THE COMPREHENSIVE APPROACH TO GLOBAL CLIMATE POLICY:

ISSUES OF DESIGN AND PRACTICALITY

Richard B. Stewart*  
Jonathan B. Wiener**

I. INTRODUCTION

The atmosphere is a global commons.¹ Unabated use of the commons as a dumping ground for greenhouse gases ("GHGs") could eventually produce significant, perhaps unacceptable environmental changes.² Yet actions to limit emissions significantly are likely to entail large costs.³ In the absence of a common regime for limiting use of the atmospheric commons, no nation will have an adequate incentive to limit its own use because it will have no assurance that others will do likewise. Its solitary control efforts would do relatively little to avert warming, and its citizens and industries would incur a potentially serious economic disadvantage.

Some nations are already taking measures or setting policies to limit GHGs.⁴ There is also discussion of a regional initiative within the European

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*Visiting Professor of Law, Georgetown University Law Center.  
**J.D. 1987, Harvard Law School; A.B. 1984, Harvard College; currently Policy Counsel, Office of Science & Technology Policy, Washington D.C. The authors' views are their own and do not necessarily reflect those of the U.S. government.

1. It is a true "global commons" in the economic sense; the term is not used in the technical meaning of International law. T.C. Schelling, Economic Responses to Global Warming: Prospects for Cooperative Approaches, in 3Global Warming: Economic Policy 198 (Rudiger Dornbusch & James M. Poterba eds., 1991).

2. This paper addresses the optimal design of policy to respond to climate change in the event such action is warranted based on its costs and benefits. It does not attempt to resolve the question of what level of emissions limitation, if any, is justified. Hence the illustrative point that unlimited emissions could entail damages worth preventing. On the possible impacts of greenhouse gas emissions on climate, see generally Intergovernmental Panel on Climate Change, WMO/UN. Environmental Program, Climate Change: The IPCC Scientific Assessment (John T. Houghton, G.Jenks & J.J.Ehrnaus eds., 1990) [hereinafter "IPCC Scientific Assessment"].


Community. These measures, however, are driven in major part by concerns relating to energy independence, economic efficiency, or environmental problems other than global climate change.

The current negotiations for a global climate convention may yield a framework convention that calls for national strategies to address climate issues and a system for tracking progress in achieving them. This decentralized, “bottom-up” approach is likely to endure for some period of time. If continued research shows no great threat from GHG emissions, the costs of more drastic measures will have been avoided. But if continued scientific research shows that there is a serious, near-term global warming threat warranting more aggressive action to limit concentrations of GHGs in the atmosphere, agreement on joint measures to protect the commons would be necessary. These measures would have to limit net GHG emissions into the commons, determine how entitlements to this limited use of the commons will be allocated, and provide some form of compliance assurances. In short, the creation of some form of property regime for the commons would be required.

The scope of these common measures is a question of critical importance. The incentive effects associated with different policy designs can profoundly affect the cost and effectiveness of environmental protection measures. Policy design issues are too often ignored in the rush to “do something,” because policymakers tend to focus on snapshot evidence of a current symptom of a problem, rather than on its full scope and on the dynamic incentive effects of different policy designs. Both economics and ecology teach that complex, integrated systems like societies and ecosystems deserve comprehensive attention. When policy formulations hastily target one of many interrelated variables, they often ignore lower-cost options to achieve better results and produce unintended side-effects that can confound the best-intended policy.


6. There are considerable uncertainties about the magnitude, timing and regional pattern of any such change. See IPCC Scientific Assessment, supra note 2, at xli. Recent findings suggest that any anthropogenic warming effect may be more gradual than previously believed because one group of gases (“CFCs”), formerly thought to be contributing 25% of enhanced radiative forcing, may be having no net effect. See IPCC, 1992 Supplement 20, 29 (1992) [hereinafter “IPCC Supplement”]. In addition, any near-term effect may be less stressful than previously predicted because the observed slight warming that has occurred over the past several decades, still within the range of natural variation, has occurred almost completely at night and in the winter, rather than increasing extreme temperatures. Id. at 27-29; Thomas Karl et al., Global Warming: Evidence for Asymmetric Diurnal Temperature Change, 18 Geophysical Res. Letters 2252 (1991).

