.[97] The Norwegian Oil Company, Statoil, is injecting approximately 1 million metric tonnes per year of recovered CO_2 into the

---

[93] IEA Greenhouse Gas R&D Programme, "Carbon Dioxide Disposal from Power Stations - Major CO_2 Disposal Options," <http://www.ieagreen.org.uk/> downloaded 12/02/02, page 3.

[94] US DOE, "Carbon Sequestration - Geologic Approaches," at page 1, <www.fe.doe.gov/coal...uestration/sequestration_geologic.shtml> downloaded 11/01/02.

[95] Byrer, C.W.,"Sequestration of Carbon Dioxide in Geologic Formations. Where we've been- Where We're Going." COAL - SEQ 1 Forum. Houston, Texas. March 14, 2002, National Energy Technology Laboratory, downloaded 12/16/02 from <http://www.coal-seq.com/Proceedings/CharlesByrer-CO2-Presentation.pdf>.

[96] Herzog, Howard and Golomb, Dan, "Carbon Capture and Storage from Fossil Fuel Use," contribution to Encyclopedia of Energy, to be published 2004, at page 6. This submission is available from the authors at Massachusetts Institute of Technology.

[97] Herzog, Howard and Golomb, Dan, "Carbon Capture and Storage from Fossil Fuel Use," contribution to Encyclopedia of Energy, to be published 2004, at page 6. This submission is available from the authors at Massachusetts Institute of Technology.

Utsira Sand, a saline formation 1000 meters under the sea associated with the Sleipner West Heimdel gas reservoir. The amount of gas being sequestered is equivalent to the output of a 150-megawatt coal-fired power plant.[98] Seismic data have been used to trace the dissemination of the injected gas and yielded confidence that "any major leakage into the overlying cap rock succession would have been detected." Based upon these observations, the authors have concluded that this reservoir may be able to trap 20 million metric tonnes of CO_2 within 12 kilometers of the injection well.

While geochemical experiments and modeling with Urtsia sands dashed hopes of substantial CO_2/mineral reactions to form a carbonate precipitate, other simulations have led to projections of up to 18% dissolution into the aquifer liquids in the sand in the near term, a more immobile form of CO_2.[99] According to one source, estimates for the domestic storage capacity in such formations is "on the order of several hundred years of CO_2 emissions."[100] Another estimate puts the U.S. capacity at 500 billion metric tonnes of CO_2.[101]

Although capture and compression of CO_2 can be practiced with reliability and definable environmental impacts, studies must still be done to define a similar level of assurance with respect to likelihood and severity of impacts from large scale deployment of these storage practices.

2. Ocean storage and sequestration. Ocean storage of CO_2 could be simply practiced but will require more analysis to determine if there are substantial negative environmental impacts.[102] Two methods to accomplish greater sequestration in oceans are stimulation of upper waters productivity and injection of CO_2 into deeper ocean zones and seabed basins.

---

[98]US DOE, "Carbon Sequestration - Geologic Approaches," at page 1, <www.fe.doe.gov/coal...uestration/sequestration_geologic.shtml> downloaded 11/01/02.

[99] Torp, T.A. & Gale, J., "Demonstrating Storage of CO_2 in Geologic Reservoirs: the Sleipner and SACS Projects," downloaded 12/16/02 from <http://www.rite.or.jp/GHGT6/pdf/B1-1.pdf> at page 1 *et seq.*

[100] US DOE, NETL "Geologic Sequestration," <www.netl.doe.gov/coalpower/sequestration/geologic.html> downloaded 12/02/02 at page 1.

[101] US DOE, NETL "Geologic Sequestration," <www.netl.doe.gov/coalpower/sequestration/geologic.html> downloaded 12/02/02 at page 2.

[102]Heinrich, J., "Legal Implications of CO_2 Ocean Storage," Working Paper, July 2002. Laboratory for Energy and the Environment, MIT.

a. <u>Oceanic food web stimulation</u>. Phytoplankton metabolize atmospheric CO_2 and thereby create biomass which supports the oceanic food web. All elements of the food web are either captured by man or avian predators and consumed or eventually die and sink to the bottom and where they are bound into sediments. The carbon in these sediments is only slowly released, thereby representing a substantial carbon sink. Increases in ocean plankton productivity could improve fisheries but could also cause imbalances that would have impacts that are difficult to predict. Scientists have proposed several fertilization strategies to increase plankton abundance (and subsequent ocean bed sequestration) including dispersal of nitrogen, phosphorus, or iron where it is the lack of these nutrients that limit plankton growth. Researchers have undertaken at least four major open ocean experiments to date have demonstrated that phytoplankton growth can definitely be stimulated. Critical scientific questions remain, however, including what proportion of the captured photosynthesized CO_2, is actually exported to the deep ocean and thereby sequestered.[103]

b. <u>Ocean water absorption</u>. Sea water itself chemically accepts CO_2, forming carbonic acid and carbonate and bicarbonate ions, (mostly bicarbonate ions), all of which are known as dissolved inorganic carbon (DIC). Colder and deeper ocean waters are not saturated and the DIC content of the oceans would change very little if they were to absorb "all the carbon in known fossil fuel reserves."[104] Although ocean currents carry North Atlantic DIC and release it at the surface of the Indian Ocean and Equatorial Pacific, the time period involved "is estimated to be around 1000 years."[105] In time, the ocean will absorb over 80% of today's emissions of CO_2.[106] If CO_2 were to be directly injected into the ocean, this natural process would be accelerated.

