

Carbon Sequestration and Policy Group

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By Kyle Baicker-McKee, Ben Hartung, John McNeil, Emma Mendelsohn, Bo Pratt, Sara Shor.

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Abstract

Federal policies in the U.S. so far have been unsuccessful in addressing carbon dioxide emissions. Early policies such as the Clean Air and Clear Skies Acts did not effectively tackle the issue of carbon emissions and climate change. State and regional efforts within the U.S. have begun to enact policies that include both carbon trading and carbon taxing and will hopefully spur progress on an international level. Internationally, the Kyoto Protocols have been the only policy effort to mitigate the causes of climate change. After reviewing the UNFCCC and the subsequent politics surrounding the ratification of Kyoto in 2001, the potential problems with terrestrial sequestration in its current roles in the Kyoto protocols will be examined. Though a positive first step, the Kyoto Protocol contains many unresolved aspects and loopholes, pertaining mostly to cost and the role of developing nations, which require evaluation. Alternative international policies have been proposed, but have yet to be considered by the international community.

The successful implementation of policy regarding carbon dioxide emissions must include legislation that promotes “clean coal” technologies such as carbon capture and sequestration from power plants. The technology currently available for carbon capture, such as amine scrubbing and Integrated Gasification Combined Cycle, provide various options for mitigation. However, the plausibility of rapid implementation of geologic sequestration remains low and needs further testing and government funding in order to be realized. Ideally, there would be a low cost means of mitigating the effects of anthropogenic climate change that would not require lifestyle changes on the behalf of consumers without placing undue strain on businesses. While the probability of finding such a solution is undoubtedly low, the potential for fame and financial gain motivate scientists and businessmen alike to continue to search. Two proposed solutions with a great deal of potential are iron fertilization of the ocean and sulfur

spraying into the stratosphere. Both provide a rapid means to begin to minimize the effects of anthropogenic releases of greenhouse gasses, but unfortunately both come with significant drawbacks. While neither proposal could be conscientiously implemented yet, continued studies of these methods and other "silver bullet" solutions represent the most optimistic ideas and warrant further study.

National, Sub-national, and Regional Emissions Policy

Introduction

In the last several years, there has been a world consensus that global climate change is in fact occurring and that humans are the cause. As we have learned, carbon dioxide emissions are a considerable part of this problem. Even though U.S. leaders have acknowledged that greenhouse gases, carbon dioxide in particular, are pollutants and are causing large-scale warming, there has been close to no national policy regarding this issue. Other countries and smaller communities within the U.S. have begun to look at strategies of carbon trading, carbon taxes, and increased regulation on non-point sources of carbon dioxide, but the U.S. Federal Government must address these important issues now because the issue of global warming is very immediate.

Federal U.S. Policies Addressing Greenhouse Gas Emissions and Clean Air, Or Lack Thereof:

Throughout the last few decades, there have been pieces of legislation to limit air pollution and greenhouse gases, but there has been no forward movement since 1990 on the Federal level. The Clean Air Act of 1970 was the first piece of legislation in the U.S. regarding these issues and had the most extensive regulatory mandates in U.S. history. While it did not cap

the emissions of carbon dioxide, it did cap the emissions of carbon monoxide and hydrocarbons, as well as lead, ozone, sulfur dioxide, particulates, and nitrogen oxides.¹ It not only put caps on stationary plants, but also, minimally monitored auto emissions. The EPA enforced these mandates by delegating the authority to the states, which had to come up with State Implementation Plans that outlined the new compliance standards. The plans had to be submitted by 1972, approved by 1977, and implemented by 1979.² The federal government used its power to withhold transportation money from states if they did not submit a State Implementation Plan. This made the Clean Air Act especially powerful because if a state did not comply, it would not only lose federal money for clean air implementation, but would lose money for public transportation as well. This task was not easy on the part of the states due to lack of information and time to implement. Setting a level for cuts was also hard because lawmakers were working with undeveloped science and didn't know new technology, or other methods of cutting emissions well enough to determine feasible goals and timetables. There was a heavy reliance on technology-based standards to significantly reduce emissions.

In 1977, there were amendments to the Clean Air act that extended the deadlines from the 1970 plan. These amendments included major compromises between industry, environmentalists and labor. To try and attain new levels, coal fired power plants were beginning to use low sulfur coal from the West. Environmentalists who were worried that this was a loophole alternative to installing pollution control technology and mining interests in the eastern states that were worried that the market for eastern coal would diminish, joined together to create a provision in the 1977 amendments. This provision said that all plants must install source performance

¹ Eisner, Marc. Governing the Environment. Boulder:2007

² Eisner, Marc. Governing the Environment. Boulder:2007.

standards technology and that they had to buy regional coal if doing otherwise would create a loss of jobs. This provision only included newly built power plants, so it ended up extending the lives of old power plants which became more cost effective because they didn't need retrofit for cleaner emissions.³ While this is an example of command and control regulation, the amendments of 1977 also began a new market-based system of regulation. The EPA began to experiment with banking savings of pollution and creating incentives for reducing emissions as a whole. That way, people who banked pollution could sell their shares to other ones that couldn't limit their waste. This was coined as environmental cap and trade, a strategy to limit air pollution and contamination that has been prevalent since its development.

The 1990 amendments to the Clean Air Act again adjusted the limits again, setting new deadlines, and increasing the coverage of auto emissions.⁴ With the introduction of cap and trade, the incentive to cut emissions was large, resulting in an abundance of leftover, unwanted shares. Nonetheless, between 1970 and 2001, quantity of pollutants decreased 25%.⁵ Though there was remarkable progress and success in policy, there has been little forward movement since the passage of the Clean Air Act of 1990.⁶ Also, this progress did not address the problem of carbon dioxide emissions.

Bush introduced the Clear Skies Act in 2002. The provisions of the Clear Skies Act were to cut sulfur dioxide emissions by 73% from 2000 levels by 2018. It also cut emissions of nitrogen oxides by 67% from 2000 levels by 2018. Lastly, it aimed to cut mercury emissions by

³ Eisner, Marc. Governing the Environment. Boulder:2007.

⁴ Eisner, Marc. Governing the Environment. Boulder:2007.

⁵ Eisner, Marc. Governing the Environment. Boulder:2007.

⁶ Eisner, Marc. Governing the Environment. Boulder:2007.

69% on the same time scale using a cap and trade approach.⁷ Many environmental groups opposed this Initiative saying that it weakened the already existing policies of the Clean Air Acts and “resulted in significantly fewer reductions of air pollutants.”⁸ For these reasons, the Clear Skies Act did not gather much support, but was used as a way for Bush to appear environmentally responsible.

While the Clean Air Acts were successful in cutting greenhouse gas emissions, they did not specifically focus on carbon dioxide when looking at point sources. There has been no federal piece of legislation that has focused specifically on carbon dioxide even though scientists are in agreement that carbon dioxide is the most powerful and harmful greenhouse gas. However, last year, a Supreme Court decision ruled that greenhouse gases are pollutants that have negative effects on human health. This provides a strong backbone for environmental organizations that are working to enact laws that will monitor carbon dioxide more closely as well as for lawmakers who are beginning to write legislation to deal with this issue. After this ruling, the EPA should have amended the Clean Air Acts to include specific caps on carbon dioxide emissions. Nonetheless, this ruling is beginning to push forward some important pieces of legislation, and should play a huge role in the enactment of better environmental policy that regulate firms that emit carbon dioxide in the next few years.

In 1997, there were worldwide efforts to address the problem of global climate change through the Kyoto Protocol. The Kyoto Protocol, which we will go into in greater detail in the later parts of this paper, is the exemplary piece of legislation regarding worldwide environmental

⁷ “Clear Skies Basic Information.” Environmental Protection Agency Website. Clear Skies Basic Information <http://www.epa.gov/air/clearskies/basic.html>

⁸ “Clean Air: Clear Skies Proposal Weakens the Clean Air Act.” Sierra Club Website. http://www.sierraclub.org/cleanair/clear_skies.asp

policy that addresses the issue of climate change. The Senate must approve any international protocol, but in 1997, the senate unanimously passed the Byrd-Hegel resolution, a symbolic act stating that the Senate would not support any protocol that did not place the responsibility of cutting emissions on developing countries as well as developed ones. This act sent a message to the executive branch of government that said that even if the Kyoto Protocol were signed, it would not be approved and therefore would not be enacted. Since this resolution passed, there has been no movement by the Federal government to address issues of climate change, and the Kyoto Protocol has been ignored.

Carbon Trading vs. Carbon Taxing- What is economically viable and equitable?

Other countries around the world are taking greater action than the U.S. There have been two major strategies in addressing climate change and carbon dioxide emissions: carbon trading and carbon taxing. Carbon trading is the idea of setting a level of carbon dioxide that can be emitted over a certain region. Once that cap is set, it is broken up into shares, and distributed in some way to carbon dioxide emitters. Those who hold shares can buy and sell their shares based upon their levels of carbon dioxide emissions. This creates incentives to emit less because they can economically benefit from cutting emissions. There are many variables in the effectiveness of carbon trading. First of all, limiting emission of carbon could be detrimental to the economy because production of most goods is based on carbon emission. Therefore, it is incredibly difficult to figure out what the caps should be so that they are effective in curbing emissions and create a large enough incentive to do so, but they are also economically feasible for a given environment. In calculating this, we must take into account the costs and benefits both monetarily and socially when looking at the harm that climate change could incur and also

looking at the short-term effects on people in a given region. Firms have the freedom to figure out where and how they are going to cut their emissions, so they can employ cost-effective and convenient methods of doing so. This is different from other policies that force technology based standards; these decrease the ability of companies to figure out what best works for them and where they want their carbon emission cuts to come from. Another variation in the implementation of such a program would be the way that the shares would be distributed. There would be the option of auctioning off shares to the companies that would pay the highest for them. The money from these auctions could be used towards curbing emissions in other ways or put into carbon sequestration methods. However, there are equity concerns with auctioning off shares. The alternative would be to hand out shares to companies based proportionally on the amount of carbon emitted, but this would initially reward companies that emitted large amounts. There could also be a set price of carbon shares that would be distributed proportionally among firms based on product output.

The European Union has enacted the Emission Trading Scheme (EU ETS), which uses a cap and trade system to monitor the emissions of carbon dioxide. This policy is the most comprehensive policy in the world dealing with carbon emissions, and will likely be the model for other nations.⁹ While the EU ETS has put into place the foundation for effective mandates that cover emissions in all of the European Union, there have been problems with the policy. The biggest problem in the first phase of implementation was that the caps were not set at low enough levels. When figuring out a number for the cap, it is inherent that the number be less than what would be emitted if the policy had not been enacted. However, after seeing the results of phase one of this policy, it was clear that there weren't cuts in overall emissions greater than

⁹ The European Emissions Trading Scheme, Review of Environmental Economics and Policy: 2007.

those that would have occurred naturally. Also, instead of auctioning off these credits, the E.U. decided to distribute them among already existing firms. Although these firms did not have to pay for these shares, they imposed the costs of these shares on their consumers and the cost of energy went up dramatically.¹⁰

The alternative to cap and trade, which has been far less prevalent in policies that have come up in the last couple of decades, is the strategy of carbon taxing. For every set share of carbon output, an individual firm must pay a proportional tax. The idea is that carbon taxes internalize externalities and force firms that emit carbon to essentially pay for the future consequences. However, carbon taxing would be a regressive tax meaning that everybody would pay the same for the amount of carbon that they were releasing, clearly favoring the wealthy. The money could go to countless places such as subsidization of energy for poorer areas, or monetary compensations and subsidizing programs for green technologies.

There is economic debate about what kind of regulation would be more equitable. According to Gary Yohe, economist co-author of the Intergovernmental Panel on Climate Change, when looking at economic uncertainties of the future, and predicted levels of climate change, developed countries wouldn't suffer the costs of global warming as much as developing countries. For this reason, it would be more equitable to impose global carbon taxing that would help offset the negative externalities of global climate change caused by carbon emissions.¹¹ There could be a sales tax imposed that would make everybody pay the same amount for a given share of carbon, or the taxes could be progressive and the more carbon shares emitted, the higher

¹⁰ Yohe, Gary. Interview 4/24/08.

¹¹ Yohe, Gary. Carbon Emissions Taxes: Their Comparative Advantage Under Uncertainty. *Annual Rev. Energy Environ.* 1992. 17:301-26.

the tax. The money from these taxes would go to the developing countries suffering from impacts of climate change. With this practice, the economic costs would be born by the emitters of the carbon; most likely firms in developing countries, but the benefits would be reaped by the people suffering from the social costs of global warming; the people in developing countries.¹²

Statewide and regional efforts to address Global Climate Change:

While the Federal government of the United States is clearly not at the forefront of global climate change policy and reduction of carbon, there have been states, regions and individual towns that have paved the way for better regulation of carbon dioxide with countless initiatives, and passage of legislation. On April 18th, 2008, the Governors of New Jersey, Connecticut, California and Kansas, and other representatives from Arizona, Colorado, Delaware, Florida, Illinois, Maryland, Massachusetts, Maine, Michigan, New Mexico, New York, Oregon, Virginia, and Washington signed The Governor's Declaration on Climate Change. This declaration stated that a federal-state partnership is vital in the advancement of climate change legislation, and the states must lead this movement. It stated that with more federal support, the efforts already enacted by the states can be strengthened, more can be developed, and it can pave the way for cost-effective reductions in greenhouse gases. It also pushed for providing states with monetary rewards for climate action, and economic incentives to propel innovation forward.

This symbolic act directly followed the lawsuit against the Environmental Protection Agency by twelve states, the District of Columbia, two cities, and several environmental organizations for failing to regulate car emissions, which they are required to do since the Clean Air Act classified carbon dioxide as a pollutant. Both of these actions put pressure on the federal

¹² Ibid.

government to act now on climate change and show the United States and the world that there is support for curbing greenhouse gas emissions in the U.S., the biggest emitter of greenhouse gases in the world.

