Climate Change

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A Gathering Storm

For more than a century it has been known that the emissions of carbon dioxide (CO_2) from burning fossil fuels would affect the climate. For most of that history, this thesis was proffered as a curiosity rather than a call for action. Geophysicists were interested in questions such as the natural cycles of ice ages; a few even considered the possibility that humans, themselves, could be affecting Nature on a planetary scale.

Only since the late 1950s have scientists been engaged in a continuous research program on human emissions of CO_2. In 1957, Roger Revelle and Han Suess famously declared: "Through his worldwide industrialized civilization, man is unwittingly conducting a vast geophysical experiment. Within a few generations he is burning the fossil fuels that slowly accumulated in the earth over the past 500 million years." Their paper, and several others published at about the same time, established a field of research on the cycling of carbon between its many different forms and reservoirs on land, in the atmosphere and in the oceans. The first permanent monitoring stations for CO_2 were established in the 1950s, and the 1960s saw the testing of the first simple computer models that allowed estimation of climatic effects from changing CO_2; since the 1970s that modeling program has become more complex as scientists have sought to simulate global climate in all four dimensions (latitude, longitude, altitude and time). The 1970s also saw the first widespread appreciation of the possible climatic consequences of deforestation, which caused large amounts of CO_2 emissions from burning and rotting trees and the release of CO_2 from the soils in deforested areas. (Today, about one-seventh of the human emissions of CO_2 is a byproduct of deforestation; nearly all of the rest results from burning fossil fuels.)

Concerns about a changing climate arose in the early 1970s, though the worry was not warming but cooling. Research had suggested that Earth was already prone to another ice age, and industrial emissions of particulates (which were thought to reflect sunlight back to space and thus cool the planet) might accelerate that shift. An even more prominent concern was supersonic transportation. Until the sobriety of economics took hold, visionaries had imagined a huge fleet of large supersonic transport aircraft. These planes would release exhaust (including nitrogen oxides and water vapor) into the high altitudes where they flew; the resulting clouds might cool the planet, and the nitrogen oxides might trigger chemical reactions that could deplete the ozone layer. (This concern about the ozone layer predated, and partly presaged, the research that linked chlorofluorocarbons to depletion of the ozone layer.) The first detailed studies of the possible socioeconomic consequences of a changing climate were completed in the middle 1970s and also focused on cooling. (Those studies, interestingly, found that cooling was generally bad news through effects such as the stunting of crops and increased demand for heating. Today, with warming a concern, much of the research also finds and emphasizes bad news. Environmental analysts, perhaps, are prone to find bad news under every stone they turn.)

While the scientific community continued to investigate the possible impacts of a changing climate during the 1970s, concerns about climate change didn't gain much traction during the decade—in part because global economic troubles and the energy crises focused minds on other topics and in part because the imagined fleet of supersonic transports was never built. (Only a handful of small Concorde aircraft ever took to the skies as commercial transports, and the small number of military supersonic fliers probably had a negligible effect on the stratosphere and, in any case, were shrouded in secrecy.)

Much of the scientific talent that worked on global atmospheric issues became focused on the question of ozone depletion, which helped to spawn a whole field in the analysis of atmospheric chemistry. The topic gained increasing public attention as the evidence mounted that chlorofluorocarbons (CFCs) and other industrial gases would deplete the ozone layer. The U.S. and a few other nations banned the use of CFCs in aerosol cans in the late 1970s. Those efforts eventually led to the 1985 Vienna Convention and the 1987 Montreal Protocol that established a legal framework for the phase-out of CFCs and other ozone-depleting substances. Polls have shown that the public often confuses (or equates) ozone depletion with global climate change when, in fact, the two problems are largely distinct. For the development of policy, however, the two problems have been deeply inter-twined. Many of the scientists and analytical tools that have been applied to the climate problem were crafted, originally, with research support that had been inspired by the desire to understand the ozone layer and other global atmospheric changes. The realization that humans could affect the global atmosphere and the policy tools for response largely emerged in the debate over the ozone layer and soon were extended to the problem of global climate change.

In the late 1980s, fresh from the creation of a mechanism to protect the ozone layer, policy entrepreneurs focused their attention on climate change. The cooling hypothesis of the 1970s gave way to concerns about warming as it became clear that the warming effects from carbon dioxide, methane and other greenhouse gases would far exceed cooling. Working mainly in the United States, Canada, and northern Europe, they called attention to the dangers of unchecked changes in climate. Media attention rose and often catalyzed its own additional attention; when the hot summer of 1988 generated many media stories in the U.S., reporters in Europe also redoubled their coverage. Through various international conferences on the science of climate change, policy entrepreneurs tried to set into motion a process for a binding international treaty on climate change—patterned on the Montrol Protocol on Substances that Deplete the Ozone Layer—but they found their efforts partly blocked by wary governments (notably the U.S.). Instead, governments crafted an international process for assessing the science of climate change: the Intergovernmental Panel on Climate Change (IPCC). The IPCC reflected, at its core, the political compromises between governments that sought policy action and those that wanted, for the moment, to focus on the science. The IPCC enlisted most of the world's leading climate scientists and many social scientists; it also explicitly engaged scientists from developing countries, and the leadership in all committees reflected a balance of industrialized and developing countries. The IPCC effort was explicitly intergovernmental, which meant that governments made the final decisions about key summaries of IPCC documents and could, in extreme cases, even block reports. Scientists were entrusted to do most of the work; throughout, the process was designed to assess what was known rather than to conduct new studies. The IPCC process has often been laden with controversy—much of it rooted in differences of interpretation about the urgency of policy action but reflected in technical disputes about the science. IPCC's research on the natural scientific aspects of the climate problem has generally been its most coherent and highest quality work; as IPCC has drifted in the social sciences its work has declined on both dimensions—coherence and quality—which is a reflection both of the political salience of those topics and the fact that the intellectual disciplines in the social sciences are generally less robust than in the natural sciences. Where disciplines ("paradigms") are weak it is much more difficult to review the state of knowledge because it is harder to see how all the pieces fit together and it is more difficult to decide which work contains the highest scientific quality.

International Legal Commitments

The first IPCC reports confirmed the central validity of the hypothesis that rising concentrations of greenhouse gases would cause global climate change. These reports, finished in 1990, immediately spawned pressure for an international policy response.

Already some governments had set targets for controlling their emissions—for example, at a 1988 conference in Toronto many prominent political figures had pledged to cut emissions 20% by 2005, although none had proffered a viable plan for achieving such aggressive goals.

A process for negotiating a global treaty on climate change was set into motion in 1991, and by the 1992 Rio Conference on the Environment and Development governments finalized the United Nations Framework Convention on Climate Change (FCCC). Some had been pressing for that treaty to include binding emissions reduction targets and timetables—akin to the Toronto pledges—but absent agreement on that subject the diplomats adopted their normal response to controversy and pushed binding decisions into the future. They required that the first meeting of the Conference of the Parties (COP), the Convention's supreme decision-making body, make a declaration about whether the Convention was "adequate" or whether additional commitments would be needed.

Today, 187 nations are members of the Framework Convention—essentially every nation on Earth except for Iraq, Somalia, Turkey, and few others. However, widespread membership and compliance reflects the Convention's exceedingly modest obligations, not a serious international commitment to combat climate change. For the United States and industrialized countries, compliance has required developing programs that "aim" to reduce emissions to 1990 levels, submitting reports on emissions of greenhouse gases and contributing to a special fund that compensates developing countries for the "agreed incremental cost" of their efforts to comply with the Convention's goals. The concept "agreed incremental cost" is a perennial feature in international environmental treaties negotiated since the late 1980s; it reflects, in essence, the desire of the developing countries to be compensated for the entire extra ("incremental") cost of abiding by the treaty's strictures while, at the same time, allowing the industrialized countries that pay these costs through special funding mechanisms to avoid the impression of a blank check.