To avoid adverse environmental impacts to the productive surface waters, injection of CO_2 would have to be deeper than 1500 meters. Because liquid CO_2 is heavier than seawater below 3000 meters and could form ice-like hydrates, deposit in deep ocean trenches could yield residence times much greater than the above estimate. Simulations have shown that sequestration

---

[103] Herzog, Howard and Golomb, Dan, "Carbon Capture and Storage from Fossil Fuel Use," contribution to Encyclopedia of Energy, to be published 2004, at page 11. This submission is available from the authors at Massachusetts Institute of Technology.

[104] IEA Greenhouse Gas R&D Programme, "Ocean Storage of CO_2," <http://www.ieagreen.org.uk/> downloaded 12/02/02, page 5 & 6.

[105] IEA Greenhouse Gas R&D Programme, "Ocean Storage of CO_2," <http://www.ieagreen.org.uk/> downloaded 12/02/02, page 5 & 6.

[106] Herzog, Howard and Golomb, Dan, "Carbon Capture and Storage from Fossil Fuel Use," contribution to Encyclopedia of Energy, to be published 2004, at page 7. This submission is available from the authors at Massachusetts Institute of Technology.

efficiency for CO_2 for a 400-year time horizon would be 35% below 1000 meters of depth, 70% below 2000 meters and 90% below 3000 meters.[107] Pipeline and tanker transportation of liquid CO_2 to deep water is feasible.[108] Diffusing CO_2 into mid-depths of between 1500 and 3000 meters would create small droplets would dissolve as they rise in about 100 vertical meters. This process would avoid the environmental concerns associated with disposal of liquid CO_2 at great depth to create a "deep lake" of relatively immobile CO_2.[109]

3. Terrestrial Sequestration. Terrestrial soils and ecosystems offer excellent media for sequestration of CO_2 both below and above ground. Below ground, soil organic matter containing carbon is made up of microorganisms and un-decayed plant biomass. Above ground, trees, crops and other plants make up the other part of sequestered carbon. Changing agriculture, forestry and land use patterns can increase sequestration rates or minimize oxidation of sequestered carbon, i.e. creation of CO_2.

In order to limit the increase in the amount of CO_2 in the atmosphere, three of many ecosystem and agricultural options can be pursued: 1) controlling deforestation and conserving existing forests, 2) increasing the amount of carbon (from airborne CO_2) stored in the soil and durable wood products, and 3) utilizing substitution management that involves extending forest use for wood products and fuels by increasing the growth of existing forests through silvicultural treatments. For example, coal burned for electrical generation releases four times the amount of carbon as does wood from a plantation. Tropical regions represent the optimum location for conserving and sequestering carbon, potentially holding an estimated 45-72 billion tons of carbon, as compared to the possibility of sequestering 13 billion tons in the United States ecosystems.[110]

---

[107] Caldeira, K., (US-DOE - LLNL-LBL), "Ocean Carbon Sequestration Simulations," Final Report, Direct Ocean Sequestration Experts' Workshop, February 27-March 1, 2001, page 16 downloaded 12/02/02 <http://www.netl.doe.gov/coalpower/sequestration/ocean.html>.

[108] IEA Greenhouse Gas R&D Programme, "Ocean Storage of CO_2," <http://www.ieagreen.org.uk/> downloaded 12/02/02, pages 13 & 14.

[109] Herzog, Howard and Golomb, Dan, "Carbon Capture and Storage from Fossil Fuel Use," contribution to Encyclopedia of Energy, to be published 2004, at page 8. This submission is available from the authors at Massachusetts Institute of Technology.

[110] Sathaye, J. *et al*,"Management of Forests for Mitigation of Greenhouse Gas Emissions," Climate Change 1995, pages 775 *et seq.*

D. Generation Mix Changes to Reduce CO_2 Emissions

Numerous approaches exist to increase the efficiency of and replace or retrofit existing fossil fuel power stations. By changing the mix of generation systems, major CO_2 savings can be achieved. Compared to today's generation of NGCCs without CO_2 capture, the additional costs of carbon reduction per ton is $326-613 for highly controlled PC plants, $250-538 for IGCC plants, $134-176 for NGCCs with CO_2 capture, $124-304 for nuclear plants, $434-2167 for PV and thermal solar systems, $47-450 for forestry and energy crop biomass fuels and minus $8-245 for wind turbines.[111] Wind power and biomass fueling represent by far the most cost-effective large scale CO_2 conservation strategies. Displacement of the CO_2 produced by an aging PC plant with equivalent wind turbine power with energy storage add-on systems for periods when the wind is not blowing largely eliminates the CO_2 produced from the fossil fuel plant.

