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Capturing Carbon

The Carbon Cycle and Climate Change

Most proposals for mitigating the effects of climate change aim to decrease the atmospheric concentration of carbon dioxide. That gas is one of the chief contributors to the greenhouse effect, the atmospheric phenomenon that keeps our planet habitably warm but that could also, in excess, make the planet uninhabitably hot. Carbon dioxide is not the only gas that contributes to the greenhouse effect; in fact, water found in the atmosphere plays a much bigger part, but since human activities don't have much effect on the atmospheric concentration of water, it is less relevant to policy discussions.

However, the comparison to water is a useful one in understanding why excessive carbon dioxide in the atmosphere is a problem—and what we might do about it. Schoolchildren are taught about the water cycle, the stages a water molecule might go through: falling from the sky as precipitation, flowing into puddles and rivers, perhaps spending time in plants or animals or in the ocean, eventually evaporating back into the atmosphere and forming clouds. Carbon, too, has a natural cycle, albeit one that generally takes a lot longer than that of water to complete. Whereas a water molecule might float about the atmosphere for a week or two, a carbon dioxide molecule can stay airborne for a hundred years before being absorbed by the ocean or perhaps being absorbed by a growing plant to form more organic material. If taken in by a plant it could be centuries before the organic material decayed, releasing carbon dioxide in the process. If sequestered by mineralogical processes, a carbon atom could remain in the earth for millions of years.

In the pre-industrial era, the natural concentration of atmospheric carbon dioxide was the result of a balance between the carbon dioxide being *emitted* by organisms (as a result of respiration or the decay of plant matter such as leaves) and by inorganic processes (such as volcanic eruptions) and being *absorbed* into plants, oceans, and even stone. These processes are fairly well known, and often quite measurable. For example, there is a noticeable annual fluctuation in the global atmospheric concentration of carbon dioxide resulting from the seasonal cycle. During the spring and summer growing season in the northern hemisphere (home to most of the planet's arable land), carbon dioxide is absorbed by growing plants. In autumn, those plants shed some of their growth and their leaves decay, releasing carbon dioxide. This small annual cycle can be seen on charts of atmospheric carbon dioxide concentration over time.

Modern technology, however, results in more carbon dioxide in the atmosphere—primarily the exhaust from the combustion that drives our power plants. Hydrocarbon fuels are oxidized when burned in the presence of oxygen, transforming strings of carbon and hydrogen into carbon dioxide and water, both greenhouse gases. This has taken place with a magnitude significant enough to make a noticeable difference in the global atmospheric concentration of carbon dioxide, contributing to an increase of about 25 to 30 percent over the highest typical levels of pre-industrial times. Our industrialization—including our carbon-dioxide-emitting power plants, factories, and automobiles—has produced unprecedented wealth and alleviated much suffering. As the world has modernized, we have built more and more sources of these emissions, to the point that man now emits 29 billion tonnes of carbon dioxide into the atmosphere annually. (A tonne is a metric ton—1,000 kilograms, or roughly 2,200 pounds.)

Meanwhile, there has not been a comparable increase in the processes that *remove* carbon dioxide from the atmosphere; nature will not remove from the atmosphere the 29 billion tonnes of carbon dioxide we emit this year, so its overall concentration in the atmosphere will rise. The slowness of the carbon cycle—specifically, the length of time that carbon dioxide spends floating about in the atmosphere—means that the carbon dioxide emissions of today could affect atmospheric concentrations for decades.

More carbon dioxide in the atmosphere means a more potent greenhouse effect, and more warming. This is true even though some global-warming skeptics have claimed that there's a natural saturation point beyond which carbon dioxide won't contribute to global warming. These skeptics have argued that the frequencies of light blocked by carbon dioxide are now as blocked as they'll ever be by the carbon dioxide *already* in the atmosphere—meaning that additional carbon dioxide won't do further harm. Unfortunately, this is a misunderstanding of the physics. Scientists define an *extinction length* as the height of a segment of atmosphere required to contain enough molecules of greenhouse gases to fully absorb a certain wavelength of energy. One could think of an extinction layer as the equivalent of a blanket around the planet. Adding more greenhouse gases would shorten the extinction length—that is, because there are more greenhouse-gas molecules floating around, the infrared radiation can be blocked in a smaller distance—thereby increasing the number of extinction layers. This is analogous to adding a greater number of blankets around the earth, thereby increasing its temperature.

While it is clear that increased concentrations of atmospheric carbon dioxide result in, on average, increased temperatures, we still must have a reasonable understanding of the extent of the problem in order to know what, if anything, to do to about it. As Jim Manzi argued in the previous issue of this journal, if the most likely scenarios for climate change as outlined by the U.N.'s Intergovernmental Panel on Climate Change (IPCC) were to come to pass, the economic losses that would likely result would be less than the economic losses caused by today's leading proposals to deal with climate change, such as the Kyoto Protocol. Nevertheless, due to the political environment—both of the 2008 U.S. presidential candidates support laws that seek to lessen the severity of climate change by capping carbon emissions—the political debate is increasingly turning to the question of *what* to do instead of the question of *whether* we should do anything at all.

Given the high economic cost of limiting emissions, and given the fact that the natural carbon cycle is not removing carbon dioxide from the atmosphere as quickly we put it there, the question arises: Are there artificial means we can pursue to lower atmospheric concentrations of carbon dioxide—or at least to prevent a significant increase—without stifling the economy and thereby causing the poverty and suffering we are trying to avoid in our very efforts to mitigate climate change?