The Convention commits all members to work toward the "ultimate objective" of limiting atmospheric concentrations to levels that will avoid "dangerous anthropogenic interference with the climate system." This aspirational framework reflected the national interests of the key participants at the time the Convention was finalized. Industrialized nations generally sought to control emissions but could not agree on the particular level of effort nor how to share the burden. Developing nations were wary of encumbering commitments and thus agreed only to those actions that imposed no cost on their economies.

In 1995, the first meeting of the COP (so-called "COP-1") predictably declared that the FCCC was not adequate and set into motion a process for negotiating stronger commitments and set COP-3, slated for December 1997 in Kyoto, as the deadline. During most of the two years that followed COP-1 the deliberations were unfocused; with the threat of failure looming, national delegations hurriedly assembled an agreement late in 1997, which they finalized at Kyoto during a marathon ten day negotiating session attended by 10,000 delegates and observers.

The Kyoto Protocol obliges industrialized nations—listed in Annex I of the FCCC—to cut their emissions on average 5% below 1990 levels during the five-year "first budget period" of 2008-2012. The target is "comprehensive," which means that it applies to all anthropogenic sources and sinks of all major greenhouse gases (table 1). Through negotiation, the overall goal of a 5% cut was "differentiated" among the Annex I countries (see table 2). These differences reflected variations in public concern and pressure to address the problem, different starting points, and different negotiating skills among countries.

The ultimately agreed upon goals (shown in table 2) only partially reflect the actual level of effort required in each country–factors exogenous to climate policy also played a part. In Europe, overall emissions had already declined because of economic restructuring following the opening of the Eastern bloc and also because the shift to a competitive electric power market in England and Wales had caused a shift to less carbon-intensive natural gas. (Natural gas emits less than half the CO_2 per unit of electricity produced when compared with coal.) In contrast, in the U.S. emissions were rising steadily throughout the 1990s with the booming growth of the American economy. Another factor affecting costs is the efficiency of the existing technologies and practices in the economy, as well as economic structure. In Japan, decades of investment in energy efficiency meant that the country would start with a low emissions baseline and thus achieving further reductions would be costly. These factors were exogenous to climate policy but had a large effect on costs because the Kyoto commitments were expressed not in terms of the level of effort required (i.e., cost) but in the output (i.e., level of emissions).

Developing countries ("non-Annex I") adamantly and successfully resisted any formal controls on their future emissions, arguing that their scarce resources must be spent on other more pressing problems such as the alleviation of poverty. The problem of global warming, they argued, is principally due to past emissions from industrialized nations. Some industrialized countries, led by the United States, had pushed developing countries to voluntarily limit their future emissions. Greenhouse warming is a global problem caused by all nations, they argued, and no solution to the problem can be effective without widespread participation. Indeed, emissions from developing countries are growing rapidly and will overtake those of Annex I nations by approximately 2030 or 2040; however, per-capita emissions from virtually all developing countries will remain lower than those in nearly all industrialized nations for the foreseeable future. The developing countries have resisted, arguing that their priority is development and (as with the industrialized countries before) the least costly path to development requires an abundance of inexpensive fossil fuels.

Although the Kyoto Protocol targets are specific and stringent, the Protocol also includes several "flexibility" measures that were designed to make it easier and less costly for Annex I countries to comply. First, because the target is "comprehensive" it includes all the major sources of greenhouse gases as well as "sinks," such as forests, that absorb the most important gas, carbon dioxide; a comprehensive approach allows freedom for countries to focus on the sources and sinks that are least costly to regulate. This approach was particularly notable in two areas. It allowed countries to offset emissions of carbon dioxide due to combustion of fossil fuels—the largest source of global warming, which was costly to control in many countries—with carbon absorbed in biomass due to afforestation and other changes in land use. In addition, the comprehensive approach has encouraged countries to capture fugitive sources of methane gas, such as leaks from landfills. Exchange rates, known as "global warming potentials (GWPs)," are used to convert between the different gases. Every ton of methane avoided is worth 21 tons of CO_2. While this flexibility offers enormous theoretical advantages, in practice it has proved difficult to accurately measure many of these sources and sinks of greenhouse gases.

Second, industrialized nations have flexibility to select favorable base years. Instead of 1990, several countries in the midst of transition from command to market economies have selected base years in the late 1980s when emissions were at their peak before economic collapse. In addition, the Kyoto Protocol allows any industrialized nation to select 1990 or 1995 as the base year for the "synthetic gases"—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of HFCs—replacements for gases phased out under the Montreal Protocol—were rising especially rapidly in the early 1990s. With higher base year emissions, a given percentage cut can be achieved more easily.

Third, and potentially the most important, is the Protocol's provision for different types of "emission trading." In principle, emission trading cuts the cost of complying with the Protocol by allowing nations and firms to trade the right to emit greenhouse gases—permits will be sold and abatement focused where regulating sources and sinks is least costly. As soon as the Kyoto Protocol was completed it became clear that any emission trading system that included Russia would lead to large international flows of emission credits out of Russia, complemented by large cash inflows. The Russian economy had collapsed in the 1990s; at the lowest point (1998) Russian emissions were about 40% below 1990 levels. In Kyoto, Russia agreed to cap its emissions at 1990 levels in the first budget period—a target it is unlikely to achieve, even in light of the current recovery of the Russian economy. In contrast, the United States, Europe and Japan all negotiated much more demanding targets for themselves. Emission projections for 2008-2012 suggested that Russia would have surplus emission credits of roughly one billion tons of CO_2. Selling those credits (mainly to U.S. firms) could have netted Russia perhaps twenty to fifty billion U.S. dollars, although the surplus would not have been the result of any active Russian effort to control emissions. Opponents of the system branded the potential trading with Russia as “hot air.” They said that Russian credits were simply a paper surplus—an artifact of the collapse of the Russian economy and not the work of any “real” policy to control emissions.

By design, an integrated international trading system would make it cheaper to move credits across borders rather than force countries to meet their targets entirely through action within their borders. In the rush to create the Kyoto Protocol, however, much less attention was given to the fact that creating an international trading system was akin to crafting a new form of money. The allocation of emission credits is crucially important in determining the allocation of benefits from the system, and the total number of credits would determine the extent to which the trading system actually had an impact on global emissions.

The Kyoto Protocol also includes two more limited forms of emission trading: "joint implementation (JI)" and the "Clean Development Mechanism (CDM)." JI allows credits to be earned and traded on a project-by-project basis, which gives an incentive for cost-effective international emission control without necessarily confronting the difficulty of allocating permits and administering a full-blown emission trading system. JI governs such project-by-project trades between countries that have agreed to cap their emissions—for example, if a German firm invests in a project to reduce methane emissions from leaky natural gas pipelines in Russia, then the credits from that project could be transferred via the JI mechanism from Russia's balance sheet to Germany's.

The Clean Development Mechanism (CDM) is the same concept applied to developing countries. However, putting the CDM into operation is more difficult because the Protocol does not set limits for emissions from developing countries. Thus, for the CDM, it is especially important to determine the baseline level of emissions that would have occurred without the investment; credits are given for the difference between (lower) actual emissions and the baseline level.