1. Low Carbon Alternative Power Production Systems. Many systems exist that will produce power without also emitting substantial quantities of CO_2. Chief among these are hydroelectric and new and life-extended nuclear power plants, wind farms and large scale solar-thermal systems and photovoltaic arrays. While many of these systems have inherent limitations (hydro plants impact free flowing streams and aquatic resources, wind farms generate little power on calm days, nuclear power has many safety, cost and waste management challenges, etc.), their introduction into an integrated power production grid will displace power supplied by centralized fossil fuel plants. The Energy Information Administration (EIA) predicted that a- renewable portfolio requirement of 7.5% renewable energy source penetration (exempting hydro-electric facilities) by 2010 would result in carbon emission reductions of 19 million tons - if the kWhr cost was capped at 1.5 cents per kWhr. If that cap was removed, this reduction could be doubled.[112]

a. Wind Power. Wind power generation is a particularly promising sector. Over the last 20 years, major improvements in the design, increases in size, field experience and mass production have transformed wind power from a bit player in the renewable energy field to a rising star. Rotor diameters have increased from 10 meters to 60 and power outputs from 50 kw to 750. Costs per kWh have dropped from 40 cents/kWh in 1979 to a projected cost of 3-5 cents per kWh. Three bladed rotor designs with special airfoils that are stall-regulated and pitch-controlled are being installed at wind farms in fields and open waters across the world. This

---

[111] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 259, Table 3.35e.

[112] Energy Information Administration, "Renewable Portfolio Standards, Appliance Efficiency Standards Could Reduce Carbon Emissions," December 9, 1999 downloaded 12/09/02 from <http://www.eia.doe.gov/neic/press/press145.html>.

relatively impact-free technology is growing at the rate of 29% per year and is expected to increase substantially. In 2001, 21 states had over 4,000 megawatts of wind power capacity installed.[113] NREL staff project that capacity will more than double by 2010, and will be generating 5% of the nation's electricity by 2020.[114] Citing several competent authorities, the IPCC observes that 844,000 megawatts of wind power could be in place by 2010 and as much as 1,200,000 megawatts by 2020 (10% of the global power demand at that time).[115]

b. Solar Systems. The US DOE is implementing the Federal Energy Management Program to introduce American businesses and homeowners to solar energy. Their goals include installations of photovoltaic (PV), hot water and space heating systems on 1,000,000 roofs by 2010.[116] The IPCC points out that PV sunlight conversion factors are improving with achievements of nearly 25% for monocrystalline cells but cost-effective deployment on a large scale will require more efficient mass production efforts.[117]

c. Fuel Cells. Since the fuel and air streams are kept separate in solid oxide fuel cells, power plants that employ this technology can offer high electrical efficiencies and high CO_2 capture rates compared to gas turbine power plants with post-combustion CO_2 capture.[118] Proton exchange membrane, phosphoric acid, and solid oxide fuel cells are examples of the technologies available now to generate electricity and pure hot water and emissions of criteria pollutants much less concentrated than other combustion cycles. Even CO_2 emissions could be near zero from this

---

[113] Flowers, L., US DOE NERL, "Wind Power Update," a 2001 presentation, downloaded from <http://www.eren.doe.gov/windpoweringamerica/pdfs/wpa/wpa_update.pdf> 12/16/02.

[114] Flowers, L. and Dougherty, P., US DOE NERL, "Wind Powering America: Progress, Plans and Perspectives," a presentation at Windpower 2002 conference, June 5, 2002 at slide 2.

[115] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 247.

[116] US DOE, FEMP, "Federal Participation in Million Solar Roofs," downloaded 12/10/02 from <http://www.eren.doe.gov/femp/millionroofs/ms-ovw.html>.

[117] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 246.

[118] Asle Lygre, Matteo Ce, Arlid Vik, and Jan Byrknes, "Solid Oxide Fuel Cell Power Plants with Integrated CO_2 Capture Nordic Minisymposium on Carbon Dioxide Capture and Storage," October 26, 2001 at page 14.

technology if the hydrogen needed for this technology is created from solar powered electrolysis or biomass derived methanol. Solid oxide fuel cells are not a mature technology (as are gas turbines), and therefore the potential still exists to further increase efficiencies gained by this technology.[119] Citing numerous authorities, the IPCC observes that PEM cells are expected to approach 55-60% efficiency "in the near term," phosphoric acid cells can be as high as 80%, and the "ultimate fossil fuel based electricity generation" system, hybrid solid oxide fuel cell/NGCC plants, "have projected efficiencies of 72 to 74%.[120]

2. Decentralized power production networks. Although utilities prefer central power stations, implementation of a decentralized network of very efficient power production systems (like fuel cells or natural gas turbines with appropriate emission controls) displace at the very least, transmission losses that reduce the final efficiency of electrical power generation.