One proposal is called carbon capture and sequestration (CCS). What if we could trap the carbon dioxide coming from the largest of the emitters—such as coal-fired power plants—and keep it someplace safe so that it doesn't enter the atmosphere? In this approach, we would agree on suitable locations for carbon dioxide and move substantial portions of it there.

Carbon dioxide emissions are already being captured at plants in several locations around the globe. The IPCC released a report on carbon sequestration in 2005, highlighting three plants in particular: Norway's Sleipner gas fields, Canada's Weyburn project, and Algeria's In Salah project. Together, the associated facilities compress and store underground between 3 and 4 million tonnes of super-critical carbon dioxide annually, which exists in a condensed state that is something between a liquid and a gas. Nearly 30 million additional tonnes are annually pumped underground in efforts to force more oil out of wells (a fairly successful technique known as *enhanced oil recovery*). In all of these cases, it has been possible to safely store carbon dioxide with very high stability. The technologies needed to capture carbon dioxide from plants, store it, and even transport it via pipeline are all readily available and thoroughly tested. Many of them are already employed in the oil and gas industries.

There are three main categories of proposals for storing carbon dioxide: in the ocean, in mineral form, or underground. With ocean storage, a pipe is placed somewhere between 1,000 and 3,000 meters under the surface and the excess carbon dioxide is pushed through it. This technique is expensive, uncontrollable, destructive to organisms, and less tested than underground storage. Similarly, though storing carbon dioxide chemically in minerals in the form of carbonates has the advantage of resulting in secure storage for millions of years, it is extremely expensive, requiring the transportation, treatment, and storage of somewhere between 1.6 and 3.7 tonnes of silicate rock for every tonne of carbon dioxide captured. For these reasons, underground (often called geological) storage is generally considered the most feasible of the three.

In underground storage, the carbon dioxide that is captured from major sources of emission would be transported via small-diameter pipeline (only a few inches across) to one of the many areas with suitable geological formations. It so happens that many of these areas coincide with sites of successful mining and oil drilling, such as in the American south. The transported carbon dioxide would then be piped to a depth of at least 800 meters, where the pressure is high enough to keep it in its dense, supercritical state. This is easiest to do at depleted mines and oil wells, where there are very well-understood cavities and perhaps reusable infrastructure. The IPCC's 2005 study concluded that over 99 percent of the carbon dioxide stored this way would "very likely" remain secure after a century (with "very likely" defined as greater than 90 percent confidence) and that this quantity would "likely" remain long after a millennium (with "likely" defined as a confidence of between 66 and 90 percent). In this time frame, stored carbon dioxide could actually become more secure, as some of the natural mineralogical processes begin to act more permanently to sequester it chemically.

Yet while underground storage is technically feasible and effective over a long time period, it is not yet economically sensible. CCS may be one of the cheapest currently available methods for preventing atmospheric carbon dioxide concentrations from getting too high, but it would still increase energy costs by anywhere from 20 to 50 percent (as estimated by the IPCC), most of which would be spent to separate, capture, and compress the gas at the sources. As a result, nearly all goods and services would see a significant price increase. As the IPCC report on carbon sequestration says, at least two things would have to happen before CCS could be pursued at a global level:

> (1) anthropogenic global climate change has to be regarded as

> a relatively serious problem; (2) there must be acceptance of the need for large reductions in carbon dioxide emissions to reduce the threat of global climate change.

That is, CCS would be a good option for reducing man-made climate change if it becomes clear that the cost of implementation is less than that of doing nothing. Regardless, it may make sense to build new plants according to CCS-ready designs—designs that emphasize efficiency even if the carbon dioxide isn't actually being captured—so that the technology could be rapidly adopted. Based on various feasibility studies and economic analyses, the IPCC estimates that between 15 and 55 percent of the climate-change mitigation in this century could come from CCS. Early adoption could push it toward the higher end of that estimate.

Meanwhile, even as CCS is stalled for economic reasons, research for dealing with carbon dioxide emissions is proceeding in other directions. The most intriguing approach—although one admittedly still only in the early experimental phase—is "carbon recycling": artificially completing the natural carbon cycle by converting excess carbon dioxide back into hydrocarbons like the gas and oil that fuel our cars, warm our homes, and power our factories. Some companies, such as San Francisco-based LS9, Inc., have been developing microorganisms capable of producing hydrocarbons. There has been a lot of success with microorganisms that secrete crude oil, but one company—Amyris Biotechnologies, based in Emeryville, California—is even attempting to engineer organisms that directly produce refined gasoline. And researchers at Sandia National Laboratory have developed a prototype apparatus that uses solar energy to heat carbon dioxide to a temperature hot enough to release one oxygen atom per molecule, resulting in carbon monoxide and pure oxygen gas, the latter of which can be vented off. Chemists have for decades used the former to create hydrocarbons (using a reaction called the Fischer-Tropsch process). Whether using microorganisms or using the solar technique, the potential exists for developed nations to obtain useful fuels directly from sunlight and the carbon dioxide we now consider a deleterious waste.

Although neither the feasibility nor the economics of these carbon recycling techniques have been fully worked out, there is reason to be hopeful. The notion of replacing some of the oil bought from the deserts around the Persian Gulf with oil produced in the American southwest by vats of microbes and with solar power is attractive indeed.

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