Still, very rapid warming, or warming that leads to unpleasant “surprises” such as strong positive feedbacks or reversals of ocean currents such as those discussed by Stephen H. Schneider, The Changing Climate, Sci. Am., Sept. 1989, at 78, could entail unexpected “catastrophes” that significantly increase the damages to societies and ecosystems. See Schelling, supra note 1, at 204.
Nowhere is the importance of the choice between "piecemeal" and "comprehensive" policy designs more evident than in the context of potential climate change. Anthropogenic activities affect both sources and sinks of several greenhouse gases, including carbon dioxide ("CO₂"), methane ("CH₄"), nitrous oxide ("N₂O"), HCFCs and HFCs, the precursors of tropospheric ozone and of CO₂, including VOCs, NOₓ, and CO, and others. CO₂ emissions represent the largest single current contribution to potential global climate change, accounting for over half of the radiative forcing effect of all GHGs. Most proposals for limitations of GHGs have been restricted to fossil fuel CO₂ emissions, or to CO₂ emissions from the energy and transportation sectors. This "piecemeal" approach, however, ignores other sources of CO₂ and all of the other GHGs. It also ignores GHG sinks, such as forests, whose destruction releases GHGs and whose expansion reduces net GHG emissions.

Two years ago, the Bush administration proposed a comprehensive approach to global climate research and policy that embraced all GHGs, their sources and sinks. The United States argued that a comprehensive approach was far superior, on both economic and environmental grounds, to a piecemeal approach directed at only a part of the problem, such as CO₂ emissions. Initial reactions to this position ranged from skepticism to hostility. Doubts were expressed about the practicality of a comprehensive approach. In addition, some saw the proposal as an excuse for inaction and delay. Those impatient for an early agreement on GHG limitations pressed for a convention controlling CO₂ fossil fuel emissions.

Today, the environmental and economic logic of the comprehensive approach is finding increasing favor among nations currently negotiating a global climate framework agreement and within the international environmental policy community. Nonetheless, doubts about its practicality remain. This essay advocates the comprehensive approach. It first explains what the approach is and how it would be implemented. It then explains the environmental and economic benefits of such an approach and the ways in which it will enhance the likelihood of international agreement on measures to limit GHGs by establishing a level playing field among nations and reducing the cost of achieving limitations. Next, the essay considers the practical scientific and institutional problems in implementing a comprehensive approach. Finally, it discusses how a comprehensive approach could be combined with international trading of net GHG emission reduction credits. Such a trading system would further reduce the costs of achieving reductions in net GHG emissions.

emissions and stimulate the development of a decentralized, effective means of transferring capital and technology from industrialized countries ("ICs") to developing countries ("DCs").

II. THE COMPREHENSIVE APPROACH

The essence of the comprehensive approach is twofold: full accounting of all anthropogenic influences on the environment; and flexibility to take the most cost-effective actions to address those influences. The first element finds its intellectual heritage in multimedia and lifecycle assessments of environmental impacts, ecology, and systems analysis; the second element, in market-based incentive approaches to environmental policy. The comprehensive approach holds that any measures to address global climate issues—whether scientific research on the causes and consequences of global climate change, projections of future net GHG emissions trends, technology assessment, R&D, policy analysis regarding the means and costs of limiting net GHG emissions, or national plans or international agreements to limit GHGs—should address the full environmental problem of concern: net emissions (sources and sinks) of all GHGs.

There are several anthropogenic GHGs whose emissions contribute to global warming. They vary in their instantaneous radiative forcing (heattrapping) ability, reactivity, and residence time in the atmosphere. The instantaneous radiative forcing potential of a molecule of CO₂ is quite weak compared to that of the other GHGs. But CO₂ is by far the most voluminous of anthropogenic GHG emissions, and also has a relatively long residence time in the atmosphere—in excess of 100 years. Taken together these attributes can be used to construct a time-integrated measure of the impact of a CO₂ molecule on the climate, called its "global warming potential" ("GWP"). Although there is uncertainty about rates of sink uptake of CO₂ and thus about CO₂ residence time, and also about the indirect chemical reactions of other GHGs, the per-molecule GWP of CO₂ remains much less than that of other GHGs, even of short-lived GHGs like CH₄. Based on total anthropogenic contributions, net emissions of CO₂ from fossil fuel combustion and other sources, such as deforestation, account for over half and perhaps over two thirds of the GWP of current anthropogenic GHG emissions.

