The Carbon Dioxide Dilemma

Promising Technologies and Policies

PROCEEDINGS OF A SYMPOSIUM

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Preface

The energy future of the United States could take a number of directions, depending on international politics, technology development, the health of the economy, and life-style changes. Added to this mix are growing concerns about climate change, specifically the role in global warming of anthropogenic carbon dioxide produced from millions of sources around the globe. Today, everyone is familiar with the chart showing the dramatic rise in levels of atmospheric carbon dioxide since the advent of the Industrial Revolution in the late 1700s, especially since 1900. Given the possible role of carbon dioxide in global warming, future controls on carbon emissions are inevitable.

One way to reduce atmospheric levels of carbon dioxide is through sequestration or the safe disposal of large quantities of carbon dioxide in locations where it will not reenter the atmosphere. A group of specialists met at the National Academy of Sciences Building, under the auspices of the National Academy of Engineering and the Board on Energy and Environmental Systems of the National Research Council, on April 23 and 24, 2002, to discuss ways of achieving this. The purpose of the meeting was not to find a consensus for dealing with the myriad issues associated with carbon dioxide sequestration, but to present a range of options for consideration by the scientific and engineering communities. The options discussed included ocean disposal, terrestrial disposal in geologic reservoirs, moving toward a noncarbon-based economy, and several biomass-based approaches. Market-based approaches coupled with carbon trading were also considered. However, no single policy emerged as a clear winner, and studies of the cost, effectiveness, and social impacts of all these options are ongoing.

Approaches to carbon dioxide sequestration vary widely and involve a wide range of disciplines. The presentations reflected this diversity and represented a broad spectrum of views regarding the severity of the problem and how we should deal with it.

Brad Allenby of AT&T opened the meeting with a broad, theoretical overview of the problem. Robert Socolow of Princeton University then described the situation as a century-scale problem. Socolow believes we will make several false starts toward a solution before we get it right, well after conventional carbon-based fuels have run out. The most basic approach currently under discussion is sequestration in geologic formations. Franklin Orr of Stanford University presented an introduction to this approach. The history of the use of carbon dioxide for enhanced gas and oil recovery was discussed by Gardiner Hill of BP Group. Sally Benson of the Lawrence Berkeley National Laboratory then discussed the research and safety aspects using these techniques.

The direct capture of carbon dioxide at energy-production facilities promises high levels of efficiency, especially when power plants are located near injection wells. This approach was discussed by Dale Simbeck of SFA Pacific, a consulting company, who has been studying this issue for many years from the point of view of the economics and associated carbon taxes for new energy technologies. David Hawkins of the National Resources Defense Council then made the case for the deployment of low-carbon technologies based on specific carbon-emission goals set far in the future.

The next group of presentations addressed the option of ocean disposal. Peter Brewer of the Monterey Bay Aquarium Research Institute described experiments with direct injection of carbon into the oceans. These experiments pointed to interesting possibilities for safe disposal. As a follow up, Ken Caldeira of Lawrence Livermore National Laboratory focused on ocean fertilization, which involves adding iron to the ocean to stimulate photosynthetic activity, thus increasing the fixation of carbon dioxide.

In a shift to terrestrial-based solutions, Gary Jacobs of Oak Ridge National Laboratory gave an overview of using terrestrial ecosystems to reduce carbon dioxide emissions to enhance photosynthesis. This was followed by a presentation by John Kadyszewski of Winrock International on ways of measuring and monitoring terrestrial-carbon dynamics. Lowell Wood of Lawrence Livermore National Laboratory then moved the discussion into space, suggesting that it might be necessary to place scattering material into space to reflect incoming radiation. This approach, although somewhat radical, might be the last step in a series of steps to address the problem.

In a complete change of direction, James Lake of the Idaho National Engineering and Environmental Laboratory turned the discussion to nuclear energy systems that have zero carbon emissions and coproduce hydrogen through electrolysis. Howard Herzog of Massachusetts Institute of Technology then enumerated the top 10 points everyone should understand about sequestration. A final talk was provided by Mike Walsh of Environmental Financial Products LLC, who discussed the feasibility and recent performance of long-term carbon-trading schemes.