Rules for operating and accounting under the CDM were left unresolved at Kyoto—in part, that is why the negotiators in Kyoto were able to achieve widespread agreement on the need for the CDM. In the years since, a complicated set of rules has emerged and is tying the CDM in red tape. The methodology for performing baseline calculations is particularly difficult since it requires a counterfactual calculation about complex economic and technological interactions that extend over the full lifetime of the CDM project (typically 21 years). Experience with similarly structured programs in the United States—known as pollution offsets—has shown that if the rules are too cumbersome then the system will fail to encourage trading.

The Kyoto Protocol entered into force in February 2005 following the decision of Russian ratification. In March 2001 the United States refused to consider joining the agreement—resulting in international opprobrium, to which we will return shortly—and that gave Russia the trump card for the treaty's fate. The Protocol includes a clause that prevents it from entering into force unless it is ratified by 55 parties to the FCCC that represent 55% of the emissions of industrial carbon dioxide from Annex I countries in 1990. This latter clause was the difficult one to satisfy since the U.S. (34% of Annex I emissions) plus Russia (17%) are sufficient to block the treaty. In general, the Russian government cares little about climate change; many Russian scientists are skeptical of the scientific basis and still others have argued that some change in climate would benefit the country. The real issue for Russian participation was the risk that a cap on CO_2 emissions would constrain the economy (which was unlikely) and the possibility that sales of CO_2 credits could be beneficial to Russia. If the U.S. ratified the treaty, the demand for those credits would have been very high, but absent U.S. membership demand collapsed and Russian policy makers saw fewer benefits (albeit with few if any costs).

NEXT STEPS AND UNFINISHED BUSINESS

Ever since the middle 1980s most policy attention on climate change has focused on the creation of international institutions to assess the science (IPCC) and to coordinate regulatory actions by countries (FCCC and the Kyoto Protocol). Attention is now shifting to the five areas that have received less attention.

Implementation

Now that the Kyoto Protocol has entered into force there has been growing attention to implementation and compliance. By far, most of that attention has focused on the major industrial regions that have ratified the Protocol—the European Union, Japan and Canada. Later, we examine the situation in the United States, which remains an outsider to Kyoto.

All three of these industrialized parties have encountered difficulties in putting their Kyoto commitments into practice. In part because the United States is not engaging in much effort to control its emissions, other industrialized countries have faced pressure from their home industries to limit the costs of Kyoto. Canada is implementing its Kyoto commitments with a set of tax incentives that lighten the cost for individual industries (but are costly to Canada's public budget), and is also creating an emission trading system that has a $15 per ton "safety valve"—a mechanism that allows the government to issue additional emission credits at an agreed upon price—so that industry can be confident that the costs of compliance are not excessive. Japan is implementing its commitments through a series of industry covenants that provide for flexibility. Neither Canada nor Japan expects to achieve their targets fully within their borders—they will rely on JI and CDM to plug holes in their balance sheets and assure compliance with their Kyoto commitments.

By far the largest and most important efforts at implementing the Kyoto commitments are in the European Union. The EU re-allocated its 8% across-the-board cut in emissions so that countries where the public was particularly keen to address the climate problem (mainly northern Europe) accepted stringent obligations while those that cared little and put a higher priority on development (mainly in the south, such as Portugal, Spain and Greece) were allowed a large increase in emissions. The EU also created an emissions trading system (ETS) that covers all major industrial sources of EU emissions (about 45% of the total). The ETS began operation in a trial phase in January 2005.

In addition to the nascent Canadian system and the new ETS, several other entities have created systems for trading emission credits. They include an effort in the U.S. (the Chicago Climate Exchange, which includes 19 North American firms) as well as one in New South Wales—both of which operate in countries that have no binding limits on emissions. The New South Wales system is a province-wide scheme that reveals that even when a national government abhors limits that some of its federal components may nonetheless proceed with their own effort.

These different trading systems reveal an important point about the implementation process—especially where (as is likely in most countries) implementation involves an effort to deploy a market-based emission trading system. In principle, the greatest gains from emission trading will arise in an international system that involves the largest number of countries from as diverse backgrounds as possible. Only then will the gains from trade be greatest. Indeed, the Kyoto Protocol envisioned that the thirty-eight industrialized countries with binding emission caps would be allowed to trade portions of their emission quotas. Economic modeling and pilot projects have already proved that flexibility in the geography of emission control can cut costs dramatically. For example, American Electric Power—the largest coal-burning U.S. electric utility—has demonstrated that it is less costly to limit net emissions to the atmosphere by protecting a rainforest in Bolivia than to control emissions from its existing power plants located in the U.S.

On the other hand, it is not practical to create an emission trading system "top down"—one that starts including the greatest number of countries. The countries that have the greatest opportunity for low cost emission controls—developing countries as well as Russia and Ukraine—are those that have the weakest internal institutions and thus are least likely to be able to monitor and enforce the system. Since emission credits are analogous to a new form of currency, countries with weak institutions could print excessive quantities of this new currency, degrading the value of the scrip held by all others and causing higher emissions that undermine the scheme's environmental objectives. An international treaty probably does not offer strong enough institutions to deter such actions—violators could be ejected, but by the time their transgressions are known certainly it may be too late for others to adjust their behavior. No durable currency has ever sprung forth by starting with large numbers of highly diverse agents in the absence of strong institutions that are essential to protecting the currency's value.

Indeed, with this currency analogy in mind, it is useful to keep in mind the experience in Europe of creating the Euro. In that case, twelve countries created a common currency within an existing context of strong collective institutions, independent courts, a robust administrative bureaucracy, and a new central bank. Even then, the transition has been far from seamless. In 2003, when France and Germany failed to comply with limits on their budget deficits, the European Monetary Union (EMU) declined to penalize them, even though this failure in essence siphoned value from compliant members. It would be a daunting task to attempt to forge a currency of emission credits in the context of much weaker international law with countries such as

Russia and most of the developing countries that question the need for any emission controls.

Thus, in practice, the countries that have the strongest internal desire to address the climate problem are pressing ahead most rapidly and building the strongest institutions. Far from casting their net widely and securing the greatest gains from trade, they are focusing their efforts on institution-building at the level where institutions are most effective—in the case of the ETS, notably, that effort spans the EU. Jurisdictions that care most about the environmental problem at hand would establish their own trading systems and enforcement rules. Then portals (exchanges) between the systems would be established according to bilateral consent. Thus countries could control their exposures to poor enforcement and excessive allocation by deciding where they open portals. Inspired by the early years of the General Agreement on Tariffs and Trade (GATT), members in this bottom-up process of regime formation might also create international rules of mutual recognition, reciprocity, and most favored nation arrangements that ensure that those who accept the strictures of core trading arrangements gain the benefit of access to all markets that are part of the regime. Enforcement would rest principally with member states and the market, which would value each country's scrip individually, just as currency markets assign different and varying values to dollars, yen, euros and rupees.

Engaging the U.S.

The Kyoto effort is, for the moment, particularly striking for its lack of engagement with the United States. From the moment that the ink dried on the Kyoto Protocol it was probably inevitable that the U.S. would require a renegotiation of its commitments or would abandon the treaty altogether. Imposing Kyoto's emission controls on the United States—a 7 percent reduction in emissions of greenhouse gases below 1990 levels during the years 2008 to 2012—was politically unsustainable. At the close of the 1990s U.S. emissions were already 17 percent above 1990 levels and rising at 1.3 percent per year. Reversing that trend before 2008 would be impossible without major economic disruptions, and thus any plan for U.S. compliance would have required prodigious use of the international emission trading system. That implied a large outflow of capital to developing countries (via the CDM) and to Russia (via emission trading), an activity in which the U.S. was unlikely to engage.