8. IPCC Supplement, supra note 6, at 20-22.
10. IPCC Scientific Assessment, supra note 2, at xx.
11. Based on the new finding that CFCs, formerly thought to contribute 25% of current additions to forcing, may play no net role. See IPCC Supplement, supra note 6, at 20, 29.
The next most important GHG is methane, which has about 58 times more instantaneous radiative forcing potential per kilogram than CO₂, but a residence time of only about 11 years. Methane emissions represent about 20% of the GWP of current GHG emissions. The next most significant GHG is N₂O, with a direct per molecule radiative forcing effect over 200 times greater than CO₂ and an atmospheric residence time of about 150 years. It represents about 8% of total current GHG GWP.

These calculations of GWP are based on several simplifying assumptions that tend to overstate, perhaps significantly, the relative importance of CO₂. These include the use of a model of the carbon cycle that omits important CO₂ sinks and thus overstates the lifetime of CO₂. Another factor is the “saturation effect”: these GWP are calculated in the current atmosphere, but as GHG concentrations rise in the future, the relative impact of additional CO₂ will diminish faster than the relative impact of other GHGs, hence increasing the importance of other GHGs relative to CO₂.

Until recently, it had been thought that CFCs, which destroy the upper stratospheric ozone layer, causing increased amounts of damaging ultraviolet radiation to reach the earth, were also a major GHG, second only to CO₂ in total GWP. The direct radiative forcing effect of CFCs is extremely powerful—several thousand times that of CO₂ on a per molecule basis—and many of the CFCs have relatively long residence times. However, recent advances in scientific knowledge focusing on the indirect reactive effects of CFC emissions have found that CFCs deplete ozone in the lower as well as the upper stratosphere and that lower stratosphere ozone reductions have a significant cooling effect that roughly offsets the warming effect from CFC radiative forcing. This new finding suggests that CFCs in the aggregate may have no net GWP. However, the GWP of different CFCs varies, and the HCFCs and HFCs which were developed to replace CFCs in industrial uses may have significant GWP.

Other trace gases of concern include CO, NOₓ, and VOCs, which as a result of atmospheric reactions form tropospheric ozone. CO and VOCs also result in the atmospheric formation of CO₂. The indirect effects of NOₓ,
CO and VOCs are highly dependent on local atmospheric conditions, however, making a rigorous GWP calculation difficult.\textsuperscript{21}

The GHGs are generated by numerous sources, including human ("anthropogenic") activities, other biological activities, and non-biological processes. Among the anthropogenic sources of trace gases are virtually every sector of human activity, including mining, energy generation, transportation, agriculture, forestry, waste disposal, industry, building and residential services, and others. Biogenic sources are similarly diverse. Meanwhile, CO\textsubscript{2} is removed from the atmosphere by "sinks" such as trees, grasses, and other vegetation; phytoplankton; and ocean mixing. Other GHGs are removed by chemical reactions. Table 1 shows a summary of GHG sources and sinks.

A key to developing a comprehensive approach is the creation and subsequent refinement of an index to compare the environmental effects of different GHG emissions and sinks. If one uses no explicit index, one must still choose which emissions to limit most, by some system of objective or subjective priorities. A quantitative index simply makes the relative environmental impact of the gases explicit, as an aid to decisionmaking.

The most basic index would compare the instantaneous radiative forcing effect of different GHGs, in units equivalent to the effect of a molecule or kilogram of CO\textsubscript{2}. For example, because a kg. of methane has 58 times the instantaneous radiative forcing effect of a kg. of CO\textsubscript{2}, it would have an index value of 58. More sophisticated indices of GWP have already been developed to take into account differences among GHGs in residence time and their indirect effects on climate due to atmospheric reactions. In the most recent IPCC index, for example, CH\textsubscript{4} has a "direct" GWP component 11 times that of CO\textsubscript{2}, and an additional (additive) "indirect" GWP component somewhere between 5 and 15 times that of CO\textsubscript{2}, for an aggregate GWP in the range of 16-26.\textsuperscript{22} As the discussion above explained, CFCs in the aggregate may have a direct GWP component 3000-7000 times larger than that of CO\textsubscript{2}, but their "indirect" effect on lower stratospheric ozone may lower their net GWP to about zero.