E. Electricity Use Efficiency Improvements

Nationwide, there is a tremendous potential to slow the growth in CO_2 emissions by reducing the demand for electricity. A wide range of energy efficient technologies are available that can reduce electricity consumption in the home, office, farm, and factory. Conservation measures can reduce electricity consumption by cutting off unneeded electricity use. Large users of electricity can shift their power usage to reduce peak demand. Through educational efforts and market incentives, Demand Side Management (DSM) programs encourage end-users to implement these kinds of measures, and can result in significant and measurable reductions in electricity consumption, electricity generation, and CO_2 emissions.

1. Examples of Energy Efficient Products and Breakthroughs. The efficiency of products is constantly improving, and new technologies are emerging that can have a positive impact on reducing greenhouse gas emissions. To note just a few examples:

- In May, Toshiba announced the availability of a new photocoupler used in many

[119] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 239.

[120] Working Group III, Intergovernmental Panel on Climate Change, Third Assessment Report, "Climate Change 2001: Mitigation," Cambridge University Press, published 2001, Section 3.8, at page 240.

consumer devices like air conditioners that cuts its electricity use by 80%.[121] This represents one of many possible chips that may be modified in consumer products to lower energy consumption.

- Over time, the efficiency of new refrigerators has improved markedly – their average annual kWhr consumption has declined from 1,986 kWhrs in 1972 to 884 in 1990 to 478 in 2001.[122]
- EPA has found on average that by 1999, lighting retrofits reduced energy use by 50%. All across America, light emitting diode (LED) light bulbs are replacing the incandescent bulb in traffic lights and sports arenas, and will soon be available for homes and businesses. It is estimated that LED efficiencies can be increased four times by 2020 if substantial investment is made in their design and manufacture and their use could reduce annual carbon emissions by 313 million tons.[123]
- The 13,000 energy efficient products labeled by EPA's Energy Star program accounted for about 90% of the emission reductions for 2000 associated with actions contemplated by the U.S. Climate Change Action Plan adopted in 1993.[124]

A Department of Energy analysis of energy efficiency standards shows how important energy efficiency is in reducing greenhouse gases. The EIA estimated that periodic US DOE energy efficiency standard upgrades for appliances could reduce carbon emissions by 8 million tons by 2010 and 20 - 23 million tons by 2020.[125] EIA further predicts that application of vigorous building standards could reduce power plant carbon emissions by more than 7 million tons per

---

[121] <http://www.electronicstalk.com/news/tox/tos149.htm> dated May, 17, 2002 downloaded 12/09/02 at page 1.

[122] Energy Information Administration, "Energy-Efficient Appliances and Equipment," downloaded 12/11/02 from <http://www.eia.doe.gov/oiaf/climate/energy.html>.

[123] Haitz, R., and Tsao, J., Sandia Laboratories, "Transforming the Lighting Sector with Semiconductor Lighting Technologies," a presentation delivered September 24-27, 2000 at the USAEE/IAEE Annual Meetings, at page 10.

[124] United Nations, "Report on the in-depth review of the second national communication of the United States of America," May 12, 1999 at page 10.

[125] U.S. Department of Energy, Energy Information Administration, "Renewable Portfolio Standards, Appliance Efficiency Standards Could Reduce Carbon Emissions," December 9, 1999 downloaded 12/09/02 from <http://www.eia.doe.gov/neic/press/press145.html>.

year by 2010.[126] Similar predictions for the U.S. can be found from other sources including the World Energy Center.[127]

2. Demand Side Management (DSM) Programs

End use efficiency can be reliably obtained by electric utilities. Indeed, DSM programs demonstrate that off-site end use efficiency could be an element in a carbon emission reduction standard. In New York State, for example, the New York State Energy Research and Development Authority (NYSERDA) administers the New York Energy $mart^SM program, which is designed to improve energy efficiency through education, improved operations, purchases and use of energy efficiency equipment and services, and technology development and demonstration. The 38 New York Energy $mart^SM programs range from market transformation (*e.g.*, ensuring that retail stores offer efficient products to their customers) to low-income assistance (*e.g.*, direct installation of efficiency measures in low-income households).

Between July, 1998 and June, 2001, NYSERDA invested $182 million to encourage efficiency and renewable power investments. These investments have yielded estimated annual electric savings of 927 million kWh, demand reduction of 521 megawatts, and an annual reduction in CO_2 emissions of 409,117 tons.[128] By 2006, the program is projected to reduce CO_2 emissions by 1.5 million tons annually.[129]

These results are measurable. The NYSERDA meets rigorous evaluation and reporting standards and performs studies to insure that its programs are the cause of the measured response. With the proper oversight, actual electric savings achieved (and CO_2 emissions avoided) by private sector programs can also be measured. Prior to deregulation, utilities in New York State were required to invest in DSM programs, and, between 1990 and 1996, reduced demand through

[126] Energy Information Administration, "Energy-Efficient Appliances and Equipment," downloaded 12/11/02 from <http://www.eia.doe.gov/oiaf/climate/energy.html>.