Early in 2001, the Bush administration adopted a policy that, in effect, withdrew the United States from the Kyoto process. It argued that the United States could not meet its Kyoto targets at acceptable cost and it was unfair to force U.S. industry to compete in a world economy without meaningful emission controls on all nations—including developing countries. In February 2002 the Bush administration announced an alternative approach that is based on voluntary actions by firms, investment in new technology—such as hydrogen-powered fuel cells for vehicles and advanced low-emission coal plants—as well as partnerships with key developing countries to assist their application of advanced technologies.

Ever since 1988, prominent Senators and Members of Congress have introduced bills to require mandatory limits on emissions, although not one of those bills has passed. In 2003, the Senate voted on a bill sponsored by Senators Lieberman and McCain, which would have imposed caps on U.S. emissions of greenhouse gases; that effort failed, and a repeat attempt in 2005 also fell short.

Absent mandatory controls, since 1992 the federal government has had in place a program to encourage private firms to make voluntary reductions. Many firms have participated in this scheme because they see it as a way to gain public credit for cost-effective reductions that they would have made anyway (or, in some cases, that they have made at very low cost). Many participants also appear to believe that acknowledged reductions will lead to future rewards, such as extra emission credits in some future emission trading program. The federal government has also made modest changes to energy efficiency standards, notably for light trucks.

Without much effective action at the federal level, various other actors are filling the vacuum. Several states have announced targets for their own emissions, and many mayors of cities (e.g., Boston, New York and San Francisco) have also pledged themselves to meet the Kyoto targets. It is hard to see how cities and states, acting individually, will make much progress on the issue since most U.S. emissions are a byproduct of economic activities that are deeply ingrained in inter-state commerce. In large part, advocates for the myriad of state-based efforts are attempting to create a modicum of chaos and patchwork in the regulatory environment. That, they hope, will put pressure on firms to lobby for federal action that will iron out the differences.

Engaging Developing Countries

It has proved particularly difficult to engage developing countries in controlling their emissions. Today these countries account for only a small fraction of the greenhouse gases that have accumulated in the atmosphere, but their share is rising rapidly with industrialization. Kyoto imposed no targets and timetables for emissions from developing countries. However, the CDM—largely the brainchild of Brazil and the United States—was designed to encourage foreign investment in projects that yield lower emissions of greenhouse gases. It was hoped that this scheme would not only cut the costs of compliance for industrialized nations but also accelerate the diffusion of new technologies to developing countries and engage them in the larger global effort. For example, the World Bank has pooled funding from a coalition of twenty-three governments and firms to invest in projects such as a small dam in Chile to produce electricity without producing CO_2 from the burning of fossil fuels. Investors seek to jump-start the CDM and to get emission credits that they can use back at home. Host countries such as Chile seek investment.

Nearly all developing countries have resisted any engagement further than the CDM and other schemes for which they are fully compensated (and then some) for their costs of participation. This impasse creates a problem since developing countries already account for nearly half the world's emissions of greenhouse gases, although their per-capita emissions are still much lower than those of the advanced industrialized nations. (China's emissions, although 12% of the world total, are about one-tenth those of the U.S. on a per-capita basis; U.S. emissions account for 23% of the world total.) So long as developing countries do little to deviate from their current emission-intensive development trajectories it will be difficult for industrialized nations to muster the political coalitions needed for deeper cuts in emissions. In a global marketplace it is difficult to sustain a policy that imposes costs on some competitors but not others. While much good research has shown that these distortions often don't have much effect on real trade and investment there are strong political forces demanding action by developing countries. In the United States, notably, the Senate passed with a 95-0 vote the "Byrd-Hagel" resolution the summer of 1997 that declared that no international treaty would be acceptable to the U.S. unless it "…also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period…" The lopsided voted reflected, in part, that the resolution was not binding and in part that Senators held quite different interpretations of the resolution's sparse language. Nonetheless, it was a shot heard around the world.

Broadly, there have been three options for engaging the developing countries.

First, the existing system can be extended—in effect, a scheme that does not engage the developing countries. Developing countries favor lack of engagement, despite the disproportionate risks they run if he climate continues to warm. They have expressed concern about climate change, and mounting evidence shows they are more vulnerable than industrialized nations to storm surges, heat waves, drought, and other changes in climate. Compared with advanced industrialized nations, their economies depend more on weather-related activities such as agriculture; they are less able to muster the capital to invest in climate-proofing for infrastructures, and they are less likely to build institutions such as systems for forecasting extreme weather events that can help reduce climate vulnerabilities. Their preference for inaction reflects not the lack of concern and exposure but, rather, the higher priority they place on the immediate task of development. The logic that they articulate for this position is that the United States and other advanced industrialized countries developed without limitations on the use of fossil fuels. They also insist that the deal originally codified in the UNFCCC—that the advanced industrialized nations take the first steps in implementing meaningful policies—has not yet been honored.

In the future it may be additionally difficult to gain developing countries' participation since the Kyoto experience is widely seen as a false promise. The Clean Development Mechanism (CDM) had been touted as a device for attracting foreign investment into projects that reduce emissions, but so far only three minor projects have gained approval. The World Bank has helped to jump start the CDM by organizing the Prototype Carbon Fund (PCF)—a $US180 million consortium of six governments (excluding the United States) and seventeen firms (none based in the United States) to fund a portfolio of CDM-like projects. Because PCF's mandate is to promote only the highest quality projects, most of the PCF projects are sited in countries with strong domestic institutions. None is in the largest developing countries—such as China, India, Indonesia, and Malaysia. Just one project is in Brazil and one in South Africa. More than one-third of the PCF projects are in Eastern Europe and do not involve developing countries at all. From the perspective of most of the key developing countries, the promised investments for climate protection are still elusive.

It might be possible to reinvigorate the Kyoto system, in particular the CDM, which could lead to a fuller engagement of developing countries. Procedures for approving CDM projects could be streamlined; true experts rather than politically instructed diplomats could be empowered to make more of the key decisions about the level of credit that would be awarded for projects. The taboo placed on certain kinds of low-carbon energy projects (e.g., nuclear and large hydro and tropical forestry management) could be lifted, making them eligible for CDM credit. While some countries would welcome such reforms, so far no coalition for CDM reform has emerged; building such a coalition would require complex negotiation arithmetic and, crucially, would require taking on the large and growing bureaucracy that is developing an interest in the CDM's status quo. In addition to that bureaucracy, other political interests favor a hobbled CDM. So long as the CDM is cumbersome to use, Russia and Ukraine remain the only potential international suppliers of large quantities of emission credits, giving these countries potential power in the Kyoto market and ensuring that international trading activities focus on paper credits rather than bona fide reductions that channel investment to developing countries.

A second option is to demand that developing countries accept caps on their emissions. However, that approach appears unlikely to gain any traction. It might be possible to design emission caps that reflect the interests of key developing countries and that are set with enough "headroom" to allow emissions to temporarily to grow. However, the developing countries will refuse caps unless they are generous—just as Russia performed in Kyoto, they will imagine their highest level of possible emissions and demand a cap at or above that level. And if they don't get an attractive cap they can simply exit the scheme without paying much of a penalty. Yet generous caps could undermine the integrity of emission trading systems, which are based on the notion that carbon credits are scarce, monitoring and enforcement will be strict, and exit is difficult.

It might be possible to force developing countries to accept strict caps by linking the climate issue to other matters like the World Trade Organization. In the past, such linkages have proved difficult to craft; indeed, the WTO agenda is already over-crowded by many issues, and developing countries (as well as most trade experts) are already opposed to integrating environmental standards into trade rules. The effects of loading environmental, labor, human rights, and other standards on the world trading system may include the loss of welfare for all nations by raising barriers to trade as well as greater risk that new trade rounds will fail to make progress due to conflicts over these new rules and standards.