Since each GHG has impacts on the environment that go beyond warming, and the point of a comprehensive approach is to optimize net environmental risk for each action or investment, a more complete index (or set of indices) would ideally include not only GWP but other environmental effects. These include ultraviolet-induced damage due to ozone depletion,\textsuperscript{23} the enhanced photosynthetic productivity and water use efficiency of trees and most crop

\textsuperscript{21} See IPCC Supplement, supra note 6, at 22.
\textsuperscript{22} See WMO, Ozone Depletion, supra note 9, at ch. 7.
\textsuperscript{23} Just such an index of "ozone depletion potential" ("ODP") has been developed and used in the Montreal Protocol phaseout of CFCs. See WMO, Ozone Depletion, supra note 9, at ch. 6.
plants resulting from higher levels of CO₂ in the atmosphere, and toxicity. If policy were made without accounting for these impacts, it could inadvertently reduce risks associated with GWP but increase other risks.

To determine the effects of human activity on global climate, one must also have information about net emissions (source emissions less sink uptake) of the various GHGs resulting from human activity. This information would of course be needed for any policy that sought to affect concentrations of the several GHGs. Limits on net GHG emissions can only be achieved by correlative changes in activities that produce such emissions. Where direct monitoring of emissions is infeasible, as it usually is, emissions factors could be developed to relate given amounts of source or sink activity, or raw materials inputs, to net emissions. For example, today CO₂ emissions are measured not at the smokestack, but by calculating the carbon input incorporated in different fuels and adjusting for different combustion efficiencies. Similarly, an acre of rice paddy of a given type could be assigned an emissions factor based on the amount of methane that it emits. Similar measures could be developed for various forms of energy consumption.

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24. The direct effects of CO₂ demonstrated in actual field tests (as compared to the computer models used to predict future climate) are impressive, showing 30-60% gains in productivity for members of the "C3" plant group that make up 80% of the world's food supply. See IPCC Impacts Assessment 25 (1990); Bert G. Drake & P.W. Leadley, Canopy Photosynthesis of Crops and Native Plant Communities Exposed to Long-Term Elevated CO₂, 14 Plant, Coll and Env't 853 (1991); Norman Rosenberg et al., From Climate and CO₂ Enrichment to Evapotranspiration, in Climate Change and U.S. Water Resources 151 (Paul Waggoner, ed., 1990). But cf. Fakhri A. Bazzaz & Eric D. Fajer, Plant Growth in a CO₂-Rich World, Sci. (Am., Jan. 1992) (cautioning against optimism on direct effects of CO₂).

25. E.g., CO and perhaps certain HCFCs are toxic.

26. Effects of the local production processes that lead to these emissions such as the energy fuel cycles that emit GHGs and alternative fuel cycles could potentially be included in this suggested index. See Scott Barrett, Economic Instruments for Climate Change Policy, in Responding to Climate Change: Selected Economic Issues 51, 68 (OECD 1991). We believe, however, that such a step would be undesirable in the context of global policy. First, those effects are not directly related to the GHG molecules themselves; restricting emissions of a GHG might or might not reduce other risks or other emissions from the fuel cycle. This is an empirical matter that depends on the particular policy design and technological responses. Although a CO₂-only tax might reduce SO₂ emissions, restricting SO₂ in the past has increased, not decreased, solid waste and CO₂ emissions. Id. at 68; Worldwatch Inst., State of the World 1990, at 111 (1990); Daniel J. Dudek, Alice LeBlanc & Peter Miller, SO₂ and CO₂: Consistent Policymaking in a Greenhouse (EDF 1990). Similarly, as we illustrate below, restricting CO₂ alone could increase emissions of CH₄. Multiple emissions cannot be assumed to vary in lockstep with each other. Second, those other fuel system risks—which may indeed be more worthy of concern than climate change—could be addressed and internalized by local or national policy: they do not raise issues of emissions into a global commons (nor, for that matter, does the local toxicity of the GHGs themselves). It is precisely on this reasoning that experts are urging state public utility commissions to internalize local but not global externalities in their environmental planning "adders". See Alan Krupnick, Environmental Costing for Electrical Utilities, Presentation at the Project '88/Round II Workshop (Mar. 12, 1992).

27. Emissions factors for agriculture are complicated by dependence on rainfall, nutrient supply, and other local factors.
pollution, agricultural practices, forest management and so forth. Uptake factors could likewise be developed for sinks. For example, an acre of a given type of forest would be assigned a value based on the amount of carbon that it stores. Technical and policy analysis would assess the extent to which various changes in human activity could most cheaply and effectively reduce net GHG emissions.