[127] World Energy Center, "Energy Efficiency Policies and Indicators, Annex 1, United States of America," downloaded 12/09/02 from <http://www.worldenergy.org/wec-geis/publ...s/reports/eepi/al_labelling/usadata.asp>.

[128] NYSERDA, **New York Energy $mart^SM** Program Evaluation and Status Report, January, 2002, page 4-12.

[129] Public Service Commission-NYSERDA, System Benefits Charge, Revised Operating Plan for **New York Energy $mart^SM** Programs (2001-2006), June 12, 2002, page 2.

DSM measures by over 1,300 megawatts.[130]

Although the information described above arises from efforts in New York State to foster energy conservation and efficiency outcomes, most other states and federal government agencies have similar programs underway.

---

[130] New York State Energy Planning Board, New York State Energy Plan and Final Environmental Impact Statement, November 1998, p. 3-62.

Addendum 1

Integrated Gas Combined Cycle Systems (IGCC) New and Retrofit Designs

A great deal of work is underway world wide to develop new approaches to burning a fuel long associated with dirty power. Below are some figures and data from recent scientific descriptions of the unit operations, options for further enhancement and emission characteristics.

FIGURE 1. GASIFICATION-BASED ENERGY PRODUCTION SYSTEM CONCEPTS

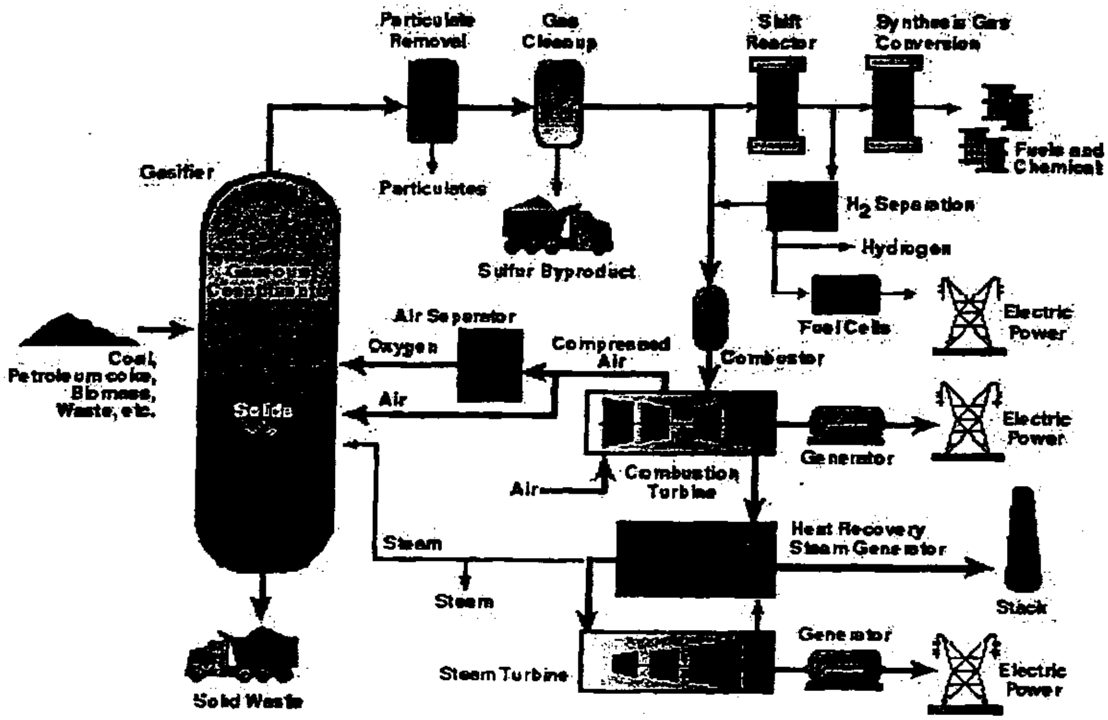

Figure 1 taken from a recent paper delivered at US DOE Coal Conference.[131]

---

[131] Ratafia-Brown, J., Manfredo, L., Hoffmann, J., & Ramezan, M., "An Environmental Assessment of IGCC Power Systems," presented at US DOE NETL's Nineteenth Annual Pittsburgh Coal Conference, September 23-27, 2002,