Third, a new strategy for engaging with developing countries could be devised. The two options presented so far—disengagement and emission caps with headroom—have dominated most policy discussion for the last decade. Neither has been effective. This third approach would involve working with developing countries to craft "climate friendly" development strategies. Unlike the CDM, which aims to animate investment by awarding credits, this approach would attempt to put climate issues into the mainstream of development policy. It would focus on broad policy initiatives, such as investment in natural gas infrastructures that make it easier for countries to operate natural gas fired electricity generators where they otherwise would pursue coal. Many countries are already making such investments. China and India, for example, are in the midst of installing large gas infrastructures. In China these include a gas pipeline from gas reserves in the western part of the nation to Beijing and Shanghai, as well as LNG terminals in southern coastal cities. In India these infrastructures include new gas pipelines, incentives to develop newly discovered offshore gas reserves, and India's first ever operational LNG terminal, which took its first delivery in January 2004. At the same time, a program to develop advanced coal power plants that allow for sequestration of CO_2 could help developing countries that are rich in coal reserves (such as China, India, Indonesia and South Africa) gain confidence that taking the climate problem seriously will not undermine their efforts to supply electricity and other modern energy services. Following this strategy would entail focusing not on the emissions but the various factors that block or accelerate the shift to low-carbon infrastructures. For example, in China's case those factors include the lack of a security compact with Russia; there are huge gas deposits in Siberia that could be shipped economically to China, but such ventures will not proceed without a better political relationship between the two countries. In India, such investments depend on an accommodation with Iran, which has the world's second-largest gas reserves (behind Russia) and could easily pipe gas to India (across Pakistan), but the U.S. has worked aggressively to block such pipeline proposals due to its over-riding concerns about Iran. (Those concerns are probably mis-placed since Iran will sell its gas anyway; the big question is whether it ships the gas by boat in liquefied form, which is expensive and will slow India's transition to gas, or by pipeline.)

This strategy of mainstreaming climate into development is closest to what the developing countries have begun to articulate themselves as their first preference. It would involve working principally with the major policy organs in developing countries that are responsible for development—for example, finance, industry, and planning ministries. Industrialized countries could play a role in supporting activities that would help countries realize their own development goals in ways that also happen to reduce carbon emissions. The advantage of this approach is that it would involve swimming with the tide—identifying activities that the host government would already favor (and fund) and activities that already align with the interests of private profit-making ventures. For example, the United States already has extensive development assistance programs in major developing countries, mainly through the U.S. Agency for International Development (USAID). These programs include attention to the improvement of energy efficiency and to the reorganization of energy systems in ways that encourage investment in modern technologies. A slight refocus of these programs could make carbon a central organizing principle; by helping these countries reorganize their energy systems to make them more profitable and to better serve the needs of the local population, such programs could also lower the intensity of greenhouse gas emissions. As Bangladesh and India have learned how to introduce gas into their electric power systems, such programs could help ensure that the lessons are learned in neighboring Nepal and Pakistan. Already, USAID programs have helped countries identify ways to make fuller use of low carbon renewable power. For example, in India a USAID project has helped a sugar cane refinery recycle crop wastes to generate heat and electricity, which has reduced the need for fossil fuel energy.

Beyond Mitigation

Nearly all of the policy effort on climate change has focused either on understanding the problem better or, increasingly, on controlling the emissions that cause global warming (known in the jargon as "mitigation"). Yet there are three other aspects of the climate problem that may also merit explicit efforts at international cooperation.

One is technology cooperation. Ultimately, a solution to the climate problem will require cutting emissions of greenhouse gases by 60% to 80% below current levels. In effect, we must either largely eliminate fossil fuels from the energy system or find ways to burn fossil fuels but contain and sequester the CO_2 before it is released into the atmosphere. Radical changes in the world energy system have historically taken about 50-80 years to consummate; for example, it took about 50 years for oil to rise from a niche product to become the dominant source of primary energy in the world. That change was slow because it was paced by a series of interlocking changes in technology (e.g., automobiles) and infrastructures (roads, filling stations, etc.). The basic knowledge required for such radical changes is, in many respects, a global public good—it is beneficial to all but hard to appropriate. As with most public goods, societies left alone may not adequately invest in radical technology R&D.

Whereas international coordination on controlling emissions of greenhouse gases is difficult because a large number of countries with highly disparate interests must be engaged, coordination on an international technology agenda is probably much easier. The United States, Japan, and the core group of large European nations together account for about 85 percent of world spending on R&D. All these nations share a common (though not identical) interest in addressing the problem of climate change, and all have well-developed public institutions for administering sophisticated and costly research programs. There is a long history of collaboration among these nations on basic research programs, from joint experiments in the atmosphere, oceans, and Antarctica; these nations also collaborate on multi-billion dollar scientific facilities, such as CERN (a high energy physics facility on the French/Swiss border) and ITER (the next generation of facilities that aims to demonstrate scientifically and economically viable nuclear fusion, which will be located in France).

At present, there is almost no international collaboration on energy R&D, except in a few special areas marked by extremely expensive facilities (e.g., ITER) or a long history of international coordination (e.g., advanced fission nuclear reactors). The main international program in this area is managed by the International Energy Agency and consists of little more than governments declaring their own greenhouse gas R&D programs and exchanging broad reports with an international secretariat. Rarely do international collaborations lead to the point of international collective funding; however, even efforts to achieve a coordinated research plan and strategy could be beneficial.

The need for international coordination may be especially great for reasons that are proving difficult for some governments to acknowledge publicly. Some technologies are so risky or stigmatized that they can't be developed in the advanced industrialized world. In crop engineering, for example, Europe has slipped far behind the world's top innovators because of public concern about the technology. Those concerns could spill over into energy systems as bioengineering could also help to create more productive energy crops. In nuclear power, even the industrialized countries that have most embraced that technology—Japan and France—find it increasingly difficult to deploy new reactors. Interestingly, industrialized countries' concerns have created niches for developing countries. One of the promising new reactor designs is currently on the drawing boards at the South African electric power utility, Eskom. China appears to have reached the #2 spot (just behind the United States) in crop genetic engineering due to a combination of generous government support for R&D, some pilfering of western intellectual property, and, notably, a public that is not encouraged to oppose field testing and growing of the novel strains.

The second area for international cooperation is in improving how societies adapt to climate change. Climate change has spawned efforts to control its root causes—emissions of greenhouse gases—because it is assumed that human societies and ecosystems are unable to adapt easily. That assumption may not be completely correct, and in any case some changes in climate are inevitable and thus adaptation will be necessary. At present, the UNFCCC and Kyoto Protocol include some language on the need for adaptation, and there have been some efforts to promote adaptation, but these efforts to date have amounted to little. The leverage on adaptation is highly scattered. Some exists at the international level—for example, improved data sharing systems and weather forecasting schemes could make it easier for societies to anticipate and adjust to weather extremes such as typhoons. Most of the leverage on adaptation probably resides within countries and is not much amenable to international action. Moreover, the single most powerful force for adaptation is economic development, and thus it is appropriate that developing countries have emphasized the need for their development above the mitigation of greenhouse gas emissions.

Even with a more active approach to adaptation, it is probably not possible to achieve complete invulnerability to a changing climate. Three types of impacts, in particular, may be difficult to manage.

First, some countries—mainly developing countries—will face enormous difficulty adapting. Low lying nations, such as the archipelago of Vanuatu in the Pacific and large swaths of coastal Bangladesh that sit barely a meter above sea level, face the specter of rising sea levels. In Bangladesh alone, more than ten million people live one meter (or less) above sea level. Economically, it may be much less costly to move these populations (or ignore their troubles), but as a matter of justice and politics that option may not be viable.