There are several regional initiatives encompassing all but 17 states that set goals for greenhouse gas reductions. In August of 2008, the Western Climate Initiative is set to be implemented. This was signed by the governors of Arizona, California, New Mexico, Oregon, Washington, and Utah in a joint effort to reduce greenhouse gas emissions by placing a cap and trade system that covers multiple sectors greenhouse gas emitters. It will aim to go 15% below 2005 levels by 2020, which is 33% below business-as-usual levels.¹³ It specifically covers carbon dioxide, methane, nitrous oxide, hydroflourocarbons, perfluorocarbons, and sulfur hexafluoride.

California has been one of the leading states in climate change policies, specifically confronting carbon emissions. California is most known for Greenhouse Gas Performance Standards for Vehicles. According to law, states can either follow federal emissions standards for vehicles, or follow California standards, which are higher than federal standards¹⁴. As of now there are 11 states in addition to California that have signed on to these emissions standards, and two more who are considering doing so. These actions have shown a clear message that the states are ready for Federal legislation that addresses carbon dioxide emissions from non-point sources. Additionally, in the last year, car companies have tried to sue the states that have adopted these tighter standards saying that they do not have the authority to create these regulations and they must be regulated on a national level, however, the courts have upheld the

¹³ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

¹⁴ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

states rights to regulate such things, putting the support of the U.S. courts behind these new initiatives as well.

California has also led the way with goals for greenhouse gas emissions targets that reach 2000 levels by 2010, 1990 levels by 2020 and are 80% below 1990 levels by 2050.¹⁵ On September 27, 2006, Schwarzenegger signed the Global warming Solutions Act, AB32, which places caps on greenhouse gas emissions. This was the first statewide program with enforceable goals that has an economy-wide emissions cap. To meet these goals, the California Commissions and Advisory Groups were formed in 2004. Their purpose was to figure out economically viable and strategic courses of action that would take into account equity in the implementation of the California emissions targets. California has also signed on to the West Coast Governors Association, an agreement to work together to curb global climate change, as well as the Western Governor's Association: Clean and Diversified Energy Initiative which sets the goal of a 20% improvement in energy efficiency by 2020.¹⁶ This stresses self-regulated incentives for firms to look into the future with new energy alternatives. California has also set efficiency standards on appliances as well as mandating 10% ethanol at all refineries in California by the end of 2009. While California has done a lot on the energy and greenhouse gas emission front, Connecticut is close behind.

Under the Climate Change Action Plan developed by New England Governors and the Eastern Canadian Premiers, Connecticut has pledged to reduce greenhouse gas emissions to 1990 levels by 2010, with an additional 10% reduction by 2020 and 75-85% below 2001 in the long-

¹⁵ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

¹⁶ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

term.¹⁷ The Connecticut Renewable Portfolio Standards also requires by 2020 to have 27% of energy to come from renewable resources such as solar, wind, sustainable biomass, landfill gas, fuel cells, ocean thermal power, and wave or tidal power.¹⁸ Connecticut has also pledged to have state government agencies and public universities have 20% renewable resources by 2010, 50% by 2020, and 100% by 2050.¹⁹ Connecticut has also adopted the California emissions standards.

In December of 2005, governors of Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont signed the first mandatory cap and trade program for carbon dioxide. Massachusetts, Rhode Island and Maryland signed on the following year. It capped emissions from power plants at 2004 levels and pledged to cut 10% by 2019.²⁰ While these goals may not seem very ambitious, this initiative was important in that it was the first mandate that dealt exclusively with carbon dioxide emissions,²¹

Conclusion and Future:

These are important examples of statewide and regional initiatives that have taken place in the United States, and there are countless others. These mandates, and initiatives have sparked some change and progress, but attention must be paid to global climate change and greenhouse gas emissions. It is likely that these state and regional acts will spark national legislation. There have been many other regulation that began at the state level including antitrust legislation, railroads and worker's compensation and it is likely that this could happen with Global Climate Change Policy as well.

¹⁷ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

¹⁸ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

¹⁹ Pew Center for Climate Change. www.pewclimate.org

²⁰ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

²¹ "U.S. States and Regions." Pew Center on Global Climate Change. <http://pewclimate.org/states-regions>

There is also support from business to develop environmental legislation on emissions. Businesses have gone towards a trend of corporate environmentalism because it is popular among consumers. There are also concerns on the part of business about statewide initiatives that are inconsistent with each other and as a result hinder commission. Businesses and environmental organizations have come together to create the U.S. Climate Action Partnership and have submitted a call for action recommending, “the prompt enactment of national legislation in the United States to slow, stop and reverse the growth of greenhouse gas emissions over the shortest period of time reasonable achievable.”²² With so much support among various groups, and the three presidential candidates all with a commitment to curbing greenhouse emissions, there is hope of Federal legislation on the horizon. We need to look into the future and look into world solutions. In order for policies against global climate change to be effective, there must be worldwide efforts and we must work together using creative, and economically viable tools that are feasible, and equitable.

The History of the Kyoto Protocol

At the 1992 Earth Summit in Rio de Janeiro, 186 countries ratified the UNFCCC (United Nations Framework Convention on Climate Change), the first concerted international effort to mitigate the causes of climate change.²³ The UNFCCC’s stated goal was “the stabilization of greenhouse gases in the atmosphere at a level that will prevent dangerous anthropogenic interference with the climate system.”²⁴ Although the UNFCCC set no binding targets for the

²² A Call for Action- U.S. Climate Action Partnership (2007)

²³ Christopher Böhringer and Michael Finus. “The Kyoto Protocol: Success or Failure?” in *Climate Change Policy* (New York: Oxford University Press, 2005), p. 253; Matthew Vespa “Climate Change 2001: Kyoto at Bonn and Marakech” *Ecology L. Q.* .

²⁴ IGBP Terrestrial Carbon Working Group, “The Terrestrial Carbon Cycle: Implications for the Kyoto Protocol,” *Science*, New Series, Vol. 280, No. 5368 (May 29, 1998), pp. 1393-1394.

reduction of greenhouse gas emissions, Article 7 of the treaty laid a basis for future commitments by sanctioning meetings known as Conferences of the Parties (COP) to occur at least once a year. At those meetings, the signatories of the UNFCCC would negotiate concrete targets for mitigating climate change. Furthermore, the UNFCCC mandated carbon inventory reports by the signatory nations, quantifying sinks and sources of carbon.²⁵ Although toothless and perhaps too late, the UNFCCC laid the groundwork for worldwide efforts to mitigate climate change.

In December 1997, the Kyoto Protocols were adopted during the third conference of the parties of the UNFCCC (known as COP 3).²⁶ The Protocols required the 38 industrialized, or Annex B, countries to reduce their greenhouse gas emissions by 5.2% on average below 1990 levels during the commitment period of 2008-2012.²⁷ Although the reduction of emissions by 5.2% was the collective goal, the targets of specific Annex B nations varied: for example, the EU committed to an 8% reduction below 1990 levels, the U.S. was supposed to reduce emissions by 7%, Japan by 6%, while Russia was to stabilize its emissions and Australia was allowed an 8% *increase* above 1990 levels.²⁸ The 38 countries adopting emissions targets under Kyoto together contributed 3.87 GtC to the atmosphere in 1990, while the rest of the world's carbon emissions amounted to 2.22 GtC in that year.²⁹ Even the successful fulfillment of Kyoto targets was known to have little impact on averting the dangerous effects of climate change: according to one

²⁵ Imke Sagemuller, "Forest Sinks under the United Nations Framework Convention on Climate Change and the Kyoto Protocol: Opportunity or Risk for Biodiversity?" *Columbia Journal of Environmental Law* vol. 31 (2006).

²⁶ Böhringer and Finus 253.

²⁷ Böhringer and Finus 266; Sandra Brown et al "Changes in the use and management of forests for abating carbon emissions: issues and challenges under the Kyoto Protocol," *Philosophical Transactions of the Royal Society*, vol. 360 (25 June 2002), 1595.

²⁸ Matthew Vespa, "Climate Change 2001: Kyoto at Bonn and Marrakech," *Ecology Law Quarterly*, vol. 29 (2002).

²⁹ Brown 1595.

estimate, to be on track for staying within the recommended 550ppm atmospheric carbon dioxide concentration, a reduction of 8GtC during the first Kyoto commitment period was necessary, whereas the reductions under Kyoto amounted to only 1 GtC.³⁰ Nonetheless, meeting the Kyoto targets would at least be a step in the right direction.

The protocol contained three “flexible mechanisms” which Annex B parties could employ towards reaching their targets. The first, emissions trading (ET), provided for under Article 17 of the protocol, allowed Annex I parties (i.e., the Annex B parties plus Russia and Turkey) to sell their emissions units to other Annex I parties, and to use emissions units bought in this way towards the fulfillment of their targets.³¹ The second flexible mechanism, Joint Implementation (JI), allowed two or more Annex I countries to collaborate on projects that take place inside one of them.³² Third, the Clean Development Mechanism (CDM) allowed Annex I countries to attain their emissions targets by sponsoring sustainable development projects in non-Annex I countries (i.e., in developing countries).³³

Though negotiated in 1997, the Kyoto Protocol would only enter into force if two conditions were met: first, the national parliaments of 55 parties would have to ratify the treaty, and second, those 55 countries had to include enough Annex I parties to amount to 55% of the total 1990 carbon dioxide emissions of all Annex I countries combined.³⁴ During the next four years, negotiations on the many details still to be hashed out at future COP meetings would be influenced by the need to ensure that enough Annex I countries would ratify the treaty in order for it to come into effect.

³⁰ Ibid.

³¹ Sagemuller.

³² Sagemuller.

³³ Sagemuller.

³⁴ Böhriger and Finus 266.

At COP meetings subsequent to the drafting of the Kyoto Protocol in 1997, two sides emerged: the EU and the Umbrella Group of Japan, Russia, Canada, Norway, Australia, New Zealand, and Iceland, and the U.S.³⁵ The EU countries emphasized the need to reduce greenhouse gas emissions at their sources in industrialized countries, and hence opposed the use by Annex I countries of flexible mechanisms such as CDM to reach their own abatement targets by setting up carbon sinks in the developing world rather than by cutting their own domestic carbon emissions.³⁶ The Umbrella Group, on the other hand, urged for market mechanisms to play a larger role in the protocol so that countries could address climate change by whatever means proved most cost effective.³⁷ The Bush administration's announcement in March 2001 that the U.S. would not ratify the Kyoto Protocol had a decisive impact on the disagreement between the EU and the Umbrella nations. After the U.S.'s rejection of the Kyoto Protocol, ratification of it would no longer have been possible under the 55% rule described above unless Japan and Russia could be convinced to join; thus the bargaining power of those nations increased dramatically.³⁸

In the July 2001 COP meeting in Bonn, 178 countries agreed to terms for the ratification of the Kyoto Protocol, despite the U.S.'s absence.³⁹ Several points of contention between the EU and the Umbrella Group were settled at Bonn in a manner which reflected the Umbrella Group's increased bargaining power after the U.S.'s withdrawal. Many of those points of contention, moreover, concerned in what way and to what extent terrestrial sequestration should be allowed to fulfill the targets set by Kyoto. The issue of supplementarity, defined by Matthew Vespa as

³⁵ Vespa.

³⁶ Ibid.

³⁷ Ibid.

³⁸ Ibid.

³⁹ Ibid.

“the extent to which Emission Trading, JI [Joint Implementation], and the CDM [Clean Development Mechanism] may be used in addition to domestic GHG reduction programs to reach emissions targets.”⁴⁰ According to the outcome of the COP in Bonn, domestic action was to be a “significant element” of the Annex I countries’ emissions reductions, but since the word “significant” was not quantified, Annex I countries were given a free hand to use flexible mechanisms to whatever extent they wanted to or could in fulfilling their emissions reduction targets.⁴¹

Another point of contention at the Bonn meeting relating to terrestrial sequestration was the role of LULUCF (land use, land use change, and forestry) sinks, a topic that had caused the collapse of the November 2000 meeting of the COP in The Hague.⁴² Under Kyoto, Annex I countries were allowed to meet their targets in part by counting carbon removed from the atmosphere by human-caused land-use change and forestry techniques.⁴³ At the Bonn meeting, two questions regarding the role of LULUCF projects were resolved. The first concerned whether such projects could be implemented domestically and counted towards an Annex I countries reduction targets. The Umbrella Group had lobbied for cropland management and forest management to be included along with afforestation, reforestation, and deforestation as techniques of terrestrial carbon sequestration that could be counted under LULUCF. Canada, Australia, Japan, and Russia insisted on the addition of cropland and forest management, and they got their way at Bonn since the ratification of the treaty would have become impossible

⁴⁰ Ibid.

⁴¹ Ibid.

⁴² Vespa.

⁴³ Sagemuller.

without their support.⁴⁴ Why these nations wished to expand the scope of LULUCF programs is easy to understand, since these offered a much cheaper way to cut carbon emissions under Kyoto than increasing energy efficiency or switching to alternative fuels. According to Vespa, one study showed that through improved forest management alone, Canada could sequester 19.3-161.8 million tons of carbon per year, or 220%-1700% of its target carbon reduction.⁴⁵ However, at Bonn a nation-by-nation cap was set on the amount of credit towards national carbon reductions targets which could be obtained through forest management: for example, Japan's cap was set at 13 million tons of carbon per year, or 3.8% of its 6% reduction in carbon emissions below 1990 levels. Russia received the largest such cap of 17.63 million tons of carbon per year, this despite the fact that by the time the first commitment period would begin in 2008, its GHG emissions would likely be well below 1990 levels due to the collapse of its economy during the 1990s.⁴⁶

The second question settled at the 2001 meeting in Bonn concerning the role of LULUCF projects was whether such projects implemented in developing countries as a part of CDM programs could be counted towards meeting an Annex I country's reduction targets. Terrestrial carbon sequestration in developing countries was attractive to Annex I countries as a way of fulfilling their Kyoto targets that was much cheaper than implementing land use or forestry changes in Annex I countries.⁴⁷ According to Vespa, "the IPCC estimates that carbon sequestration costs in several tropical countries range from US \$.1 to US\$20 per ton carbon

⁴⁴ Vespa.