FIGURE 2. GASIFICATION-BASED ENERGY CONVERSION SYSTEM OPTIONS

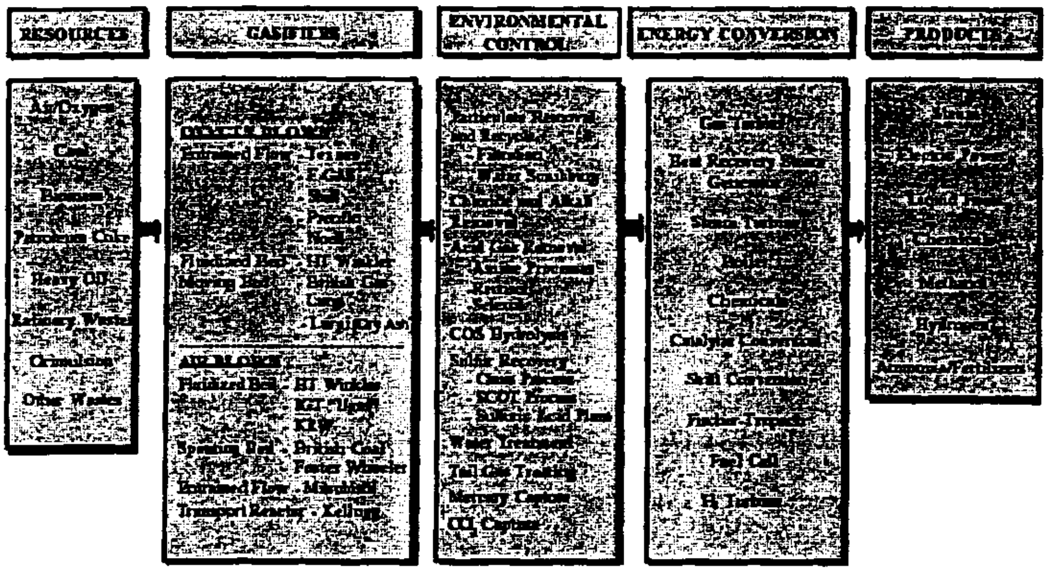

Figure 2 is taken from a recent paper delivered at US DOE Coal Conference.[132]

---

http://www.netl.doe.gov/coalpower/gasification/pubs/pdf/18.pdf downloaded 12/09/02 at page 3.

[132] Ratafia-Brown, J., Manfredo, L., Hoffmann, J., & Ramezan, M., "An Environmental Assessment of IGCC Power Systems," presented at US DOE NETL's Nineteenth Annual Pittsburgh Coal Conference, September 23-27, 2002, http://www.netl.doe.gov/coalpower/gasification/pubs/pdf/18.pdf downloaded 12/09/02 at page 3.

TABLE 4. COMPARISON OF ENVIRONMENTAL PERFORMANCE OF IGCC WITH OTHER COAL-FUELED TECHNOLOGIES

CRITERIA POLLUTANTS, IONIC SPECIES, CO_2, and BYPRODUCTS	PC-FIRED PLANT (With Advanced Pollution Controls[a])	AFBC[b] (With SNCR)	PFBC[c] (Without SNCR)	IGCC PLANT[d]
SO_2, lb/10^6 Btu (lb/MWh)	0.2 (2.0)	0.4 (3.9)	0.2 (1.8)	0.08 (0.7)
NOx, lb/10^6 Btu (lb/MWh)	< 0.15 (< 1.6)	0.09 (1.0)	0.2 – 0.3 (1.7 – 2.6)	0.09 (0.8)
PM10, lb/10^6 Btu (lb/MWh)	< 0.03 (< 0.3)	0.011 (0.12)	0.015 – 0.03 (0.13 – 0.26)	< 0.015 (<0.14)
CO_2, (lb/kWh)	2.0	1.92	1.76	1.76
Chloride as HCl (lb/MWh)	0.01	0.71	0.65	0.007
Fluoride as HF (lb/MWh)	0.003	0.05	0.05	0.0004
Cyanide as HCN (lb/MWh)	0.0003	0.005	0.005	0.00005
Ammonia (lb/MWh)	0	0.001	0.001	0.004
Water Usage, (gallons/MWh)	1,750	1,700	1555	750 – 1,100
Total Solids Generated, (lb/MWh)	367 (Ash and Gypsum)	494 (Ash and Spent Sorbent)	450 (Ash and Spent Sorbent)	175 (Slag and Sulfur)

a. PC with SCR, ESP, FGD. Heat rate equals 9,750 Btu/kWh (35% efficiency). SO_2 emissions based on 2.5% sulfur, 12,000 Btu/lb coal, and 95% reduction via wet limestone FGD. NOx emissions are based on control with SCR and uncontrolled emissions of 0.45 lb/106Btu. PM10 emissions based on actual ESP experience. Ionic species emissions based on average of DOE-sponsored toxic emissions tests at three power plants: Bailly (NIPSCO), Coal Creek (Cooperative Power), and Yates (Georgia Power). CO_2 emissions are based on coal with 67% total carbon content.

b. AFBC plant. Heat rate equals 9,400 Btu/kWh (36% efficiency). Performance source is Final Environmental Impact Statement for The JEA Circulating Fluidized Bed Combustor Project, DOE/EIS-0289, June 2000. SO_2 emissions based on 2.5% sulfur, 12,000 Btu/lb coal, and 90% reduction via in-bed limestone. NOx emissions are based on low-NOx combustion and control with SNCR. PM10 emissions based on Nucla demonstration plant experience. Ionic species emissions not presented since they weren't measured in Nucla demo plant. CO_2 emissions are based on coal with 67% total carbon content.