Second, it may prove very difficult to contain and manage some climate hazards—especially those that tend to move across borders. For example, many scientists have suggested that a warmer and wetter climate will facilitate the spread of malaria, yellow fever, and other water-borne diseases. Industrialized countries have already brought these diseases under control, and developing countries will probably do the same as they become wealthier. However, it may prove difficult to check the spread of climate-linked diseases as borders become more porous. When the United States brought malaria under control one hundred years ago, it was difficult for malarial patients to travel and re-infect a zone; today, every major malarial zone in the world is less than twenty-four hours from the United States by airplane, and forty million international air passengers arrive in the United States every year.

Third, and finally, it may be extremely difficult to adapt to the consequences of abrupt climatic changes—such as a rapid shift in the North Atlantic Ocean circulation or an accelerated century-long melting of the West Antarctic Ice Sheet. Better monitoring and gaming of these scenarios could improve our adaptive capacity, but the dislocations could be so large that adaptation is not an option. It is difficult to assign probabilities to these extreme possible effects of a changing climate; for risk-averse societies these lowprobability high-impact events are likely to be the driving force for stringent actions to mitigate emissions of greenhouse gases.

The third and final area of activities beyond mitigation would apply technology as part of an adaptation strategy. To the extent that societies believe that changing climate may present abrupt, irreversible and catastrophic changes in climate they may want to prepare "geoengineering" technologies that allow prompt and direct intervention in climate. Many of the technologies that have been considered involve altering the reflectivity of Earth, such as the installation of mirrors in orbit between the Earth and Sun, so as to cool the climate. Such proposals raise interesting questions of concerted action since they create dangers, and they may affect nations in differential ways. The legality of deploying such schemes—or even whether legal matters would affect national choices—has not been explored in detail. There are general legal duties not to cause harm to others, and there is a 1970s-era international treaty that governs weather modification efforts, but it may prove difficult to apply these laws to the practice of geoengineering. In any case, for now geoengineering is a topic that excites physicists and engineers; so far, there has been essentially no large-scale investment in geoengineering schemes so that the option would be available for deployment if desired.

<u>Choosing Policy Instruments: Beyond Kyoto</u>

Finally, the entry into force of the Kyoto Protocol has assured that for the next few years the actual focus of implementation efforts in much of the industrialized world will be on the Kyoto commitments. But, at the same time, it has raised questions about the design of future commitments and the international institutional mechanisms for codifying them into practice.

On the design of policy instruments, the central questions relate to the capping of emissions. This approach has been attractive to advocates for environmental protection because it is simple to explain and guarantees that a certain environmental outcome (i.e., a limit on emissions) will be achieved. The danger of this approach is that by specifying the environmental goal the policy leaves uncertain the cost. At caps are ratcheted tighter, the danger of a policy that becomes more costly than countries are willing to tolerate will rise. Indeed, that was the U.S. experience with Kyoto: an unachievable cap forced the United States to consider either a politically unrealistic shell game of purchasing credits from Russia or simply exiting the regime. One solution to this problem is to create a "safety valve" in the trading system. In effect, this "valve" would limit the price of the emission credits and would make a cap-and-trade system behave like a tax if the cost of compliance rose higher than expected—if, for example, firms did not have enough time to meet a stringent cap on emissions with the normal turnover of the capital stock. However, critics of the "safety valve" approach argue that only the terror of potentially high prices will force firms to focus on low-carbon innovations.

Over the short term, the greatest single factor in determining emissions in the United States has been the size of the economy; when the U.S. economy grew rapidly in the late 1990s so did its emissions, making the Kyoto targets increasingly beyond the American grasp. By setting obligations in terms of the total volume of emissions, Kyoto unwittingly appeared to put environmental protection into direct conflict with economic growth. Indeed, when measured in terms of emission volumes the advanced industrialized countries that have achieved the greatest emission reductions have done so through economic weakness. Germany shut down factories in East Germany; Luxembourg, which achieved the deepest percentage cut in emission volumes of any industrialized nation in the 1990s, owes its success to closing a major steel plant and relying more heavily on imported (rather than domestically generated) electricity. When President Bush announced his climate change policy in February 2002 he therefore adopted the measure of "greenhouse gas intensity"—the ratio of emissions to the size of the economy. Figure 2 shows this measure for some key countries. Judged on the basis of "intensity," the United Kingdom and United States are in the pack at about 210 grams of carbon emitted per dollar of economic output (gC/$). Japan and France rest at about two-thirds that value, reflecting aggressive energy efficiency policies and high energy prices as well as large sources of carbon-free nuclear power in both countries'. Most developing countries have higher carbon intensity. China's official statistics suggest a carbon intensity of around 300 gC/$, although that has declined from its peak of about 600 gC/$ in the early 1980s. South Africa has among the highest carbon intensities with 400 gC/$, as its heavy mining and industrial economy is based on the least costly electricity in world, nearly all of it powered by carbon-intensive coal. India's carbon intensity is about the same level as the United States, but the level is rising due to industrialization of the Indian economy.

In addition to a fresh debate about the design of policy goals, there is also much unfinished business in the design of international commitments. Most of the canon of international environmental law is based on binding treaty commitments—often in the form of a framework convention followed by specific regulatory protocols (as is the case with climate change). In some areas, this approach has been very effective, but the attention to binding commitments carries a large drawback: compliance. Diplomats pay very close attention to negotiating commitments with which they are sure they can comply. Yet commitments that entail uncertain effects on the economy, negotiated by democratic governments whose interests are fickle, create strong pressures for conservatism by diplomats. The result may be agreements that trade ambition for assurance that the parties will be able to comply; yet the most important task of coordination may in fact be found in setting ambitious goals.

There are many types of international institutions that deserve attention—either as replacements for Kyoto or as complements to the Protocol. In some areas of environmental law, governments have crafted highly effective non-binding agreements along with review procedures that set ambitious goals and then provide a regular assessment of the extent to which governments are approaching their goals. Such approaches have been used, for example, to set the pace for controlling nitrogen oxide emissions (a leading cause of acid rain) in Europe and pollution of the North Sea. A similar concept, known as "pledge and review," was floated in the early days of the climate change negotiations but rejected (wrongly, in my view) by environmental advocates as too lax. Another novel concept would involve the creation of a standing group of leaders of the twenty primary players among industrialized and developing countries (a concept dubbed the "L20" by its leading advocate, Canadian Prime Minister Paul Martin). The L20 could tackle a range of global issues that require compromises that only leaders could forge; through communiqués and a system of peer review, akin to the G8, it could lead and frame action.

Conclusion

Climate change has become the grand-daddy of all international environmental problems. Not only does the problem create physical dangers (and opportunities) that will be felt globally, but it also requires an unprecedented degree of global cooperation. The effects of climate change and the consequences of sustained policy efforts accumulate only slowly since the lifetimes of the main greenhouse gas, carbon dioxide, is extremely long—decades to centuries.

So far, most policy action on climate change has focused on efforts to review the state of scientific knowledge on the problem and on the international coordination of policy. Two clusters of international institutions have emerged from those efforts. One, the IPCC, operates in a somewhat ad hoc fashion and is constituted every few years to provide a fresh review of the science. The other, the network of activity surrounding the UNFCCC, including the Kyoto Protocol, is a permanent fixture with a permanent secretariat and is the host for a complex array of policy negotiations.