⁴⁵ Ibid.

⁴⁶ Ibid.

⁴⁷ Ibid.

compared to US \$20 to \$100 in subtropical countries.”⁴⁸ At Bonn, the role of LULUCF through CDM was limited to afforestation and reforestation during the first commitment period, and could be used only for up to 1% of the Annex I country’s baseline carbon emissions.⁴⁹

At the next COP meeting in Marrakech in November 2001, the parties agreed on final details to allow the protocol to go into effect. At this meeting, additional concessions to the Umbrella Group countries resulted in expanding the role that terrestrial carbon sequestration would play in the implementation of the treaty. Russia insisted on raising its limit on the amount of carbon sequestered in LULUCF projects that could be counted towards its emission targets to 33 million tons of carbon per year, giving it an even bigger surplus.⁵⁰ Several additional kinds of LULUCF activities would be countable towards emission targets: forest management, cropland management, grazing land management, and revegetation.

By 2001 it had become clear that terrestrial sequestration would be a major component of whatever activity the Annex I countries undertook in order to meet their targets under Kyoto. On the one hand, terrestrial carbon sequestration offered great potential for mitigating climate change: terrestrial ecosystems sequester approximately 3 Gt of carbon per year, or half the amount emitted annually by the industrial use of fossil fuels.⁵¹ Moreover, 1.6 Gt of carbon dioxide get released into the atmosphere per year from the destruction of tropical forests.⁵² Improved forest management techniques seem to offer a cheap way to withdraw carbon from the atmosphere without making fundamental changes to the fossil fuel economy.

⁴⁸ Ibid.

⁴⁹ Ibid.

⁵⁰ Ibid.

⁵¹ Sagemuller

⁵² Ibid. (Check this. What year?)

Despite its promise, the rules for terrestrial carbon sequestration as set out by the terms set for the ratification of Kyoto in 2001 create several problems. LULUCF projects are prone to inflated accounting due to their impermanence and to the problem of leakage, where the creation of one forest sink leads to deforestation elsewhere;⁵³ moreover, since Annex I countries do not have to count deforestation due to “natural” causes *against* their Kyoto targets, they could potentially through LULUCF projects get credit for removing carbon from the atmosphere even when net biomass change has been negative.⁵⁴ LULUCF projects set up by Annex I parties in developing countries (under the CDM flexible mechanism) could also cause social disruption and put biodiversity at risk. As the World Rainforest Movement stated in a press bulletin after the Bonn meeting, these projects might turn developing countries into “northern carbon garbage dumps.”⁵⁵ The provision for forest sinks creates an incentive for countries to destroy old-growth natural forests in order to replace them with faster-growing monoculture tree plantations, with grim consequences for the conservation of biodiversity.⁵⁶ As Vespa argues, “Exotic monoculture tree plantations, while more efficient in terms of carbon sequestration, threaten local biodiversity, impoverish soil, and may affect the ability of Indigenous People and other local communities to live off their land, as land traditionally used for subsistence purposes is converted to large scale tree plantations without input by local communities.”⁵⁷

More fundamentally, the very aspect of terrestrial sequestration that makes it so attractive, namely its low cost compared to other mitigation methods, tends to undermine any

⁵³ Sagemuller

⁵⁴ Sagemuller

⁵⁵ Ibid.

⁵⁶ Ibid.

⁵⁷ Ibid.

incentive for Annex I nations to reduce fossil fuel emissions.⁵⁸ If it is doubtful that meaningful mitigation of climate change can be affected without reducing the use of fossil fuel, then the role of terrestrial sequestration in the Kyoto protocol may be to postpone the day when industrialized nations will take the steps that are actually necessary to address climate change. As David King remarks, “of the options for reducing emissions, [carbon] capture and storage is the only one that would allow us to continue to burn fossil fuels far into the future,” thus making it a “fig leaf for avoiding the issue of how to replace the carbon economy.”⁵⁹ Per capita carbon emissions in 1987 were .3 tons for Zaire, 2.12 tons for Japan, and 5.03 tons for the United States.⁶⁰ Terrestrial sequestration, if it creates forest sinks in developing countries rather than reducing carbon emissions in developed countries, may be an approach to mitigating global warming without addressing or rectifying fundamental inequalities in who causes the problem.

Kyoto Protocol Failures and Possibilities

The Bush administration’s announcement in 2001 that the United States would withdraw from Kyoto Protocol negotiations dimmed the future of the international agreement, set to be implemented in 2005. Though the decision represented the reluctance of the American government to commit to greenhouse gas reducing strategies, it also pointed to the flawed nature of the agreement. The high cost of implementing the Kyoto Protocol was the main deterrence for the U.S., but further scrutinizing of the agreement proves it has many unresolved aspects and even fundamental defects. The European Union Emissions Trading Scheme, a microcosm of the Protocol, underscores the relatively inefficient nature of the agreement, particularly its

⁵⁸ Sagemuller.

⁵⁹ David King, “Science Informing Policy on Climate Change,” in *Climate-change Policy* (New York: Oxford University Press, 2005), p. 40

⁶⁰ Vespa.

susceptibility to corruption and manipulation of terms. Ultimately, international climate policy has had sluggish effects, failing to halt the world's increasing rate of greenhouse gas emissions. Nonetheless, the climate policy movement seems to be heading toward correcting Kyoto's faults while introducing new, and perhaps more internationally agreeable, strategies.

The United States exited the agreement because of the tremendous costs associated with implementation in contrast to the limited projected benefits. Calculations estimate the Kyoto Protocol's costs to range anywhere between \$800 billion and \$2.5 trillion, while the benefits are supposedly worth \$120 billion,⁶¹ with the economic burden expected to fall on nations most responsible for greenhouse gas emission, particularly the United States, producer of the greatest proportion of global emissions. The Protocol's international flexibility mechanisms, designed to relieve the responsibility of meeting designated emissions targets for those countries with high abatement costs, are expected to cause a great transfer of wealth among nations. Economists Warwick McKibbin and Peter Wilcoxon roughly estimate that if the United States ratified the Protocol it would have to import permits equal to about 268 million tons of Carbon from lesser producing nations in 2010. With the price of permits estimated to range between \$100 and \$200 per ton, such transactions would add anywhere between \$27 billion to \$54 billion to the U.S. trade deficit every year.⁶² To put to scale, the February 2008 trade deficit was \$62.3 billion.⁶³ Clearly, permit trading would reconfigure the world trading system and the balance of power among the participants. Thus, as the United States government expected the costs to overshadow the gains, not estimated to be realized until decades into the future and to be of little monetary

⁶¹ As cited in: Warwick J. McKibbin and Peter J. Wilcoxon Climate Change Policy after Kyoto (Washington D.C.: Brookings Institution Press, 2002)52-3.

⁶² McKibbin 52-3.

⁶³ US Census Bureau <http://www.census.gov/indicator/www/ustrade.html>

value, it has declared it will not support any quantitative commitments in international agreements.⁶⁴

While it is true that the Kyoto Protocol in full effect would only reduce the rate of global warming, not prevent it, and that more drastic international policy is necessary to substantially affect climate change, the U.S.'s quantifying of benefits in terms of monetary value is somewhat problematic. Preventing further global warming would surely limit suffering and death in the world's population, something that should not be assigned monetary value in the capitalist system. Furthermore, by arguing in 2001 that taking action to prevent such an ominous future is economically infeasible, and then launching a war in Iraq in 2003, costing already \$526 billion and estimated to reach trillions,⁶⁵ the U.S. government poses questionable priorities. However, one should not let the U.S.'s condemnable withdrawal from negotiations prevent serious criticism and reevaluation of the Protocol.

The United States government also cited the adverse effects of leaving unrestricted the emissions of developing countries in its decision to withdraw from negotiations. Developing countries, historically of little significance in anthropogenic emissions, face greater uncertainty about the future and have less access to funds to support greener technologies.⁶⁶ For the U.S., the leniency towards these countries translates into restricted benefits in term of greenhouse gas reductions, amidst the high economic costs. What the U.S. government has failed to consider is that the cost of cutting emissions in developing countries would likely be the failure of their economies and widespread poverty, while in the U.S. the costs would be significant, but nowhere

⁶⁴ Joyeeta Gupta and Alison Lobsinger "Climate Negotiations from Rio to Marrakech: An Assessment" in *Climate Change Five Years after Kyoto* (Enfield: Science Publishers, 2004) 77.

⁶⁵ "Iraq Casualties, Iraq Costs, Iraq Numbers" March, 2008. http://www.huffingtonpost.com/2008/03/19/iraq-casualties-iraq-cos_n_92303.html

⁶⁶ Mckibbin 57.

near as extreme. It is true, nonetheless, that developing countries account for 30 percent of global carbon dioxide emissions, and this number is expected to rise with economic development.⁶⁷ To have any significant impact on climate change, international policy must eventually limit the emissions of developing countries. Yet this must be done with precaution, so as to protect the fragile economies of developing countries. Discussions of how this can happen are limited, and to date most considerations of the role of developing countries have only been in relation to CDMs, which are meant to offset developed countries' emissions. Nonetheless, prospects for the future Kyoto agreement after its expiration in 2012 point to greater funding for clean technology in developing countries. Jose Manuel Barroso, president of the European commission, released a statement in April 2008 declaring that a transfer of such technology to developing countries would be necessary for China, a developing country with rapidly increasing emissions, to accept the Protocol.⁶⁸ The leaders of 2007 G8 summit expressed similar interests in devoting revenue from emissions trading to promote climate protection projects in developing countries. Ideally, future negotiations will take greater steps in this direction. It seems also that as developed countries implement abatement policies, the price of their exports will increase, giving developing countries exporting similar goods a competitive advantage; increased export revenue can then be directed toward cleaner technology.

The U.S. withdrawal from the Protocol resulted in greater hesitation among other countries to ratify the agreement. Without the compliance of the entire global community, the Protocol is potentially economically dangerous. Because reducing greenhouse gas emissions would increase the price of commodity exports, the U.S. would have a competitive advantage in

⁶⁷ Richard B. Stewart and Jonathan B. Wiener Reconstructing Climate Policy: Beyond Kyoto (Washington D.C.: AEI Press, 2003)38.

⁶⁸ Point carbon (2007): "Carbon 2007- A new climate for carbon trading" Roine, K and H Hasselknippe

the global markets.⁶⁹ Furthermore, the U.S. withdrawal highlights the prevalence of the “tragedy of the commons” in global climate change. The issue of climate change is fundamentally global—it affects everyone, though not always proportionally, while its reversal benefits everyone; thus it is essential that every country participate in action against it. One country’s inactions, particularly the U.S. as the largest producer of emissions, can negatively affect international agreements, and thus the entire world population.

International policy is a necessity, but it must take care to resolve the flaws in the Kyoto Protocol in order to effectively limit climate change. Though the motivations behind the U.S. withdrawal were questionable, it does point to the limitation of the agreement in incurring beneficial changes in the global environment. A major unresolved aspect of the Protocol is enforcement mechanisms; until this issue is resolved, emissions will be likely to continue rising. Currently, governments do not have incentive to regulate the Protocol’s enforcement, as monitoring and punishment are expensive.⁷⁰ The emission trading market is particularly susceptible to cheating, which will distort the market severely. Ideally, all permits should be of equal value, as a ton of carbon abated is a ton of carbon abated, no matter where from. But if an industry sells permits without enacting the equivalent reduction in carbon, and it is revealed in the international markets that these permits are invalid, then all other permits from the country apparently unregulated by its government will become associated with risk and lose their value. As a result, the amount of abatement in a country will be determined by its permit price and the global demand for their permits, rather than the actual cost of abatement, and many industries

⁶⁹ Gupta 77.

⁷⁰ McKibbin 55.

will lose their incentive to abate emissions.⁷¹ Insufficient enforcement mechanisms also permit “leakage,” the transferring of emitting industries in capped countries to countries that are not required to regulate emissions. Under the Kyoto Protocol, emissions of developing countries will rise at a faster rate than previously anticipated, while emission limitations in industrialized countries will be offset between 5 and 30 percent.⁷²

“Hot air” is another significant impediment to greenhouse gas reduction under the Kyoto Protocol. The term refers to the surplus of emission allowances given mainly to Russia and the Ukraine, who substantially, though unintentionally, reduced carbon emissions with the economic collapse following the fall of the Soviet Union. Hot air dilutes the emissions trading markets, thus allowing Annex I emissions to be higher than would otherwise be permitted.⁷³ The withdrawal of the U.S. from Kyoto significantly expanded the proportion of hot air in the market. If allowed to be traded freely, hot air will become a low-cost mitigation option, while other more effective mechanisms of reduction, such as JI, will be rarely employed. Simply removing hot air is opposed by influential Annex I permit-purchasers because reducing the supply will increase the price. It has been suggested that hot air be temporarily excluded from trading and banked for future trading, thus maintaining the price associated with the supply, but while preventing its usage. However, such a strategy would not affect the level of greenhouse gases in the long run.⁷⁴ Another, perhaps more viable option, is to require the trading of hot air be in conjunction with usage of the CDM sinks. This will be relatively efficient because it does not require a vast

⁷¹ *Ibid.*

⁷² Stewart 39.

⁷³ Michael Faure, Joyeeta Gupta, and Andries Nentjes Climate Change and the Kyoto Protocol: The Role of Institutions and Instruments to Control Climate Change (Cheltenham: Edward Elgar, 2003)33.