c. PFBC plant. Heat rate equals 8,600 Btu/kWh (40% efficiency). Performance source is Tidd PFBC Demonstration Project - A DOE Assessment, DOE/NETL-2001/1159, August 2001. SO_2 emissions are based on 2.5% sulfur, 12,000 Btu/lb coal, and 95% reduction via in-bed limestone. NOx emissions are based on low-NOx combustion. PM10 emissions based on Tidd demonstration plant experience. Ionic species emissions based on DOE-sponsored toxic emissions tests at the Tidd PFBC demonstration plant. CO_2 emissions are based on coal with 67% total carbon content.

d. IGCC plant. Heat rate equals 8,600 Btu/kWh (40% efficiency). SO_2 emissions based on 2.5% sulfur, 12,000 Btu/lb coal, and 98% reduction via acid gas removal system. NOx emissions based on turbine combustor that achieves 15 ppm NOx (15% O2, dry). All other emissions based on measured performance of LGTI plant. CO_2 emissions are based on coal with 67% total carbon content.

Figure 3 is taken from a recent paper delivered at US DOE Coal Conference.[133]

---

[133] Ratafia-Brown, J., Manfredo, L., Hoffmann, J., & Ramezan, M., "An Environmental Assessment of IGCC Power Systems," presented at US DOE NETL's Nineteenth Annual Pittsburgh Coal Conference, September 23-27, 2002, http://www.netl.doe.gov/coalpower/gasification/pubs/pdf/18.pdf downloaded 12/09/02 at page 3.

Appendix C

Global Warming Bibliography - Effects

February 2003

Broecker, W.C. 1995. *The Glacial World According to Wally*, 2nd edition. Eldigo Press, Columbia University, Palisades, New York.. 318 pp.

Broecker, W.C. 1997. Thermohaline circulation, the Achilles heel of our climate system: will man-made CO_2 upset the current balance? *Science,* 278:1582-1588.

Comiso, J.C. 2002. A rapidly declining perennial sea ice cover in the Arctic. *Geophysical Research Letters*, 29 (20).

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387:253-260.

Crowley, T.J. 2000. Causes of climate change over the past 1,000 years. *Science*, 289:270-277.

EDF. 1999. *Hot Nights in the City: Global Warming, Sea-Level Rise and the New York Metropolitan Region*. J. Bloomfield (ed.). Environmental Defense Fund, New York, New York. 36 pp.

Gornitz, V., S. Couch, and E.K. Harding. 2002. Impacts of sea level rise in the New York City metropolitan area. *Global and Planetary Change*, 32:61-88.

Hurrell, J.W., Y. Kushnir, G. Ottersen and M. Visbeck, (eds.). 2003. *The North Atlantic Oscillation: Climatic Significance and Environmental Impact*. Geophysical Monograph Series, Volume 134. American Geophysical Union. Washington, D.C. 279 pp.

IPCC (Intergovernmental Panel on Climate Change). 1997. *Stabilization of Atmospheric Greenhouse Gases: Physical, Biological and Socio-economic Implications*. IPCC Technical Paper III. J.T. Houghton, L.G. Meira Filho, D.J. Griggs, and K. Maskell (eds.). IPCC, Geneva, Switzerland. 52 pp.

IPCC (Intergovernmental Panel on Climate Change). 2000a. *Emissions Scenarios*. Special Report of the Intergovernmental Panel on Climate Change. N. Nakicenovic and R. Swart (eds.). Cambridge University Press, U.K. 570 pp.

IPCC (Intergovernmental Panel on Climate Change). 2000b. *Land Use, Land-Use Change, and Forestry.* Special Report of the Intergovernmental Panel on Climate Change. R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D. J. Dokken (eds.). Cambridge University Press, U.K. 375 pp.

IPCC (Intergovernmental Panel on Climate Change). 2001a. *Climate Change 2001: Synthesis Report.* A contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. R.T. Watson, and the Core Writing Team (eds.). Cambridge University Press, U.K. 398 pp.

IPCC (Intergovernmental Panel on Climate Change). 2001b. *Climate Change 2001: Impacts, Adaptation & Vulnerability.* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.). Cambridge University Press, U.K. 1000 pp.

IPCC (Intergovernmental Panel on Climate Change). 2001c. *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P. J. van der Linden, and D. Xiaosu (eds.). Cambridge University Press, U.K. 944 pp.

IPCC (Intergovernmental Panel on Climate Change). 2001d. *Climate Change 2001: Mitigation.* Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). B. Metz, O. Davidson, R. Swart, and J. Pan (eds.). Cambridge University Press, U.K. 700 pp.

IPCC (Intergovernmental Panel on Climate Change). 2002. *Climate Change and Biodiversity.* H. Gitay, A. Suarez, R.T. Watson, and D.J. Dokken (eds.). IPCC, Geneva, Switzerland. 85 pp.

Jablonski, L.M., X. Wang, and P.S. Curtis. 2002. Plant reproduction under elevated CO_2 conditions: a meta-analysis of reports on 70 crop and wild species. *New Phytologist,* 156:9-26.