Considering the century-scale nature of the climate problem and its sheer complexity, much of this apparatus has come into place quite quickly. The IPCC was first constituted in 1988 and has since completed four major assessments. The UNFCCC was completed in 1992; the Kyoto Protocol has existed since late 1997, albeit in incomplete form since critical details on its implementation were left vague in Kyoto and are still being settled.

The really important actions relate to the implementation of efforts to control carbon at the ground level—within countries and, ultimately, at the level of firms and individuals. While there is much unfinished business, complex systems for controlling carbon are being put into place—notably in Europe. These systems are creating expectations and constraints that will exert a strong influence on the future shape of international efforts to address the climate problem. In large part, the international response will be forged by stitching together the many different national and regional schemes because the institutions that are strongest and most capable of action are not those that operate globally but, rather, the ones in place within nation-states.

Bibliographic Essay

On the causes and consequences of climate change

For the most comprehensive international reports on the causes and possible consequences of climate change, see the results of the Intergovernmental Panel on Climate Change (IPCC): http://www.ipcc.ch

These reports have framed much of the debate; however, the United States government has also periodically asked the National Academy of Sciences to investigate particular issues. For several of their most important reports see:

Climate Change Science: An Analysis of Some Key Questions (2001): http://books.nap.edu/openbook/0309075742/html/R1.html.

Reconciling Observations of Global Temperature Change (2000): http://www.nap.edu/books/0309068916/html/

Abrupt Climate Change: Inevitable Surprises (2002): http://books.nap.edu/openbook/0309074347/html/

For more on the impacts of climate change in the United States see the National, reproduced in part as Appendix B: http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewfindings.htm

For more eclectic and highly opinionated accounts, here are two particularly active and irreverent sources:

Stephen H. Schneider: Climate Change: http://stephenschneider.stanford.edu/

Science and Environmental Policy Project (SEPP): http://www.sepp.org/

On the economic costs of controlling emissions

Where Kyoto was taking shape there were many efforts to model the economic consequences. A far-ranging and systematic inter-comparison of model results in Stanford University's Energy Modeling Forum (EMF) provides a good introduction to the results: http://www.stanford.edu/group/EMF

The EMF also contributed heavily to the IPCC reports (cited above), and chapters in the report from IPCC Working Group #3 provide overviews of the issues and introduce in detail some of the controversies in economic modeling.

A key issue in assessing possible costs of control is the future structure of the world and regional energy systems. Here are two reports on that:

On the world's energy systems generally, with assessments of key regions, see the International Energy Agency World Energy Outlook (2004) and World Energy Investment Outlook (2003): http://www.worldenergyoutlook.org/pubs/index.asp

On future emissions see the IPCC Special Report on Emission Scenarios (SRES): http://www.grida.no/climate/ipcc/emission/

On International Cooperation and the design of international agreements

Key international agreements (*United Nations Framework Convention on Climate Change*, and the *Kyoto Protocol*), information on activities under those agreements such as the Clean Development Mechanism (CDM), and links to government-reported data on emissions and policies are all online at: http://unfccc.int

There is a large and growing literature on international "architectures" or "regimes" to address climate change. Much of it is based on analogies with other areas of international cooperation on environmental and economic problems as well as analogies with policy instruments that have been utilized to address national environmental problems, such as the sulfur dioxide emission trading program used in the United States. For some windows into that huge literature see:

Schelling, Thomas C., "Costs and Benefits of Greenhouse Gas Reduction", AEI Studies on Global Environmental Policy, AEI Press, Washington, D.C., 1998.

Morgan, M. Granger, "Climate Change: Managing Carbon from the Bottom Up", *Science* 2000 289: 2285.

Victor, David G., The Collapse of the Kyoto Protocol and the Struggle to Slow Global Warming, Princeton University Press, Princeton, N.J., 2001.

Barrett, Scott, Environment and Statecraft: The Strategy of Environmental Treaty-Making, Oxford University Press, Oxford, 2003.

Aldy, Joseph E., Barrett, Scott and Stavins, Robert N., "Thirteen Plus One: A Comparison of Global Climate Policy Architectures", *Climate Policy* 2003: 373-397.
Stewart, Richard B. and Wiener, Jonathan B., Reconstructing Climate Policy: Beyond Kyoto, AEI Press, Washington, D.C., 2003.

Pew Center on Global Climate Change, "Beyond Kyoto: Advancing the International Effort Against Climate Change" (2003): http://www.pewclimate.org/global-warming-in-depth/all_reports/beyond_kyoto/index.cfm

The "L20" project has focused on possible roles for a standing body of heads of state drawn from the major industrialized and developing countries; the group of leaders of these roughly 20 countries ("L20") would focus on global problems for which engagement at the highest levels of government is essential. Among the topics that the L20 architects have considered is climate change. For more, including background papers on major aspects of the climate issue, see: http://www.l20.org.

On Implementation

For attention to U.S. policy options on energy topics generally—including climate change see the National Commission on Energy Policy, http://www.energycommission.org/

For a focus on policy options for the United States see David G. Victor, 2004, *Climate Change: Debating America's Policy Options* (New York: Council on Foreign Relations); online at http://www.cfr.org. Appendix A of that book also reprints the Byrd-Hagel resolution and excerpts from the floor debate after which the resolution was approved.

For attention to the emerging "currency" of carbon credits see Victor, David G/. and Joshua C. House, "A New Currency: Climate Change and Carbon Credits", *Harvard International Review* Summer 2004: 56-59.

Table 1: Gases included in the Kyoto Protocol. Table shows the six main gases included in the Kyoto Protocol. The percent contribution to global warming is the percent of the total increase (appx 2.3 watts per square meter) over pre-industrial ("natural") levels of greenhouse forcing in the 1990s. Global Warming Potentials (GWPs) are 100-year values adopted by the Intergovernmental Panel on Climate Change in 1995. Only major anthropogenic sources and sinks are listed. (Most of the gases that deplete the ozone layer are also greenhouse gases; however, they are already tightly regulated by the Montreal Protocol on Substances that Deplete the Ozone Layer and thus excluded from the Kyoto Protocol.)

Gas	Percent of total global warming in 1990s	GWP	Anthropogenic Sources	Anthropogenic Sinks
Carbon Dioxide (CO_2)	70%	1	fossil fuels, cement, deforestation & other land-use changes.	afforestation and other land use changes.
Methane (CH_4)	20%	21	rice paddies, domestic animals, fossil fuels, biomass burning, landfills	no direct sinks
Nitrous Oxide (N_2O)	6%	310	nitrogen fertilizers, fossil fuels	none
Hydrofluorocarbons (e.g., CHF_3, CH_3CHF_2)	<1% (rising rapidly)	11700 (CHF_3)	replacements for ozone-depleting substances (e.g., refrigerants, solvents)	none
Perfluorocarbons (e.g., CF_4, C_2F_6)	<1% (rising rapidly)	6500 (CF_4)	byproduct of aluminum smelting, semiconductor production	none
Sulfur Hexafluoride (SF_6)	<1% (rising rapidly)	23900	electrical equipment, magnesium smelting	none

Table 2: Emission targets for Annex I countries. The percentage change is from emission levels of 1990 (for all gases, weighted by GWPs), with some provisions for flexibility discussed in the text. Parties may pool and reallocate their targets among their members; so far only the European Community has indicated that it will do so. Targets are listed in Annex B of the Protocol; that Annex includes the same list of countries as in Annex I of the FCCC, except that Turkey had objected to its listing in Annex I and thus was excluded from Annex B in Kyoto.