⁷⁴ Faure 33.

reconfiguration of the Protocol to fix the hot air problem, and it will offset the replacement of flexibility mechanisms with cheap hot air.⁷⁵

The possibility of including developing countries in the emissions trading market may further disrupt the market and possibly damage developing countries' economies. Similar to hot air, "cool air" is the potential excess supply of credits from developing countries that fall below some determined emissions level, a level likely to be high to allow for continued development. Cold air may not correspond to any actual reduction, but may be sold to developed nations to meet their emission reduction requirements. Furthermore, emissions trading may harm developing countries' export industries. With the availability of credits, permit trading could become the primary export, appreciating exchange rates but causing a decline in other, less profitable, exports.⁷⁶ It is required that permit revenue be devoted to developing clean technology, which would free up more credits, but do little to promote more heterogeneous and stable economic growth.

Though the future of the Protocol is largely unresolved, the state of the Protocol today requires immediate attention. The European Union Emissions Trading Scheme (EU ETS), currently the largest carbon trade in the world and a template of the Protocol, is optimistically called "the learning phase" because of its inability since its onset in 2005 to affect rising greenhouse gas emissions from Europe. The basic problem has been the abundance of credits, allocated by governments unwilling to disadvantage profitable emitting industries.⁷⁷ The setting of emissions targets occurred at a time when 21 of the 25 participants had produced 2.5% less

⁷⁵ *Ibid.*

⁷⁶ McKibbin 58.

⁷⁷ Stephen Mulvey "EU Leads 'Carbon Revolution'" February 2005
<http://news.bbc.co.uk/2/hi/europe/4269021.stm>

carbon dioxide than expected, disguising the excessiveness of allowance levels.⁷⁸ The United Kingdom's proposed allotment of credits, for example, will allow for a 3% increase in emissions.⁷⁹ If such a trend continues among the EU ETS participants, the price of credits could theoretically reach zero. There has also been speculation that hot air will enter the EU ETS, potentially contributing to the devaluing credits.⁸⁰ Though the EU ETS has not reduced greenhouse gas emissions, it is currently a very profitable business. UK power companies, some of the worst polluters, were given one billion pounds in excess credits by the government, and then proceeded to raise prices and pass off the credits as a cost.⁸¹ The EU ETS presents the pressing issue of how allocation of credits should be determined, and raises the question whether governments will ever be willing to act in opposition the nation's most economically and politically powerful businesses.

Many economists, scientists and politicians have discussed in detail the various problems associated with the Kyoto Protocol and international policy to date. Unfortunately, it has been difficult to conceive of more viable options. Economists Warwick McKibbin and Peter Wilcoxon, reacting to the U.S. withdrawal from the Protocol, have notably proposed a more cost-efficient international policy, which they claim will be practical and appealing. Drawing on the chief debate between emissions trading and emissions taxing as the fix to climate change, McKibbin and Wilcoxon suggest a hybrid policy that incorporates both schemes, allowing for maximum flexibility. They argue that because of the uncertain nature of climate change, as well

⁷⁸ Clare Davidson "Carbon Trading's Real Colours" May 2006 <http://news.bbc.co.uk/2/hi/business/4985332.stm>

⁷⁹ Stephen Mulvey "EU Leads 'Carbon Revolution'" February 2005
<http://news.bbc.co.uk/2/hi/europe/4269021.stm>

⁸⁰ Jason Anderson and Rob Bradley "Joint Implementation and Emissions Trading in Central and Eastern Europe" in *Climate Change and Carbon Markets* (London: Earthscan, 2005) 224.

⁸¹ Clare Davidson "Carbon Trading's Real Colours" May 2006 <http://news.bbc.co.uk/2/hi/business/4985332.stm>

as the volatile economic parameters determining abatement costs, an effective international policy must incorporate uncertainty into its design. The policy would essentially employ the tax when it is most effective, at rising marginal costs of abatement, in which emissions will not be cut voluntarily, while maintaining a permit system targeting lower marginal costs.⁸² This flexibility would minimize the costs of reducing emissions, contrasting Kyoto, which employs one method at any cost. Furthermore, under this policy governments would sell permits, rather than distribute them, increasing government incentive to monitor the markets and to punish cheating. Ultimately, McKibbin and Wilcoxon put forth a policy that corrects some of the problems of Kyoto, namely cost and enforcement, but does not address many other pressing issues, particularly those pertaining to developing countries.

The Kyoto Protocol and the hybrid policy both aim to reduce greenhouse gas emissions in the context of global capitalism. While emissions trading and emissions taxing may potentially reduce the rate of climate change, they maintain a profit-based outlook on international climate policy, and thus will not be able to affect greenhouse gas emissions at the level needed to substantially limit global warming. Several representatives from the Center for Energy and Environmental Policy at the University of Delaware argue that a commons-based regime with commitments to sustainability and equity, rather than efficiency and profitability, must become the paramount international policy.⁸³ Sustainability implies a world reduction of at least 60% of 1990 carbon dioxide emission, as recommended by the IPCC to achieve long term

⁸²Warwick J. McKibbin and Peter J. Wilcoxon "The Role of Economics in Climate Change Policy" *Journal of Economic Perspectives* Vol. 16.2 (2002)177.

⁸³ John Byrne et al. "Reclaiming the Atmospheric Commons: Beyond Kyoto" in *Climate Change Five Years After Kyoto* (Enfield: Science Publishers, 2004) 446.

stabilization of atmospheric greenhouse gas concentrations.⁸⁴ Equity refers to meeting this target by distributing the burden of emissions reduction in proportion to individual nations' per capita wealth, allowing flexibility for developing countries.⁸⁵ One could argue that this proposal is infeasible because it is not economically credible, but would then be implying that business as usual, or close to business as usual superficial policies, is an acceptable choice in the face of potential climate disaster.⁸⁶ This so-called "Beyond Kyoto," sustainable and equitable approach, though expensive, would straight-forwardly reduce emissions to safer levels without the untenable use of sinks and permits.

While the world has come to the consensus that climate change must be addressed, the best method to do so is hotly debated. Though sustainability and equity may be the priorities of environmentalists, the reality is that most nations are searching for cost-efficient, even profitable, global market solutions. The Kyoto Protocol proved an agreeable option for the international community, with the obvious exception of the United States. Though the EU ETS example of the Protocol has been profitable for industries (but utterly inefficient in cutting greenhouse gases), the Protocol is generally considered within the U.S. to be economically infeasible. Thus alternative hybrid policies, efficiently combining emissions trading and taxing, may be a more viable option for future international negotiations that aim to include the United States. Hybrid or not, any future agreement must address all the flaws of the Protocol, with particular attention to the issues surrounding the developing world, facing the largest uncertainty with the furthering of climate change.

⁸⁴ *ibid*

⁸⁵ *ibid.*

⁸⁶ *ibid.*

Economic incentives to deter climate change are expected to increase in the years to come; the 2006 Stern Review on the Economics of Climate change suggests that increasing percentages of global GDP will be directed towards the adverse effects of climate change, and the costs will inevitably cause economic disaster. How international negotiations will react to this foreseeable future is unclear, but perhaps rather than capitalizing on the atmosphere with limited impact on emissions, nations will understand the atmosphere as commons-based, and thus reduce emissions to safe levels to the benefit of the global community.

The Challenges of Coal-based Carbon Dioxide Emissions

The current reality of curtailing or controlling carbon dioxide emissions into the earth's atmosphere must include methods to mitigate the emissions of coal-fired plants. Although the United States has been moving away from building new coal plants⁸⁷, nations in the developing world, specifically China and India, exploit coal because it is the cheapest and most abundant source of power. The Pew Center on Global Climate Change predicts, "86 percent of the incremental world coal demand between now and 2030 will come from China and India". The precedent of heavy coal use was set by the United States and other developed nations. In 2000 the United States still derived 43 percent of its electricity from coal-fired plants⁸⁸. The US reliance on coal persists even though only 12 new coal-fired plants have been built since 1990 in the U.S⁸⁹. By comparison, China outshines the United States coal use. The Chinese depend on coal for 76 percent of their electricity and burned more coal in 2006 "than the United States,

⁸⁷ Brown, Lester R. 2008.

⁸⁸ EIA, 2000.

⁸⁹ Pew Center on Global Climate Change. 2007.

Japan, and the United Kingdom combined”⁹⁰. As use of coal continues to spread in China other developing nations may follow suit. The construction of technologically outdated coal-fired power plants means a dramatic increase in the burning of the “dirtiest” fossil fuel, without any remediation of the carbon dioxide in exhaust emissions. Coal’s dirtiness is evident from the fact that “its use accounts for a quarter of world energy consumption, [but] it generates 39 percent of energy-related carbon dioxide emissions”⁹¹. The potential for expansion of coal-burning plants in the United States still exists, as seen by the 151 coal burning power plants in the planning stages in the beginning of 2007⁹².

Even with the increasing international focus on the effect that burning fossil fuels has on the concentration of carbon dioxide in the air; the use of coal for energy is still expanding because it is cheap and abundant. For example, China holds 13 percent of the worlds coal and could “sustain its economic growth for a century or more”⁹³ just using coal alone. In order to mitigate the effects of the increase in burning coal on the atmosphere, new technologies are being developed and tested to capture and sequester the carbon dioxide created from the combustion of coal so it does not enter the atmosphere, thereby releasing carbon from the long carbon cycle into the short carbon cycle and contributing to changes in the radiative equilibrium established by the greenhouse effect.

Currently, there are two styles of carbon capture being explored for use in pulverized coal (PC) power plants, post-combustion capture and pre-combustion capture. In the post-combustion process the method used for carbon capture utilizes aqueous amines as “scrubbers” of the carbon

⁹⁰ Economy, Elizabeth.

⁹¹ Mufson, Steve, Harden, Blaine. 2008

⁹² Brown, Lester R. 2008.

⁹³ Fairley, Peter. 2007.

dioxide in the exhaust flue gas. In pre-combustion capture, which captures the carbon dioxide before it enters an exhaust stream, two different processes are being explored, Integrated Gasification Combined Cycle (IGCC) or Oxyfuel Combustion. An analysis of the details of each technology can help increase understanding about which method should be pursued for larger application.

The basic process performed by the post-combustion monoethanolamine (MEA) capture is the absorption of carbon dioxide through a chemical reaction between MEA, the solvent, and the carbon dioxide in the flue gas, which is diluted to only 3-15 percent of the flue gas⁹⁴. The MEA solvent can be separated from the carbon dioxide through application of heat to the compound formed from the reaction. After separation, the carbon dioxide is cooled and leaves as a concentrated product that can be transported and sequestered. The MEA solvent is mostly conserved and sent back through a cooler to be reused in the initial absorption process. The MEA scrubbing process removes carbon dioxide from the exhaust at up to 90 percent efficiency⁹⁵.

The benefits of the amine scrubbing process are that the technology has been around for thirty years and is readily available. The nature of amine based post-combustion capture, that it is effective for dilute carbon dioxide exhaust streams and can be operated at pre-existing plant levels of temperature and pressure, also means that it is possible to retrofit existing coal plants for the amine process⁹⁶. The efficiency of the amine reaction with carbon dioxide has not yet been improved with the use of different solvents, although there is still ongoing research in

⁹⁴ Wilson, Elizabeth J., Gerard, David. 2007.

⁹⁵ Strakey, Joseph P. 2007.

⁹⁶ Wilson, Elizabeth J., Gerard, David. 2007.

improving the properties of the solvent to increase efficiency. There is also a potential for an increase in efficiency from research to better understand the kinetics of the chemical reaction.

Negative aspects of MEA capture compared to regular pulverized coal plants are that the heat energy needed for separating carbon dioxide and regenerating the MEA solvent and the electricity needed to compress the pure carbon dioxide captured after the regeneration process, in order for it to be transported for sequestration, can require 20-25% of the total Megawatt capacity of the plant which can make cost a prohibiting factor⁹⁷. The problems inherent to the amine scrubbing process are evident from the pilot project at Shady Point, Oklahoma. The biggest issues with the Shady Point plant are the regeneration power, the compression ratio, and the cost of the MEA solvent⁹⁸.

The first of two existing pre-combustion carbon capture technologies is the process of capturing carbon dioxide from coal combustion using Integrated Gasification Combined Cycle (IGCC). The IGCC process differs from regular PC plants in that it starts with the gasification of coal into a syngas rather than normal combustion. After gasification, the products are carbon monoxide (CO), carbon dioxide (CO₂), hydrogen (H₂), Hydrogen sulfide (H₂S), and methane (CH₄). The stream of syngas next goes through two units one to remove particulate matter and another to convert the CO product to CO₂ by use of a catalyst. After preparation, the syngas moves on to the Selexol unit, which removes H₂S and CO₂ from the gas, and then onto the Claus unit that strips the elemental sulfur from the H₂S and also removes the remaining CO₂ by using Selexnol solvent. The energy for the production of power comes from the use of the separated

⁹⁷ Wilson, Elizabeth J., Gerard, David. (20). 2007.

⁹⁸ Bozzuto, Carl. 2007.

hydrogen gas flowing through gas turbines and steam from recovered heat to produce electricity⁹⁹.

The benefits of IGCC are that the energy requirements for the capture process are lower than post-combustion scrubbing. This is because the flue gas already contains high levels of CO₂ and is highly pressurized and, therefore, can be physically, as opposed to chemically in MEA absorption, stripped of its pollutants so it does not have to be re-pressurized for storage. The removal of sulfur from the flue gas also helps reduce the potential of the creation of acid rain from power plant emissions without the needed addition of exhaust scrubbers, which are currently utilized in many plants.

The major problems with fast implementation of IGCC technology are that the initial capital investment needed to start a combined cycle plant is significantly higher than a non-capture PC power plant. Besides the initial building costs, a carbon capture IGCC plant costs 2,500 dollars/Kilowatt-hour as opposed to a non-capture PC plant which costs 1,600 \$/kWh to operate¹⁰⁰. Also, the problems of the complexity of the gasification process, which needs to be fine-tuned for each type of coal, requires new experts at the power plants. The ability to retrofit an existing combined cycle plant that is not capable of capturing carbon dioxide is also not very feasible for IGCC. Currently there are fewer than thirty IGCC plants in the world¹⁰¹. However both the total plant cost per Kilowatt hour and the cost of electricity produced by an IGCC carbon capture plant are lower than both Amine scrubbing of PC plants or oxyfuel capture. With carbon capture, IGCC's operating cost is 2,500 \$/kWh, while both MEA scrubbing and oxyfuel

⁹⁹ Wilson, Elizabeth J., Gerard, David. (22). 2007.