This collection of transcribed, informal talks is intended to be an introduction to the major approaches to carbon sequestration. The positions of the speakers do not represent current government policy or a consensus of best approaches. They do reflect fairly recent thinking on the subject. Much more research will be necessary, of course, before the government and its partners in the private sector can begin to chart a course of action. All of the participants agreed that the concentration of carbon dioxide in the atmosphere will continue to increase for some years to come and that humankind will have to find ways of dealing with the impacts. The scope, scale, and severity of these impacts are relatively unknown, however, and it may be several decades before the atmospheric concentration of carbon dioxide reaches a steady state, which will be significantly higher than it is today.

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There are six important things to remember about the greenhouse problem and carbon management.

1. The greenhouse problem is a century-scale problem.

The greenhouse problem is not a decade-scale problem or a millennium-scale problem. It cannot be solved in the short term, but it does not require an extremely long view either. This observation is based on a simple quantitative estimate of when the greenhouse problem will become dangerous. It won't be next year—but when? If we assume the greenhouse problem will become serious when the carbon dioxide (CO_2) concentration in the atmosphere reaches twice the preindustrial concentration, it will happen sometime in the second half of this century, if current trends continue. Is doubling the right place to locate the yellow flashing light warning us that we are entering the danger zone? Some have proposed a lower figure. The 1992 U.N. Framework Convention on Climate Change gives no guidance on how to decide when human interference in the climate system becomes dangerous.

It is hardly surprising that, faced with a century-scale problem, the tendency is to postpone taking action. Moreover, if we wait, the argument goes, we will no doubt be smarter about the science, the risks, and the technologies.

Can we justify acting now? One argument for acting now is that it would leave us room to maneuver. We are currently unsure of future damage from higher levels of CO_2 in the atmosphere. At a later time, when we know more, we may decide that today's estimates of damage are underestimates and that tougher concentration objectives are warranted. Acting now will make adjusting to such knowledge less painful. Another argument for acting now is that we are ready now. In many cases, all we have to do is combine already commercialized technologies in new ways.

2. From a one-century perspective, the characteristics of fossil fuel production look complex and unfamiliar.

Today, two of the most debated issues are the geopolitics of oil and competition between coal and natural gas. But by midcentury, conventional oil and natural gas are not likely to be as prominent as energy sources. Coal will still be very much in evidence, but unconventional fuels, like tar sands and shales and methane clathrates, may also be major sources of energy.

We must understand the importance of coal. Relative to oil and gas, coal is abundant, and it has a low feedstock cost. China and India, as well as the United States, are certain to be using a great deal of coal far into the future. But coal has a terrible legacy—danger to workers, acid runoff, subsidence, air laden with particulates, acid rain. A great deal of interest is being focused on "clean coal," which usually means coal burned with greatly reduced emissions. But to earn the attribution "clean," coal must meet other criteria as well.

Coal comes out of the ground contaminated with elements other than carbon, hydrogen, and oxygen . Many of these contaminants require management. Work is now being done to capture the carbon in coal as CO_2. Might we be able to co-capture and co-store ("co-sequester") some of these nasty contaminants along with the CO_2? Today, in Alberta, Canada, and elsewhere, CO_2 and hydrogen sulfide are routinely removed together from natural gas and co-stored below ground. Could that practice be extended and generalized? A complete answer will require working out the effect of impurities on the components of power plants (which could be redesigned), on pipelines to disposal sites, and on storage reservoirs.

3. Hydrogen is intimately connected with carbon management.

About half of the fossil carbon we use today is distributed to small users (e.g., vehicle engines, furnaces in buildings, etc.) before being burned. It is unlikely that we could collect CO_2 out of the tailpipes of cars and out of the chimneys of home furnaces the way we collect aluminum cans. Once these fuels are dispersed, the cost of carbon retrieval is probably prohibitive. Electricity is a carbon-free form of energy, but an all-electric economy is unlikely. Fuels are likely to continue to be preferred for many applications. The most likely carbon-free system will involve the distribution of both electricity and hydrogen, which would be used either in fuel cells or in combustion devices.