Kyoto Target	Annex I country (*or regional economic integration organization)*
-8%	*European Community*
	Austria
	Belgium
	Denmark
	Finland
	France
	Germany
	Greece
	Ireland
	Italy
	Luxembourg
	Netherlands
	Portugal
	Spain
	Sweden
	United Kingdom of Great Britain and Northern Ireland
-8%	Bulgaria
-8%	Czech Republic
-8%	Estonia
-8%	Latvia
-8%	Lichtenstein
-8%	Lithuania
-8%	Monaco
-8%	Romania
-8%	Slovakia
-8%	Slovenia
-8%	Switzerland
-7%	United States of America
-6%	Canada
-6%	Hungary
-6%	Japan
-6%	Poland
-5%	Croatia
0%	New Zealand
0%	Russian Federation
0%	Ukraine
+1%	Norway
+8%	Australia
+10%	Iceland

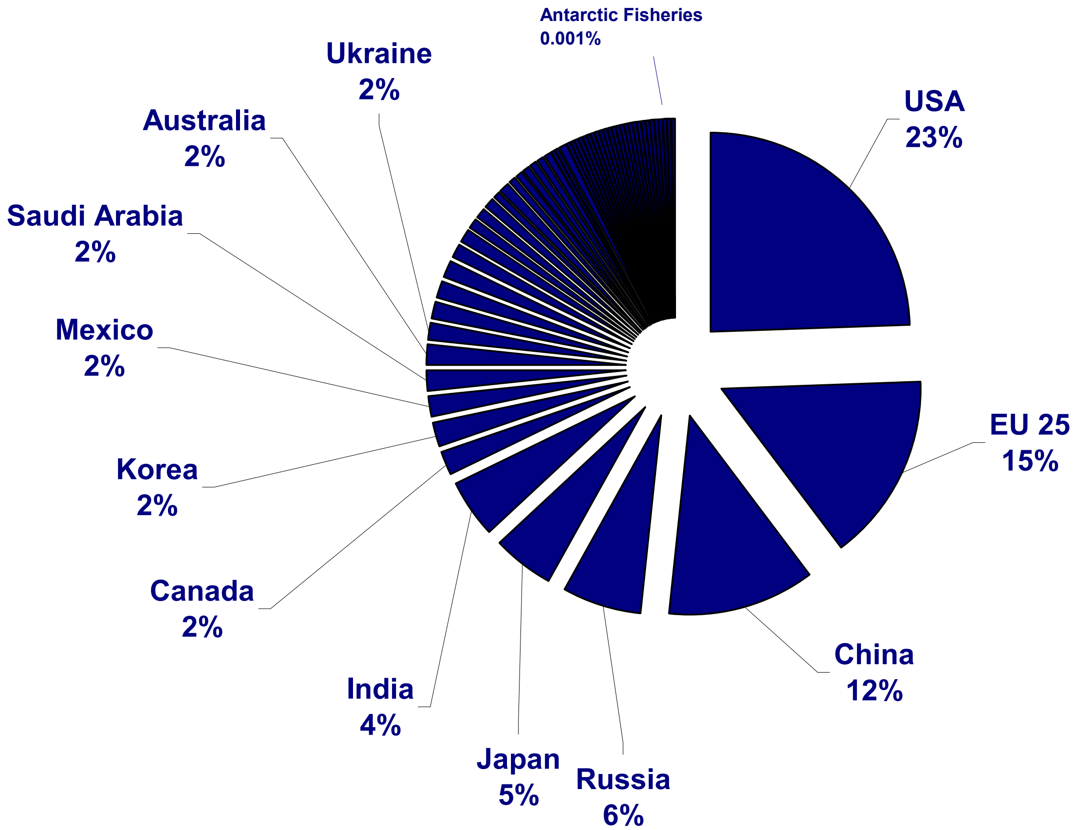

Figure 1: Major worldwide sources of carbon dioxide from burning fossil fuels, 2000. Source: Gregg Marland, Tom Boden, and Bob Andres, Oak Ridge National Laboratory & University of North Dakota.

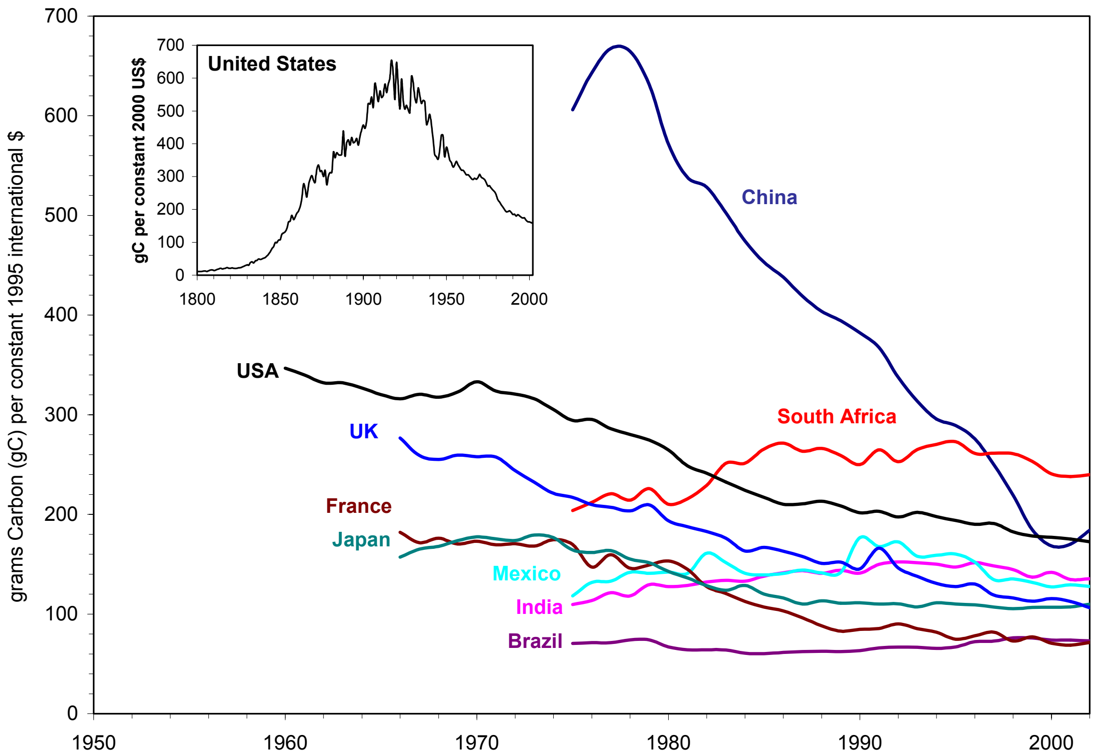

Figure 2: Carbon Intensity of Major Economics, measured as grams of carbon emitted as CO_2 per constant 1995 international dollar of economic output. Inset shows carbon intensity for the United States from 1800 (grams of carbon emitted as CO_2 per constant 2000 US dollar of economic output). Emissions statistics are from the Oak Ridge National Laboratory. Economic output is reported by the Department of Commerce (U.S.) and the World Bank (all other countries) that were converted into constant 1995 international dollars using the World Bank's "purchasing power parities," which account for the higher purchasing power of money in developing countries. Use of market exchange rates would give developing countries much higher carbon intensities than the United States and other industrial economies. These data show only CO_2 emissions from burning fossil fuels and thus do not account for potentially important but less well-documented sources of greenhouse gases, such as deforestation (a major factor in the United States and other industrializing countries in the decades surrounding 1900 and a major factor today in Brazil and other forest-rich tropical nations) and emissions of methane from animal husbandry, growing of certain crops (e.g., rice), drilling for oil and gas, and other sources. Notably absent are CO_2 and methane released from the submerged biomass in lakes behind hydroelectric dams.