¹⁰⁰ Strakey, Joseph P. 2007.

¹⁰¹ Haupt, Zimmerman 2007.

combustion cost 2,900 \$/kWh and IGCC's cost of electricity to the consumer is 10.6 cents/kWh, while MEA scrubbing is 11.4 cents/kWh and oxyfuel combustion is 11.3 cents/kWh¹⁰². These figures clearly show that IGCC is currently the most cost efficient form of capture, assuming that initial building costs can be eased through government subsidies or other investment.

The technology required for large-scale use of oxyfuel combustion, the second technology available for pre-combustion capture, in coal-fired power plants is still in the early stages of growth and development. The general principle behind the process is that using pure oxygen, through air separation, for the combustion of coal would lead to an extremely high concentration of CO₂ in the gas created from combustion. The possibility of zero carbon emissions exists using this technology because the high concentration of CO₂ in the flue gas and low levels of other impurities in the flue gas. This combined with electrical generation through use of the steam cycle process, allow for sequestration of all the exhaust gas¹⁰³. Oxyfuel combustion also has been shown to cost less than MEA capture, mostly because of reduction in flue gas volume through burning of only oxygen in combustion. Burning only oxygen leaves out nitrogen, the largest component of air on earth, which does not combust in the boiler reaction. Although research continues on the prospects of oxyfuel capture, it is still in the early stages of development and will not become a feasible technological implementation for carbon dioxide mitigation for a number of years¹⁰⁴.

Further comparison of the three main carbon capture technologies requires analysis into several economic factors. The reduction in the efficiency of transferring heat from combustion

¹⁰² Strakey, Joseph P. 2007.

¹⁰³ Wilson, Elizabeth J., Gerard, David. (25). 2007

¹⁰⁴ Wilson, Elizabeth J., Gerard, David. (30). 2007.

into electrical power is a main concern for Amine Scrubbing and IGCC technologies. The “energy penalty” or reduction of HHV, or higher heat value efficiency, through use of amine capture is a 20 % to 25 % reduction¹⁰⁵ and a 6% to 9% reduction¹⁰⁶ in IGCC capture. The reduction of efficiency from carbon capture means increases the cost of operating the power plants, which in turn leads to increases in the price of electricity for consumers generated from that power plant. For example, a study on the economic results of carbon capture in IGCC plants showed that the total plant cost, or how much money is needed per kilowatt of electricity, increased by 500 to 600 dollars¹⁰⁷. This increased operating cost led to increases in the cost of electricity by around 30 percent, or a 1.5 to 2.2 cent increase per kilowatt-hour¹⁰⁸. However, the increases in cost from carbon capture with IGCC technology represents the cheapest form of carbon capture of the three listed options. The increase in electricity prices would also cover costs for transport, storage, and monitoring of the sequestered carbon dioxide, Strakey calculated. Another benefit of IGCC over the post-combustion amine scrubbing is that the raw water usage by the power plant increases much less. The estimated increases for IGCC are an extra 2 gallons per minute/Megawatt, versus 12 gpm/MW for MEA scrubbing¹⁰⁹. Raw water, taken from lakes, reservoirs, and aquifers, is used to cool the plant. Since the MEA solvent must be heated and cooled multiple times to capture carbon dioxide and regenerate itself the need for water increases with MEA scrubbing. The current combination of water shortage and rapid construction of coal burning power plants in China makes this aspect of IGCC technology another reason for favoring IGCC technology in newly built plants.

¹⁰⁵ Wilson, Elizabeth J., Gerard, David. (20). 2007.

¹⁰⁶ Ciferno, Jared P. 2007

¹⁰⁷ Ciferno, Jared P. 2007.

¹⁰⁸ Ciferno, Jared P. 2007.

¹⁰⁹ Strakey, Joseph P. 2007.

The decision about which carbon dioxide capture technology should be implemented will most likely vary by country depending on their current coal-burning situation. For example, the United States, which has not been building many new coal-fired power plants, could opt to retrofit their existing plants with MEA post-combustion capture while investing in renewable energy for the future instead of pursuing IGCC technology. The Chinese, conversely, have been adding coal burning power plants at a very high rate. In 2006 they added enough coal plants to generate 90 gigawatts, or more than “the entire fleet of generating plants in the United Kingdom”¹¹⁰. Ideally, the Chinese would turn to experimenting and implement on a large scale the use of carbon capture IGCC plants to counteract their tremendous carbon dioxide emissions. Using IGCC with capture would raise the cost of electricity by the smallest percent of any capture technology, increasing cost by only 35 percent as opposed to 73 percent with MEA capture¹¹¹. However, it is unlikely that China will begin to build IGCC plants soon because they still represent a much higher building cost, approximately 20-47 percent more expensive¹¹², than normal PC power plants. Currently this means that there must be “large subsidies from the federal, state, and local governments”¹¹³ for an IGCC plant to be built. Although the technology for IGCC exists today, implementation of the more expensive technology depends highly on government backing. It requires top down measures, such as carbon taxes or carbon emissions caps to create a pricing pressure that, if combined with government subsidies could create an economic incentive that encourages rapid production of IGCC plants. This reality means that MEA retrofitting of current PC plants represents an immediate option and that IGCC represents a goal to strive for in the near future.

¹¹⁰ Pew Center for Global Climate Change. 2007.

¹¹¹ Wilson, Elizabeth J., Gerard, David. (12). 2007.

¹¹² LaPlace, Nancy. 2007.

¹¹³ LaPlace, Nancy. 2007.

After the carbon dioxide has been captured from the products of coal combustion, the second step to securing the reduction of carbon dioxide in the atmosphere from electrical generation is to sequester the carbon dioxide geologically. This geologic sequestration would remove the carbon dioxide from the short carbon cycle for millennia. Sequestration guarantees carbon dioxide generated in coal plants will not contribute to the rising carbon dioxide concentration of the earth's air. The process of geologic sequestration still poses a challenge to widespread use of carbon capture and sequestration because of the complexities involved in injecting carbon dioxide gas into the subsurface of the earth. Research and pilot projects are attempting to better understand how the carbon dioxide will act underground over long periods of time.

The properties of carbon dioxide gas under terrestrial geologic sequestration conditions must be explored in order to understand how it will behave immediately after injection, and for periods of thousands of years if correctly sequestered. When carbon dioxide is injected into the subsurface the pressure of injection controls its behavior. After injection, "the main driving force for CO₂ migration will be the upward buoyancy force"¹¹⁴. Carbon dioxide's buoyancy is driven by its density, which is 725 kg/m³ at 2 km below the surface, which is much smaller than the saline brine it would be injected into, if a saline aquifer were used for storage, which has density of 1191 kg/m³ at 2 km below the surface¹¹⁵. The properties of carbon dioxide depend on its phase, which is determined by the interaction between temperature and pressure. Under normal geothermal gradient conditions, or a gradient of a 20 degree Celsius increase in temperature per kilometer below the surface, carbon dioxide would remain in a supercritical gas stage when

¹¹⁴ Wilson, Elizabeth J., Gerard, David . (127). 2007.

¹¹⁵ Wilson , Elizabeth J., Gerard, David. (131). 2007.

sequestered geologically. This supercritical stage is described as “liquid-like in density and gas-like in viscosity”¹¹⁶. Even with these characteristics, most of the injected carbon dioxide will behave like a plume and spread vertically and laterally until sequestered by several processes.

The most feasible application of carbon sequestration within the continental crust lies in the storage of carbon dioxide in saline aquifers or in already discovered reservoirs of fossil fuels such as oil, coal, or natural gas¹¹⁷. Storage of carbon dioxide in hydrocarbon reservoirs would occur in already depleted oil or natural gas reservoirs or unmineable coal deposits. For carbon capture and sequestration to be implemented in newly built coal-powered facilities the most logical location for the plant would be above a saline aquifer, which “represent the largest volume in the subsurface with potential for CO₂ storage”¹¹⁸. A saline aquifer is defined as an aquifer, most commonly formed from sandstone or limestone, that does not contain water suitable for drinking or agricultural purposes¹¹⁹. The benefits of saline aquifers compared to hydrocarbon reservoirs are that they are far more prevalent and larger in size. The worldwide capacity of saline aquifers to hold stored carbon dioxide is greater than 1000 gigatons as opposed to up to 900 for oil and gas reservoirs¹²⁰. However, the integrity of the geologic seal is less obvious for saline aquifers and leakage risks would be higher than at already established drilling sites¹²¹. Once a saline aquifer is identified there are many characteristics that must be analyzed in order to determine whether or not it is suitable for sequestration. The three geologic areas of importance are the overburden, the seal, and the storage formation. For example, the overburden

¹¹⁶ Wilson, Elizabeth J., Gerard, David. (133). 2007.

¹¹⁷ Hurter, Suzanne.

¹¹⁸ Wilson, Elizabeth J., Gerard, David. (36). 2007.

¹¹⁹ Hurter, Suzanne.

¹²⁰ Bachu, Stefan. 2006

¹²¹ Hurter, Suzanne.

of saline aquifers must not contain active drinking water wells. The overburden could also have features that lead to extra sealing potential. For the seal, the rock must be seismically stable and be totally sealed if there are faults or fractures. The seal layer must also be very impermeable without being inductile, since this can lead to faulting under the new pressure of the buoyancy of the stored gas. The actual storage formation, or the stone that holds the saline water, must have small pore size to slow the diffusion of carbon dioxide and capture it within the pores¹²².

The injection of carbon dioxide into deep saline aquifers involves four separate processes of sequestration: structural, mobility, dissolution, and chemical trapping¹²³. Structural trapping involves the presence of a large, impermeable geologic structure that will stop the vertical buoyancy of carbon dioxide in its supercritical gas phase. Mobility trapping involves the interaction between gaseous injected carbon dioxide with the liquid brine present in the aquifer structure. Pressure conditions determine which substance will displace the other over long periods of time. The trapping of carbon dioxide through dissolution and chemical interaction are the most stable long-term sequestration. In dissolution, carbon dioxide dissolves into the aquifer brine and increases the density of the brine. Therefore, the brine with dissolved carbon dioxide will sink, as it is less buoyant than either the regular brine or the gaseous carbon dioxide. Chemically trapped carbon dioxide results when the gas interacts with rock minerals (mica, illite clays) to create carbonates that immobilize the CO₂ in solids¹²⁴. Both of these more stable forms of sequestration occur over much longer periods of time than structural or mobility trapping, occurring on the order of centuries to millennia versus weeks or years. The most important trapping process for geologic CO₂ storage is the structural trapping of the gaseous carbon dioxide

¹²² Hurter, Suzanne.

¹²³ Wilson, Elizabeth J., Gerard, David. (41). 2007.

¹²⁴ Wilson, Elizabeth J., Gerard, David. (41). 2007.

because most of the injected CO₂ will remain like this for long periods of time. The ability of saline aquifers to sequester carbon dioxide also depends on the interaction between the gaseous carbon dioxide and the different types of rock formation in and around the storage formation.

The process of injecting carbon dioxide into the subsurface has precedents before the current emphasis on its potential to reduce carbon dioxide emissions. The potential to utilize captured carbon dioxide gas to help recover stagnant hydrocarbon resources, specifically oil, has become an area of interest in the United States recently. The process of injecting carbon dioxide gas into a partially depleted oil reservoir is called tertiary, or enhanced oil recovery (EOR). After the carbon dioxide gas is injected back into the reservoir it dissolves into the remaining oil and reduces its viscosity making the oil easier to pump through the well¹²⁵. The potential benefits for a company using EOR are two fold. First, the EOR process can produce “20 percent more of the original-oil-in-place in a reservoir”¹²⁶, or up to sixty percent of the oil in the reservoir¹²⁷. Second, the injected carbon dioxide has the potential to remain sequestered in the geologic formation if there is a sufficient seal. The Department of Energy recently gave the University of Alabama Birmingham a grant to start research on an enhanced oil recovery project at Citronelle oilfield. The project’s research will help provide understanding about the potential to use depleted oil reservoirs for long-term captured carbon dioxide gas storage. The proximity of the plant to the reservoir means low transportation costs for the sequestration. By comparison, a newly built coal plant might have to pay to transport its captured carbon dioxide several miles to the nearest usable reservoir, most likely a saline aquifer. Another benefit of sequestration through EOR is that EOR “represents an opportunity to sequester carbon at low net cost, due to the revenues

¹²⁵ Wilson, Elizabeth J., Gerard, David. (14). 2007.

¹²⁶ USDOE. 2006

¹²⁷ USDOE .2008

from recovered oil/gas”¹²⁸. The storage capacity of oil and gas fields is lower than that of saline aquifers. However, the projected sequestration capacity for all the oil and gas reservoirs on earth is “125 years of current worldwide CO₂ emissions from fossil fuel–fired power plants”¹²⁹. Since many of these reservoirs are already being mined, the infrastructure exists to exploit depleted reservoirs that are still producing carbon dioxide emissions.

If operated properly, research points to evidence that power plants could safely sequester their carbon dioxide geologically. However, the most significant global risk of geologic storage of carbon dioxide is the possibility of a large percentage of the gas leaking back to the surface, thereby rejoining the short carbon cycle. If measures are taken to begin large-scale sequestration of carbon dioxide, while global expansion of the coal fired power plants continues, and significant leakage of a majority of the sequestered reservoirs occurs the concentration of carbon dioxide in the atmosphere could start to rise even more sharply. Currently, research shows that “geologic storage will be an effective mitigation option if seepage rates are less than from 0.01%/year up to about 0.1%/year”¹³⁰. This rate of seepage would mean that the carbon dioxide would be stored for a period of 1000 years. A period of storage on this magnitude would help mitigate global warming because the residence time of carbon dioxide in the atmosphere is an order of magnitude smaller.