Hydrogen can be produced in many ways. One way is from natural gas or coal, with co-product electricity and with a stream of concentrated CO_2 ready for transport and storage. Hydrogen produced from either natural gas or coal, with CO_2 captured and stored, may be cheaper than hydrogen produced from renewable or nuclear energy. If hydrogen is produced from coal, probably the first step will be oxygen-blown gasification.

If we were to begin right now to implement a hydrogen-plus-electricity economy, one benefit would be that we would confront, rather than vaguely worry about, hydrogen safety. Today, hydrogen is handled only in specific industries by trained workers, with, I believe, a low accident rate. But could the general public be given a hydrogen system that is safe and, in some sense, idiot proof?

4. Early action on the permitting of CO_2 storage sites will reveal many difficult, largely unresolved issues.

What level of storage integrity should be required in the permitting of a CO_2 storage site? Clearly, no catastrophic releases that present substantial risks to human health can be tolerated. But should we be relaxed about the loss of 1 percent of the stored CO_2 each year through slow leaks? What about the loss of 1 percent a year from 10 percent of the sites? Probably, the level of leakage allowed during the first few decades of storage can be higher than in later decades, not only because we will learn as we go and make improvements, but also because the total quantities stored will increase over time.

Other questions arise. Should we strive to develop a storage system that future generations can undo? What techniques are available for monitoring a storage site and responding constructively to evidence that the behavior of stored materials is deviating from what we expected? How will we keep the overall costs of storage from escalating to the point where the prognosis for the whole strategy becomes bleak, as has happened with nuclear power.

There are two obvious precedents for storage of CO_2 in the United States, and both of them are poor. These precedents are the underground injection of hazardous waste and the storage of nuclear waste. The underground injection of hazardous wastes is governed by a permitting process regulated by the Environmental Protection Agency. As best I can tell, the process involves absurdly detailed modeling intended to prove that nothing serious will happen below ground after injection, followed by little, if any, postinjection monitoring and verification of what is actually happening below ground. The program to store nuclear waste began with great hubris; the public was promised leak-proof, very long-term storage. But under close scrutiny, these promises could not be met. If the nuclear community had admitted from the start that containment in waste repositories might occasionally lead to small leaks, long-term nuclear waste disposal facilities might already be operating.

The public will understand that carbon storage has imperfections. Only some, not all, of the carbon brought out of the ground will be captured. And some additional carbon will be brought out of the ground to provide the energy necessary to capture and store carbon.

5. Carbon management is not a winner-take-all strategy.

We have a whole portfolio of options for achieving major changes in the global energy system. And we will need many of them. Two options, at opposite ends of the spectrum in readiness for deployment, are: (1) improved energy efficiency; and (2) the direct capture of CO_2 from air.

Those of us who have worked on improving energy efficiency have been frustrated that many good ideas have not been implemented. We still build buildings as if energy were practically free. Most of the relevant institutional issues were identified back in the 1970s but have still not been addressed.

David Keith and Klaus Lackner are investigating ways to pull CO_2 directly out of the atmosphere and concentrate it (e.g., using the reactions $CaO + CO_2 \rightarrow CaCO_3$ and $CaCO_3 \rightarrow CaO + CO_2$). Could machines, located wherever we wish, remove CO_2 from the atmosphere as fast as we put it in, or maybe even faster?

6. Carbon management confronts us with ethical issues.

Carbon management is intended to avoid dangerous interference with the climate system. "Dangerous" to whom? To what? Carbon management is, simultaneously, environmental technology and survival technology. As environmental technology, it is directed toward minimizing the impact of human activity on the biosphere. As survival technology, it is directed toward maximizing human welfare. The two objectives are not necessarily at odds, but they are distinct.

Engineering is the profession most closely associated with maximizing traditional measures of human welfare. Earth systems engineering is a name often given to attempts to take charge of the Earth and organize its processes for human benefit. "Stabilization," our newly articulated goal for future CO_2 concentration in the atmosphere, is a word borrowed from engineering, specifically from control theory.

Trying to take charge of the planet via Earth systems engineering is rather like trying to take charge of our own bodies via genetic engineering. We need rules for both activities. One difference is that we can choose not to modify the human genome, but we are already changing the planet week by week.