Kerr, R.A. 2002. A warmer Arctic means changes for all. *Science,* 297:1490-1492.

Lemley, B. 2002. The new ice age. *Discover.* September 2002. p.35-40.

Michener, W.K., E.R. Blood, K.L. Bildstein, M.M. Brinson, and L.R. Gardner. 1997. Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. *Ecological Applications,* 7:770-801.

NASA (National Aeronautics and Space Administration). 2002. *Global Temperature Trends: 2002 Summation.* Goddard Institute For Space Studies, New York, New York. Website:www.giss.nasa.gov/research/observe/surftemp, 3 pp.

NAST (National Assessment Synthesis Team). 2000. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview.* U.S. Global Change Research Program, Washington D.C. 154 pp.

NAST (National Assessment Synthesis Team). 2001. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Foundation.* Report for the U.S. Global Change Research Program, Cambridge University Press, U.K. 620 pp.

NERAG (New England Regional Assessment Group). 2001. *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change. New England Regional Overview.* U.S. Global Change Research Program. 96 pp.

NERAG (New England Regional Assessment Group). 2002. *The New England Regional Assessment of the Potential Consequences of Climate Variability and Change: a Final Report.* U.S. Global Change Research Program. 108 pp.

New York Times. 2002. Warming waters and dying lobsters. November 9, 2002.

NRC (National Research Council). 2001. *Climate Change Science: An Analysis of Some Key Questions.* National Academy Press, Washington D.C. 42 pp.

NRC (National Research Council). 2002. *Abrupt Climate Change: Inevitable Surprises.* National Academy Press, Washington D.C. 230 pp.

O'Neal, K. 2002. *Effects of Global Warming on Trout and Salmon in U.S. Streams.* Defenders of Wildlife, Natural Resources Defense Council. 46 pp.

Parmesan, C. and G. Yohe. 2002. A globally coherent fingerprint of climate change impacts across natural systems. *Nature,* 421:37- 42.

Patz, J.A., M.A. McGeehin, S.M. Bernard, K.L. Ebi, P.R. Epstein, A. Grambsch, D.J. Gubler, P. Reiter, I. Romieu, J.B. Rose, J.M. Samet, and J. Trantj. 2000. The potential health impacts of climate variability and change for the United States: executive summary of the report of the health sector of the U.S. national assessment. *Environmental Health Perspectives,* 108:367-376.

Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig, and J.A. Pounds. 2002. Fingerprints of global warming on wild plants and animals. *Nature,* 421:57-60.

Rosenzweig, C. and W.D. Solecki (eds.). 2001. *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change - Metro East Coast.* Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York. 224 pp.

Rosenzweig, C., X.B. Yang, P.R. Epstein, and E. Chivian. 2001. Climate change and extreme weather events: implications for food production, plant diseases, and pests. *Global Climate Change & Human Health*, 2:90-104.

Snyder, M.A., J.L. Bell, L.C. Sloan, P.B. Duffy, and B. Govindasamy. 2002. Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulnerable region. *Geophysical Research Letters*. June 7, 2002, 29(11).

Still, C.J., P.N. Foster, and S.H. Schneider. Simulating the effects of climate change on tropical montane cloud forests. *Nature*, 398:608-610.

Titus, J.G. 1992. U.S. EPA. The costs of climate change to the United States. Originally published in: Majumdar, S.K., L.S. Kalkstein, B. Yarnal, E.W. Miller, and L.M. Rosenfeld (eds). *Global Climate Change: Implications, Challenges and Mitigation Measures*. Pennsylvania Academy of Sciences.

UNEP (United Nations Environment Programme). 2002. *CEO Briefing: Climate Risk to Global Economy.* July 2002. 8 pp.

U.S. Department of Energy. 2002. *Emissions of Greenhouse Gases in the United States 2001.* DOE/EIA-0573(2001). December 2002. 104 pp.

U.S. Department of State. 2002. *U.S. Climate Action Report-2002.* Washington, D.C. May 2002. 263 pp.

U.S. EPA. 1997. U.S. Environmental Protection Agency. *Climate Change and New York.* EPA 230-f-97-008ff. Office of Policy Planning and Evaluation. 4 pp.

U.S. GAO. 2002. U.S. General Accounting Office. *Air Pollution: Meeting Future Electricity Demand Will Increase Emissions of Some Harmful Substances.* GAO-03-49. October 2002. 43 pp.

Walther, G-R., E. Post, P. Convey, A. Menzel, C. Parmesani, T.J.C. Beebee, J-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. *Nature*, 416:389-395.

WWF. 2002a. *Habitats at Risk; Global Warming and Species Loss in Globally Significant Terrestrial Ecosystems*. World Wide Fund for Nature, Oslo, Norway. February 2002. 39 pp.

WWF. 2002b. *Polar Bears at Risk.* World Wide Fund for Nature, Oslo, Norway. May 2002. 27 pp.

WMO (World Meteorological Organization). 2002. *WMO Statement on the Status of the Global Climate in 2001*. Geneva. 12 pp.