The local risks of carbon dioxide leakage have more obvious and immediate consequences than the global increase in carbon dioxide concentration in the atmosphere. The most dangerous risk associated with carbon dioxide gas leakage is the potential for fatality from

¹²⁸ USDOE .2007

¹²⁹ USDOE 2006

¹³⁰ Wilson, Elizabeth J., Gerard, David. (94). 2007.

carbon dioxide poisoning. Since carbon dioxide is heavier than air it can form into low-lying clouds in the atmosphere. Studies have shown concentration levels of above three percent can lead to death¹³¹. The normal concentration of carbon dioxide in the atmosphere is .037 percent¹³². The potential for a “well blowout or a pipeline transport accident”¹³³ represents the greatest risk for a large-scale release of carbon dioxide.

Leakage of carbon dioxide also poses a risk to the levels of dissolved carbon dioxide in soils. A study has shown that “at about 20% volume CO₂, the Mammoth Mountain vegetation began to show sign of stress”¹³⁴. The leakage from Mammoth Mountain occurs from volcanic activity, not carbon sequestration. This means that ecosystems above a carbon dioxide sequestration project could be dramatically affected from relatively slow carbon dioxide seepage. Other problems in the subsurface that could arise from geologic sequestration of carbon dioxide deal with the contamination of groundwater. One process through which groundwater, specifically drinking water, could be disturbed is if carbon dioxide gas displaces the salt water from the aquifer into a neighboring drinking well’s storage structure. Overall, the benefits of reducing carbon dioxide emissions through sequestration seem to outweigh the risks. However, it still remains to be seen how the public will react to a sequestration project when it is proposed in their area.

Country	Percent of Electricity From Coal Fired	MWh From Coal Production	Kilograms of CO ₂ /MWh using PC power	Kilograms of CO ₂ /MWh with MEA	Kilograms of CO ₂ /MWh IGCC with	Kilograms of CO ₂ /MWh IGCC plant with	Reduction in kg CO ₂ using MEA with	Reduction in kg CO ₂ using IGCC with
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¹³¹ Wilson, Elizabeth J., Gerard, David. (110). 2007.

¹³² Wilson, Elizabeth J., Gerard, David. (110). 2007.

¹³³ Wilson, Elizabeth J., Gerard, David. (109). 2007.

¹³⁴ Wilson, Elizabeth J., Gerard, David. (111). 2007.

	Plants		plant	Capture	plant	capture	capture	capture
United States	43%	1,640,880,000	795	116	757	113	1.11 x 10 ¹² kg	1.06 x 10 ¹² kg
China	80%	2,859,000,000	795	116	757	113	1.56 x 10 ¹² kg	1.47 x 10 ¹² kg

Derived From Data from CIA World Factbook and Wilson, Suzanne. Values are for 2005. Calculations were done by me.

The need for rapid reduction in carbon dioxide emissions has been well attested by the International Panel on Climate Change. Any strategy for mitigation of carbon dioxide emissions must include implementation, research, and funding of carbon capture and sequestration in coal burning power plants. The most feasible, current technological options for carbon capture are MEA post-combustion scrubbing and pre-combustion Integrated Gasification Combined Cycle technology. While MEA capture has much higher costs for capturing carbon dioxide than IGCC, directly related to the decrease in efficiency of 20-25% because of its heat and water requirements¹³⁵, it can be quickly and easily added to existing coal burning power plants. If MEA scrubbing with sequestration had been applied to all coal-fired power plants in the United States in 2005 it would have decreased coal-fired power plant carbon dioxide emissions by 1.11 trillion kilograms, or 1.11 gigatons of carbon dioxide¹³⁶ (Table 1). The current MEA technology has the potential to create globally significant reductions in emissions if applied widely. While MEA can help mitigate already existing coal burning plants the logical choice for future coal power plants is implementation of Integrated Gasification Combined Cycle technology. IGCC technology would have reduced the United States' carbon dioxide emissions in 2005 by 1.12 gigatons if implemented in 2005. The IGCC process is also much more energy efficient, and therefore cost efficient, than post-combustion amine scrubbing. There also is hope for

¹³⁵ Wilson, Elizabeth J., Gerard, David. (20). 2007.

¹³⁶ CIA World Factbook. 2005.

improvement of its efficiency to reduce the increased cost of electricity to only 1 cent/kWh as opposed to the current 2 cents/kWh¹³⁷.

The reduction in worldwide coal-fired power plant carbon dioxide emissions could be one of the greatest challenges posed to the international community. As shown above, technology exists, and is being tested. However, there is a need for both strong government support and funding for carbon capture and sequestration technology to become commonplace. As the previous leader in coal-powered power plant pollution, the United States holds a responsibility for much of the increase in global increase in carbon dioxide concentration. One way in which the United States could take responsibility for its contribution is by setting an example for other nations to follow through mandating the retrofitting of its existing coal-fired power plants with MEA carbon capture. Until the problem of coal burning is addressed on an international scale, the goals set by treaties such as Kyoto will be unattainable.

Oceanic Storage

Carbon capture has been a relative recent way of dealing with cutting back on the amount of anthropogenic carbon dioxide released into the atmosphere. Scientists have developed ways to extract CO₂ directly out of flue gas emissions from factories which release large amounts of CO₂. Once this carbon dioxide is captured, it must be stored away somewhere where it can't be released into the atmosphere. The main idea is to somehow place the CO₂ into a place where it will possibly be buried away from the atmosphere. There have already been methods developed for trapping the carbon underground in geological settings. These methods, although relatively

¹³⁷ David, Jeremy, Herzog, Howard. MIT.

new, have proven to be sufficient ways of carbon storage. Scientists have also been researching the possibility of oceanic carbon dioxide storage. The oceans cover over 70% of Earth's surface and currently contain more than 50 times the amount of carbon contained in the atmosphere. The sheer size of the ocean proves it to be an adequate reservoir for anthropogenic carbon dioxide. The idea of intentional carbon storage in the ocean is relatively new, and it is just in the research phase as of now. Many factors must be considered before this idea can actually happen, such as costs, proper methods, and environmental impacts.

After carbon has been captured, however, it needs to be transported somehow before it can be stored. Carbon transport is the linking step between capture and storage. Currently there are existing methods of transport, the most common being pipelines. Pipelines have been already been used to transport large volumes of natural gas, oil, condensate and water over large distances. There have already been many CO₂ pipelines constructed in the United States, and these include the Canyon Reef pipeline, Bravo Dome pipeline, Cortez Pipeline, Sheep Mountain Pipeline, and Weyburn Pipeline. Carbon dioxide pipelines extend more than 2500 km in the Western United States, and they can carry about 50 MtCO₂/yr from natural sources to sites of enhanced oil recovery projects¹³⁸. Besides pipelines, the option of ship transport is also available for the transport of carbon. These marine tankers are used to transport CO₂ in liquid form, and the tankers are already being used today to transport other liquid gases such as propane. These tankers also can currently ship CO₂, but they do so on a small scale because the demand is low.

Once carbon dioxide has been captured and transported, there must be a way of storing it so the CO₂ does not enter the atmosphere. Researchers have found ways to store this CO₂

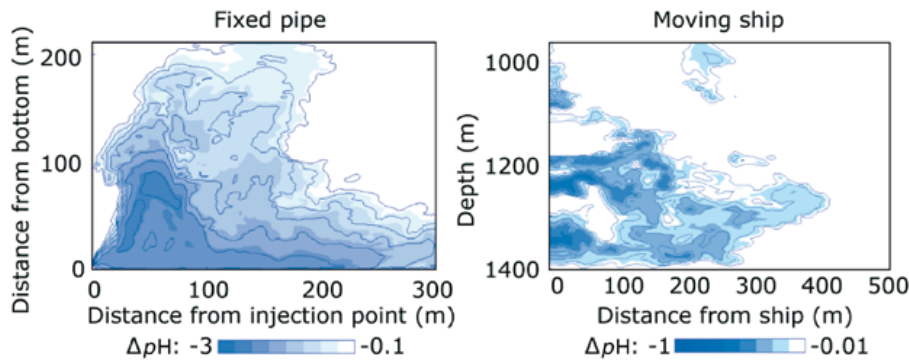
¹³⁸ Intergovernmental Panel on Climate Change. Cambridge University Press. New York, New York, 2005

geologically into oil fields and other areas which have proven successful and are currently being executed. Researchers are also considering the possibility of oceanic carbon dioxide storage. Since the oceans take up so much of Earth's surface and are so deep, the amount of anthropogenic CO₂ able to be stored in the oceans is basically limitless¹³⁹. However, this option of ocean storage is in its beginning phases and not much actual experimentation has been done. There have been different options developed for the injection of CO₂ into the oceans at various depths and a variety of phases of CO₂. At above 500 meters in the ocean carbon dioxide is less dense than the water so it will rise. It has been suggested that it is possible to inject CO₂ in gas form at around 500 meters and the CO₂ will dissolve into the water and become part of the oceanic carbon cycle before it can reach the surface. Below 500 meters ocean depth CO₂ can exist as a liquid, and above 2500 meters it is less dense than ocean water so it will rise. Carbon dioxide diffusers can be designed to produce CO₂ droplets which would rise towards the surface and dissolve within 100 meters of the depth of release. Below 3000 meters liquid CO₂ is denser than sea water, so it has been proposed that liquid CO₂ released below 3000 meters would sink and form CO₂ lakes on the sea floor. Other options have also been considered, such as creating solid CO₂ hydrates which would be released and would sink towards the ocean floor, dissolving on its way down. All of these possibilities have only been explored in the lab and in some small scale experiments in some areas of the ocean, but they have not been tested on a large scale situation and therefore the effects additional CO₂ injection into the ocean would have on the ocean and ocean life.

Carbon dioxide released as a gas above 500 meters in the ocean would rise to the surface and dissolve on the way up. This dissolution would mix the injected carbon into the ocean and

¹³⁹ Intergovernmental Panel on Climate Change. Cambridge University Press. New York, New York, 2005

the CO₂ would become part of the oceanic carbon cycle. The method proposed for this injection relies on the transport of CO₂ by boat. The boat would transport the CO₂ to a platform on the ocean surface which would take the captured CO₂ and inject it using a pipe into the ocean. Scientists doing experiments with carbon dioxide in the gas form in the lab have found the CO₂ to dissolve as bubbles at a radial speed of .1 cm/hr¹⁴⁰. Engineers are capable of creating CO₂ diffusers which could produce gaseous CO₂ bubbles that are small enough to completely dissolve after they are released and before they reach the surface. When dissolved into the ocean water, CO₂ makes the water denser than normal, so the water is more likely to sink. As the CO₂-enriched water begins to mix with other ocean water it becomes more diluted and the CO₂ is mixed in with the entire ocean. To create a better environment to allow for easier dilution of CO₂ into the sea water, it has been suggested that instead of injecting the CO₂ from a stable platform on the ocean the carbon dioxide can be released by a moving boat dragging a pipe in the water.



¹⁴⁰ Intergovernmental Panel on Climate Change. Cambridge University Press. New York, New York, 2005

As seen in the graph above (Chen et al., 2005), the release of CO₂ from a moving ship rather than a fixed pipe can reduce the concentration of CO₂ in the plumes which could accelerate the dissolution and dispersal of the injected CO₂. By increasing the dispersal of CO₂ in the water the release of carbon dioxide by moving ships can decrease the environmental impacts by the injection of mass amount of CO₂ into the ocean.

At ocean depths of around 2500 meters, carbon dioxide can exist as a liquid. However, even though it is a liquid at these depths the CO₂ is still less dense than the ocean water and will still rise towards the surface. Scientists consider it possible to release droplets of CO₂ at depths around 2500 meters and the CO₂ would rise and dissolve before it reached the surface. At these deep ocean depths the water temperature is around 9 degrees C and solid CO₂ hydrate would form around these droplets because of the cold. Under these conditions it has been calculated that the carbon dioxide droplets would rise and dissolve at a rate of 0.5 cm hr¹⁴¹. At this rate a .9 cm diameter droplet would rise about 400 m in an hour before dissolving completely, and 90% of its mass would be dissolved within the first 200 meters¹⁴². Engineers could design CO₂ diffusers which would release droplets at a size which would dissolve within 100 m of the depth of release. Even if the droplet did not dissolve before it reached 500 m depth, it would turn into a gas bubble and dissolve within the next 500 m¹⁴³. Injecting the liquid CO₂ at this depth would allow it to dissolve in the water and make it the water denser and therefore more likely to sink. Making ocean water denser at the depth around 2500 meters would allow the water to become

¹⁴¹ Brewer, P.G., E.T. Peltzer, G. Friederich, and G. Rehder, 2002: Experimental determination of the fate of a CO₂ plume in seawater. *Environmental Science and Technology*, 36 (24), 5441-5446.

¹⁴² Brewer, P.G., E.T. Peltzer, G. Friederich, and G. Rehder, 2002: Experimental determination of the fate of a CO₂ plume in seawater. *Environmental Science and Technology*, 36 (24), 5441-5446.

¹⁴³ Intergovernmental Panel on Climate Change. Cambridge University Press. New York, New York, 2005.

more likely to sink to the deep ocean¹⁴⁴. Diffusers could be designed to produce large CO₂ droplets which would allow for more carbon dioxide to be dissolved into the water and create large CO₂ plumes which would sink more quickly. Once in the deep ocean, the water could be channeled naturally by deep ocean currents towards deep sea canyons and other topographical features which would allow for CO₂ rich plumes to reach greater depth¹⁴⁵.

Below 3000 meters depth in the ocean liquid CO₂ is denser than water, so it is possible to inject carbon dioxide in liquid form so that it sinks to the ocean floor where it forms lakes of CO₂. Long pipes descending from a station on the ocean surface would be necessary for this method, and the pipes would need to reach down past 3000 meters. The injected liquid CO₂ would be expected to sink to the ocean floor and accumulate in topographic depressions to form liquid lakes on the floor. Once set on the bottom of the ocean floor, the liquid CO₂ lake develops a layer of CO₂ hydrate over top of it. The hydrate layer would help limit CO₂ dissolution into the water, which increase the amount of time the carbon dioxide is kept isolated from ocean water. The hydrate layer dissolves into the overlying water but is continuously rebuilt from the formation of new crystals¹⁴⁶.

¹⁴⁴ Liro, C., E. Adams, and H. Herzog, 1992: Modeling the releases of CO₂ in the deep ocean. *Energy Conversion and Management*, 33(5-8), 667-674.

¹⁴⁵ Adams, E., D. Golomb, X. Zhang, and H.J. Herzog, 1995: Confined release of CO₂ into shallow seawater. *Direct Ocean Disposal of Carbon Dioxide*. N. Handa, (ed.), Terra Scientific Publishing Company, Tokyo, pp. 153-161.

¹⁴⁶ Mori, Y.H., 1998: Formation of CO₂ hydrate on the surface of liquid CO₂ droplets in water—some comments on a previous paper. *Energy Conversion and Management*, 39(5-6) 369-373.

Studies and experiments have shown that the addition of carbon dioxide in the ocean has some negative impacts on the environment. Increased CO₂ in the ocean can cause a decrease in the pH levels of the water because CO₂ leads to a decrease in carbonate ion concentration and an increase in hydrogen ion concentration. Minerals dissolved in the ocean have made the waters mildly alkaline, and this alkalinity can be attributed to the presence of carbonic acid H₂CO₃ in the water. This H₂CO₃ can be broken down into bicarbonate ion HCO₃⁻, carbonate ion CO₃⁻ and hydronium ion H⁺ through the reaction $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}^+ \rightarrow \text{CO}_3^{2-} + 2\text{H}^+$. When CO₂ is added into ocean water it reacts with the water and carbonate ions to form bicarbonate in the reactions $\text{CO}_2 + \text{H}_2\text{O} + \text{CO}_3^{2-} \rightarrow \text{H}_2\text{CO}_3^-$ and $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{HCO}_3^-$. Both of these reactions combined causes an increase in hydronium ion and a decrease in carbonate ion, which leads to a decrease in pH. The current levels of atmospheric CO₂ which is dissolved in the ocean cause the water pH to decrease at a rate of 0.1 per year. With the direct injection of anthropogenic CO₂ into the ocean, this rate can increase and the ocean can become more acidic faster. Additionally, the decrease of carbonate ions effect organisms in the ocean which use carbonate to build shells and skeletons. With less carbonate available these organisms will not be capable of constructing a protective shell and will die.

The addition of CO₂ to the ocean also has direct effects on the biota of the deep ocean. Since there is currently limited knowledge on deep sea ecosystems it is hard for scientists to predict how sensitivity deep sea life is to increases of carbon dioxide. The predictions that scientists have made are based on laboratory experiments and small scale simulations in the ocean. The injection of CO₂ into the deep ocean will create volumes of water with large amounts of CO₂ in them, and when exposed to these waters animals will be affected. Water breathing animals may experience hypercapnia when they breathe water which is CO₂ enriched.

Hypercapnia occurs when organisms are surrounded by high concentrations of CO₂ and the CO₂ enters the organisms through diffusion across respiratory surfaces and equilibrates with the rest of the body¹⁴⁷. This hypercapnia is responsible for most of the effects of CO₂ observed in animals, including respiratory distress, narcosis, and mortality.

There have been studies performed off of the coast of California in which 20-70 kg of liquid CO₂ were released in small corrals on the sea floor at 3600 m depth and the response of animals to this CO₂ was observed and recorded¹⁴⁸. The response of deep sea organisms to the CO₂ lake varied between specific animals. When directly exposed to CO₂ sea cucumbers and brittle stars died immediately, and fish which came close to the liquid CO₂ immediately swam away in a different direction. A different but similar experiment found that some species such as the scavenger species hagfish did not avoid the CO₂ plumes but instead went into the plume to feed on bait¹⁴⁹. These simulations have found that the survival rates of deep sea animals exposed to CO₂ enriched waters depended on the range of pH perturbation and proximity to the CO₂ (IPCC, 2005). Organisms held in cages within 1 meter of the CO₂ and exposed to significant decreases in pH (1-1.5 units) experienced high mortality rates. Organisms held further away from the CO₂ (3-10 meters) and exposed to a moderate decreases in pH (0.1-0.2 units) also showed moderate mortality rates, although not as high as the organisms held within 1 meter of

¹⁴⁷ Intergovernmental Panel on Climate Change. Cambridge University Press. New York, New York, 2005

¹⁴⁸ Barry, J.P., K.R. Buck, C.F. Lovera, L. Kuhnz, P.J. Whaling, E.T. Peltzer, P. Walz, and P.G. Brewer, 2004: Effects of direct ocean CO₂ injection on deep-sea meiofauna, *Journal of Oceanography*, 60(4), 759-766

¹⁴⁹ Tamburri, M.N., E.T. Peltzer, G.E. Friederich, I. Aya, K. Yamane, and P.G. Brewer, 2000: A field study of the effects of CO₂ ocean disposal on mobile deep-sea animals. *Marine Chemistry*, 72(2-4), 95-101

the CO₂¹⁵⁰. Although performed in small scale settings, these experiments help show how carbon dioxide can affect deep ocean life in negative ways.

The predicted costs of oceanic carbon storage depend on the separate costs of the transport to and the release from ocean platforms and moving ships. In order for carbon to go from being captured from a power plant to being injected into the ocean, it must be stored onshore, shipped to the platform, and injected from the ocean platform. The cost of this possibility of ocean storage relies on three major mechanisms: tank storage of CO₂ onshore waiting for shipping, the shipping of CO₂, and the injection platform pipe and nozzle (IPCC, 2005). The table below, reconstructed from a table presented in the 2005 IPCC report, shows the individual and total costs of these mechanisms for carbon dioxide transported either 100 km or 500 km.

Ship transport distance	100 km	500 km
Onshore CO ₂ Storage (US\$/tCO ₂ shipped)	3.3	3.3
Ship transport to injection platform (US\$/tCO ₂ shipped)	2.9	4.2
Injection platform, pipe and nozzle (US\$/tCO ₂ shipped)	5.3	5.3
Total		
Ocean storage cost (US\$/tCO ₂ shipped)	11.5	12.8

¹⁵⁰ Barry, J.P., K.R. Buck, C.F. Lovera, L. Kuhnz, P.J. Whaling, E.T. Peltzer, P. Walz, and P.G. Brewer, 2004: Effects of direct ocean CO₂ injection on deep-sea meiofauna, *Journal of Oceanography*, 60(4), 759-766

Ocean storage cost (US\$/tCO ₂ net stored)	11.9	13.2
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The table represents three cases in which CO₂ is captured from separate power plants and transported by ship to one ocean platform¹⁵¹. The cost of ocean storage is the sum of the three individual mechanisms, and in this case the total cost of ocean storage is 11.5 to 12.8 million US dollars/tCO₂ shipped between 100 and 500 km.

Liquid CO₂ could also be stored in a transport ship and transported to another ship which would inject the CO₂ into the ocean using a tow pipe at a depth of 2,000 to 2,500 m. Similar to the ocean platform method, the cost of injection of CO₂ from a moving ship relies on the costs of three separate factors. These factors include the onshore storage of CO₂, which costs 2.2 million US\$/tCO₂ shipped, the shipping of CO₂, which is predicted to cost between 3.9 to 5.3 million US\$/tCO₂ shipped, and the injection ship, pipe and nozzle, which is predicted to cost about 7.7 million US\$/tCO₂ shipped¹⁵². The sum of these three factors comes out to a total cost of between 13.8 to 15.2 million US\$/tCO₂ shipped 100 to 500 km. This method proves to be more expected than the other proposed method of injection from a stationary ocean platform which would inject CO₂ from a fixed pipe. Although this method is proven to be more expensive, it might be worth the price because CO₂ injected from a moving ship would produce smaller CO₂ plumes than a stationary pipe would produce.

The issue of public perception of oceanic CO₂ storage is at a beginning phase because there have only been a few of studies performed. The studies that have been performed have

¹⁵¹ Akai, M., N. Nishio, M. Iijima, M. Ozaki, J. Minamiura, and T. Tanaka, 2004: Performance and Economic Evaluation of CO₂ Capture and Sequestration Technologies. Proceedings of the Seventh International Conference on Greenhouse Gas Control Technologies.

¹⁵² Akai, M., N. Nishio, M. Iijima, M. Ozaki, J. Minamiura, and T. Tanaka, 2004: Performance and Economic Evaluation of CO₂ Capture and Sequestration Technologies. Proceedings of the Seventh International Conference on Greenhouse Gas Control Technologies.

shown that the public is largely uninformed about the issue and therefore they have no real solid basis to make an opinion. It has been found that the public knows very little about the role of the oceans in absorbing anthropogenically produced CO₂ released in the atmosphere¹⁵³. It has been suggested that if further information about the subject was provided to the public, the public's perception would change. Two studies have been conducted which support this claim. In Japan, a study conducted by Itaoka et al. (2004) asked members of the public to rate ocean and geologic storage options on a scale of 1 to 5 (1 = no, 5 = yes). Initially, the mean rating for dilution-type ocean storage was 2.24 and lake-type ocean storage was rated at 2.47. After receiving more information about the subject from researchers, the mean rating for dilution-type ocean storage increased to 2.42 and the rating for lake-type ocean storage increased to 2.72¹⁵⁴. In a similar study conducted by Palmgren et al. (2004) in Pittsburgh, United States, a sample of the public was asked to rate ocean and geologic storage on a scale of 1 to 7 (1 = oppose, 7 = agree). The mean rating for ocean storage was 3.2 initially, and after the public was exposed to further information from researchers, the mean rating for ocean storage decreased to 2.4¹⁵⁵. Both of these studies show that further education of direct CO₂ injection into the oceans can change the public opinion of the subject, even though the Japan study showed an increase of approval for the idea and the United States study showed a decrease in approval of the subject. In order to attain a better concept of public perception of CO₂ storage in oceans, the public must be exposed to more information on the subject.

¹⁵³ Curry, T., D. Reiner, S. Ansolabehere, and H. Herzog, 2005: How aware is the public of carbon capture and storage? E.S. Rubin, D.W. Keith and C.F. Gilboy (eds.) Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies (GHGT-7), September 5-9, 2004, Vancouver, Canada.

¹⁵⁴ Itaoka, K., A. Saito, and M. Akai, 2004: Public Acceptance of CO₂ capture and storage technology: a survey of public opinion to explore influential factors. Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies (GHGT-7), September 5-9, 2004, Vancouver, Canada.

¹⁵⁵ Palmgren, C., M. Granger Morgan, W. Bruine de Bruin and D. Keith, 2004: Initial public perceptions of deep geological and oceanic disposal of CO₂. *Environmental Science and Technology*, 38(24), 6441-6450.

Although the possibility of storing carbon dioxide in the oceans is still in the developmental stages, researchers have come up with some realistic methods for CO₂ injection. The methods proposed differ mainly in the phase of the CO₂ injected and the depth at which the CO₂ is injected. Because there has not been much actual experimentation done within the ocean it is difficult to predict how the CO₂ will act and what effects it will have on ocean chemistry and biology. It has been shown that CO₂ in the ocean will decrease the pH of the water which may cause harm to biota and will also cause a decrease in carbonate production. Researchers have predicted that many animals which are sensitive to CO₂ changes will react negatively when encountered with CO₂-enriched waters and some organisms may die. In order for this possibility of carbon storage to become more realistic, there must be more research done within the actual ocean environment so sci

Silver Bullets or Potential Disasters:

High Risk, High Reward Global Climate Change Prevention

Introduction

As the reality of global climate change becomes increasingly real, and as the perceived window of time before catastrophic effects shrinks, scientists and businessmen alike are proposing and exploring an increasing number of radical solutions. Often, these proposals are more theoretical and less research-based; however, the individuals involved are often convinced that their ideas may provide the key to protecting the global climate, or at least making some fast cash. Nevertheless, because these ideas have received less funding and have been the subject of fewer, (or in some cases none at all,) long term studies, and the environmental and ecological

impacts are far less understood, and they can be dangerous as a result. In an era where results bring investors, the possibility of a group or company implementing their ideas before the full implications of their proposal can be understood becomes increasingly likely with every passing day. Two of the highest risk, highest reward solutions being discussed today are the fertilization of the ocean with iron to facilitate primary ocean productivity and sequester carbon, and the release of sulfur into the atmosphere to block the sun's energy and cool the earth..

Iron Fertilization

Iron fertilization has been one of the hottest climate change topics in the media recently. The theory behind iron fertilization is simple and easily explained in ways that appear logical and foolproof. Proponents note that the world is roughly three-quarters water, and large portions of the photic zone, the portion of the ocean where the sun's rays reach, are relatively empty of life. The main reason for this lack in production is that there are not enough of certain nutrients to sustain more organisms. Early studies have shown the limiting nutrient in some of the high nutrient, low chlorophyll areas to be iron¹⁵⁶. Fans of iron fertilization then argue that the introduction of iron would create phytoplankton and algae blooms that would draw CO₂ out of the atmosphere as they grew, and then sequester it in carbonate shells. Because carbon dioxide acts as a green house gas, trapping outgoing radiation in the Earth's atmosphere and contributing to global climate change, proponents of iron fertilization argue that the introduction of iron into low production areas of the ocean would lead to a drop in CO₂ levels as marine productivity increased, which would drastically reduce the effects of anthropogenic climate change. The idea appeals to the general public on many levels. Consumers could stop feeling as guilty about

¹⁵⁶ [Iron Fertilization Limits Phytoplankton Growth in the North-East Pacific Subarctic, Nature 331, 1988](#)

carbon footprints without any personal effort themselves, and the proposal would require none of the lifestyle changes that reducing the global output of CO₂ would. The technology already exists, and implementation requires none of the restrictions on businesses or consumers that accompany other proposed measures to reduce the amount of carbon dioxide in the environment. This aspect also makes it more appealing to economists who fear that the carbon caps or taxes would be an economic disaster. Iron fertilization's comparatively low price tag -- the amount of iron needed to fertilize even huge portions of the ocean would cost only \$27 billion,¹⁵⁷ -- adds to its economic appeal.

Thus, iron fertilization of low productivity regions of the ocean seems like a silver bullet: a rapid, low cost, high-effect means of removing carbon dioxide that relies only on existent technology. However, a closer inspection of the theory behind the practice and the existing studies raises many key questions about the actual efficiency of iron fertilization and reveals other potential negative drawbacks and consequences.

Factors ignored by proponents that could influence the ultimate viability of the theory include: the impact of iron on ocean ecosystems, both local and on a larger scale; the effects of gasses given off by algae blooms; and the issue of the bacteria that decompose the dead plankton. Also, before a proper risk assessment of iron fertilization can be undertaken, larger scale studies on the efficiency of iron uptake and carbon sequestration as well as more detailed studies about the types of algae blooms likely to be caused by iron fertilization and the possibility of harmful algae blooms occurring should be undertaken; there are too many unknowns given the current state of the science.

¹⁵⁷ [Green Sea Ventures Inc.](#)

Historically, over-fertilization of the soil has resulted in devastating results. Nitrogen fertilizers used in farming would appear to have an effect analogous to iron for ocean fertilization. Nitrogen is a key nutrient in plankton blooms, and nitrogen fertilizer runoff has been demonstrated to cause algae blooms. Rather than being consistently beneficial, however, nitrogen fertilization can result in hypoxia: as the plankton bloom dies off, bacteria digest the plankton, sometimes removing enough oxygen from the water to make it uninhabitable for most marine life. This effect has been observed in the Gulf of Mexico, where the Mississippi river dumps thousands of tons of agricultural runoff into the ocean. The fertilizer runoff from farms causes massive algae blooms that are digested by bacteria, depleting the ocean of dissolved oxygen. A massive dead zone of over 5,800¹⁵⁸ square miles now exists in these waters, where oxygen levels are too low to support most marine life. Opponents of iron fertilization fear that a similar phenomenon could result from it, ultimately reducing ocean productivity further if hypoxic events result in jellyfish blooms and eliminate larger fish. Although not all types of algae blooms result in hypoxia, determining exactly what type of algae blooms will develop has proved difficult. Although larger plankton such as diatoms tend to dominate in the fertilized algae blooms, the complexities of ocean currents and local plankton populations makes certain prediction of the type of algae unlikely.

While the depletion of oxygen presents a possible problem on one front, the emission of gasses by algae and bacteria present an equally complex dynamic on the other. Plankton clouds have been experimentally observed to release the gas dimethyl sulfide. Once in the atmosphere, the dimethyl sulfide oxidizes and forms sulfate particles that can play a key role in cloud production. If the plankton release DMS as well as sequestering carbon, then the cooling effect

¹⁵⁸ John Cullen, WHOI Ocean Fertilization 2007

on the global climate would be two fold; the removal of CO₂ from the atmosphere, as well as the production of more clouds, leading to increased albedo. However, bacteria involved in the decomposition of algae blooms may also produce nitrous oxide, a potent greenhouse gas, but the extent of this effect is currently unknown.¹⁵⁹ Data from small-scale studies cannot be extrapolated to the large-scale endeavors that would be necessary to impact the global climate, because the ocean presents too many variables.

These possible risks associated with iron fertilization projects make iron fertilization less appealing to governments; however, most of the high nutrient, low chlorophyll zones exist outside of national waters, and thus individual governments have little power to prevent small scale experiments or even full implementation projects should someone decide to undertake them. Some laws, treaties and trade agreements, govern the preservation of the open ocean but most of these regulations were written before iron fertilization was as well known. Currently there are few legal obstacles to prevent a corporations from dumping thousands of tons of iron into the ocean.

The lack of legal controls is particularly significant because the risk of a company independently deciding to go ahead with an iron fertilization project remains high, despite growing doubts and concerns. Iron fertilization projects require low financial investment and have high likelihood of large profits from selling carbon offsets. Already, a number of iron fertilization companies, such as Planktos and Climos, have formed and are posed to begin projects. Under the Kyoto Protocol, carbon credits from iron fertilization are not currently accepted, but proponents of the industry are hopeful that not only will iron fertilization credits

¹⁵⁹ John Cullen, WHOI Ocean Fertilization 2007

eventually be included under the Kyoto Protocol, but that the credits could be sold to the public in the same way reforestation or wind farm credits are sold now by companies such as Travelocity and Hertz to offset emissions from travel.

A further difficulty of iron fertilization projects is determining the size of its effects and thus its profitability. Only carbon sequestration that would not have occurred otherwise can be legally sold, and measuring the sequestration of carbon by algae blooms is a difficult task. Even to the extent that the premise of iron fertilization is sound, in order for the carbon to be removed from the carbon cycle on a meaningful timescale, the captured carbon must be deposited on the ocean floor. If the captured carbon does not reach the ocean floor, it will remain part of the short carbon cycle, and will only be removed from the atmosphere for an insignificant amount of time. Determining how much carbon is absorbed by a bloom, and more importantly what percentage of the absorbed carbon actually reaches the ocean floor, is difficult to measure with any kind of accuracy or precision. Even in small-scale studies, currents and difficulty tracking growth have resulted in varying estimates of how much carbon consumed during an algae bloom are actually sequestered. Conservative estimates are that as little as 5%¹⁶⁰ of the carbon mass in a plankton bloom reaches the ocean floor; however, proponents claim that as much as 25% ultimately reaches the ocean floor, just less directly, often in the form of fish fecal pellets. Although improvements in tracking the carbon from plankton blooms has been made, including the use of thorium tagging, no good system exists yet for measuring the difference between how much carbon reaches the ocean floor due to the induced algae bloom versus how much would have reached it naturally, however, estimates of how much carbon could potentially be sequestered are

¹⁶⁰ [Nature 446, Effect of natural iron fertilization on carbon sequestration in the Southern Ocean,](#)

as high as three gigatons a year¹⁶¹. This technological shortcoming makes selling the offsets potentially ethically dubious, because without precise measuring methods, more offsets could be sold than were actually generated. Thus, even ignoring the ecological risks, until the efficiency of iron fertilization is better understood, its value as a conservation technology cannot be accurately ascertained or marketed.

In summary, while iron fertilization initially appears to be a nearly miraculous means to cheaply and easily reduce the atmospheric CO₂ production, the practice comes with too many risks and unpredictable consequences to be responsibly undertaken at this time. Current deficits in measurement technology also prevent large-scale projects from being practical or ethical to sell. Nonetheless, the financial potential of iron fertilization combined with the lack of regulation of the high seas makes it likely that iron fertilization projects will be implemented before a more complete risk analysis can be completed. Thus, an idea that initially appeared to be an easy, no-sacrifice environmental savior now appears to harbor the potential for varied and serious ecological damage.

Sulfur Spraying:

Another ambitious proposed solution to global warming that has recently become a popular media subject is sulfate spraying. Like iron fertilization, the idea holds a lot of potential appeal in that it would likely be a relatively low cost solution that does not rely on consumer lifestyle changes, or increased regulations on industry. The practice is also known as sulfate injection, and like the theory behind iron fertilization, the basic principle appears sound. Sulfur particles have long been recognized to increase planetary albedo, which in turn acts to cool the

¹⁶¹ [John Cullen, WHOI Ocean Fertilization 2007](#)

earth. Scientists have also suggested that sulfur particles can help form clouds, which constitutes an indirect means of increasing albedo. The goal of sulfate spraying would be to enhance Earth's albedo by increasing the amount of sulfur in the atmosphere. In addition to small scale experiments and studies, volcanic eruptions have provided further evidence supporting sulfur spraying. Large volcanic eruptions can spew particulate sulfur into the atmosphere, and scientists have observed the cooling effect this causes.¹⁶² Also, an increase in particulate sulfur emissions has been connected to the temperature drop that occurred during the mid twentieth century¹⁶³.

Another attraction of sulfur spraying is that one of its strongest advocates, Paul Crutzen received the Nobel Prize in chemistry for his work on the hole in the ozone layer in 1995, and he brings with him a sense of scientific credibility. Unlike climate skeptics such as Richard Lindzen, whom have lost their standing within the scientific community, while Crutzen may be considered a pessimist by his colleagues, his work continues to appear in peer-reviewed publications such as *Science*. Crutzen believes that only 5.3 billion kilograms of sulfur released into the atmosphere per year would compensate for a doubling of carbon dioxide levels in the atmosphere¹⁶⁴. While different methods of releasing the sulfur each come with their own price tag, the overall cost of sulfur spraying would likely be drastically cheaper than many global warming solutions¹⁶⁵.

¹⁶² [DAAC: Volcanoes and Global Climate](#)

¹⁶³ [Science 173 Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate, Rasool and Schneider](#)

¹⁶⁴ [Crutzen P \(2006\). Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma?](#)

¹⁶⁵ [Crutzen P \(2006\). Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma?](#)

However, sulfur-containing emissions from power generation and heavy industry cause deleterious environmental effects such as acid rain¹⁶⁶, and adversely impact human health, causing increased rates of heart disease, asthma and lung cancer; collectively making sulfate spraying an unappealing solution¹⁶⁷. The negative effects of sulfurous emissions have resulted in major efforts to reduce the amount of sulfur released each year. Many coal-burning power plants now use scrubbers to reduce their output of sulfur,¹⁶⁸ and there are even international regulations governing sulfurous emissions. Compared to the side effects, the global climate benefits caused by increased sulfate emissions are outweighed considerably, however proponents of the practice today have developed a variety of means aimed at preventing the more serious negative effects. By releasing the sulfur directly into the stratosphere, the new proposals would still gain the albedo benefits from the sulfur, but because the sulfur would stay in the stratosphere, the acid rain and lung cancer causing side effects could be avoided.¹⁶⁹

However, critics note that sulfur only stays in the stratosphere for a few years, while some Green House Gasses such as carbon dioxide can stay in the atmosphere for decades. This means that while the price tag seems low, the cooling benefits obtained by sulfate injection would only be temporary. While proponents argue that the process could be fine tuned and repeated, but this not only raises the price but also increases the risk in a global temperature spike. If carbon dioxide levels rose significantly during the time when sulfur particles were being released to cancel out the effects of green house gasses, and sulfur spraying is then halted, when the particulate sulfur leaves the atmosphere, the effects of the green house gasses that were

¹⁶⁶ [The National Science Foundation, *Acid Rain Has Disproportionate Impact on Near-Shore Ocean Waters*](#)

¹⁶⁷ [EPA: Health and Environmental Impacts of SO₂, *www.EPA.gov*](#)

¹⁶⁸ [US Department of Energy's Pollution Control Innovation Program, *www.fossil.energy.gov*](#)

¹⁶⁹ [Crutzen P \(2006\). *Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma?*](#)

being masked by the sulfur would be left unchecked and a rapid temperature spike could occur. Nevertheless, sulfur injection still appears capable of buying scientists and politicians a few years in order to find a more permanent solution and prevent any global climate catastrophe. Unfortunately, as more studies have been conducted, the idea has become less and less appealing. Scientists have suggested that the decrease in incoming radiation caused by increased albedo could lead to the extinctions of some plant species and potentially to crop failures that would cause famines.¹⁷⁰ On April 28, 2008, scientists from the National Center for Atmospheric Research in Boulder, Colorado published a study containing another major setback for proponents of Sulfur injections. While the researchers acknowledged that the release of sulfur particles would act against global warming, they focused on their more negative discovery. The researchers found that the aerosols formed by releasing sulfur into the stratosphere react with chlorine gasses¹⁷¹ that are found only at Earth's polar regions. The resulting chemical reaction caused by the interaction between chlorine gasses and the sulfur aerosols would potentially destroy large portions of the ozone layer. This could cause another ozone hole over the Arctic to form, or just intensify the existing hole over Antarctica.¹⁷² Ultimately, while sulfur spraying will undoubtedly result in short term cooling, the long term health and ecological effects currently outweigh the benefits. While this means that sulfur spraying should not be implemented now, the guaranteed climate benefits demand further research be conducted, and in the future, sulfur spraying may play a larger role in managing Earth's climate.

¹⁷⁰ [The National Center for Atmospheric Research: Stratospheric Injections to Counter Global Warming Could Damage Ozone Layer, April 28, 2008](#)

¹⁷¹ [The National Center for Atmospheric Research: Stratospheric Injections to Counter Global Warming Could Damage Ozone Layer, April 28, 2008](#)

¹⁷² [The National Center for Atmospheric Research: Stratospheric Injections to Counter Global Warming Could Damage Ozone Layer, April 28, 2008](#)

Conclusion

While neither of the above solutions currently represents a viable means to control the earth's environment, the importance of exploring more radical means of climate control increases daily. The reluctance of consumers to change their lifestyles, and the slow rate of legislative changes means that technological solutions may be the best means to curtail global climate change. However, waiting for a silver bullet technology to fix the global climate is a poor strategy. While a technology may be developed that can rapidly repair the damage done to the climate, in the mean time, it would be irresponsible not to take other steps now, such as implementing energy efficiency measures or converting to more efficient vehicles, to minimize the damage to the environment. These two ideas also demonstrate the necessity for caution. Initially both looked like cheap, easy solutions, only to later reveal potentially disastrous side effects, and any potential solution to the global climate problem should be rigorously investigated before being implemented.

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