A hypothetical international agreement to limit net GHG emissions that followed the comprehensive approach would allow each nation to assemble actions that address net GHG emissions. If the agreement contained a performance goal, it would set for each signatory nation an emissions trajectory (e.g. X% reduction by year Y) or an allowance of net GHG emissions, expressed in CO₂ equivalents. In order to stay within this limit, each nation would have the flexibility to limit different GHG sources and to expand (or reduce destruction of) different GHG sinks, so long as it did not exceed its total limit. The GWP index for different gases, direct monitoring, and emissions factors linking source and sink activities with net GHG emissions would provide the foundation for an auditing system of accounting for net emissions in order to determine compliance with allowance limitation agreements.

The utility of the comprehensive approach, of course, is not limited to the design of policies to limit net GHG emissions. It can be used to design research strategies to improve understanding of all relevant gases, sources, sinks, and source/sink processes; to develop monitoring systems to calculate relevant atmospheric concentrations and net emissions for all relevant gases by nation, source and sink, or sector; to calculate the effect on net emissions of all gases of current or proposed technologies and practices; to generate “report cards” calculating the effect on net emissions of current national policy actions; to analyze the impact on net emissions of proposed policy actions; and to define the criteria for providing financial and technical assistance to achieve GHG limitations in developing countries.

The Montreal Protocol on Substances That Deplete the Ozone Layer provides an important precedent for use of a comprehensive approach to deal with degradation of the global atmospheric commons.²⁸ Parties to the Protocol agree to limit and then reduce their production (and their imports, exports, and consumption) of two groups of designated chemical substances that deplete stratospheric ozone. Each one of these substances is assigned an “Ozone Depleting Potential” (“ODP”), based on the comparative contribution of an additional unit of that substance to ozone depletion. Rather than require each nation to achieve specific percentage reductions in each ozone-depleting substance, signatory nations are required to achieve an overall

limitation on production of each group of substances. Compliance with the overall limitation is determined by multiplying the production of each substance in a group by its ozone-depleting index number.

III. THE ADVANTAGES OF A COMPREHENSIVE APPROACH

A. Environmental Advantages

The comprehensive approach has a simple ecological logic: the policy response to an environmental problem should be as broad as the sources of the problem. By ignoring important sources of the problem, a piecemeal approach neglects important opportunities to solve it. Moreover, a piecemeal approach tends to be self-defeating because its effort to solve one source of the problem has the effect of intensifying other, neglected sources of the problem by driving economic activity into sectors and technologies not subject to emissions limitations.

The history of pollution control in the United States illustrates the self-defeating character of a piecemeal approach to environmental problems. Early federal regulation focused on air pollution. Industry reacted by disposing of residuals in the water rather than the air. When a far-reaching system of water pollution control was adopted, facilities dumped residuals on the land. Not until many years later was an effective system of controls on toxic waste treatment, storage, and disposal enacted. In the interim, the problem of toxic waste contamination of ground and groundwater was aggravated. Even now, requiring scrubbers to remove sulphur from the air creates sludge solid wastes that must be disposed of in another medium. Like squeezing one end of a balloon, this piecemeal, media-by-media approach to pollution control simply shifted a substantial part of the problem elsewhere.

A piecemeal approach to GHG limitations would have a similar self-defeating character. If only CO₂ emissions were subject to limitations, economic activity could tend to shift to activities that generated other GHGs not subject to limitation or to activities that destroy sinks. For example, a system of controls limited to CO₂ emissions would encourage fuel switching in the energy sector from coal to natural gas, because combustion of natural gas produces just over half as much CO₂ per unit of energy produced than does coal. But increased natural gas combustion brings CH₄ leakage from natural gas mining and transmission systems (pipelines and local distribution

29. Reducing SO₂ emissions by 10 million tons per year through scrubbing would generate 45 million tons per year of sludge—about 1/3 the current total municipal solid waste volume in the United States. See Winston Harrington, Acid Rain: A Primer 16 (1989).


networks). Because CH$_4$ is about 20 times more potent a GHG per unit than CO$_2$, about a 6% rate of CH$_4$ leakage from natural gas systems would negate all of the CO$_2$-related radiative forcing avoided by switching from coal to natural gas.\textsuperscript{32} Natural gas flowing from the former Soviet Republics into the European Community would leave in its wake CH$_4$ leaks ranging from 4 to 10%;\textsuperscript{33} the average would quite likely be 6% or higher.\textsuperscript{34} Even in an industrialized country like the U.K., the CH$_4$ leakage rate of pipelines is estimated to range between 1-11%,\textsuperscript{35} with a conservative best estimate of the national average falling between 5.3% and 10.8%.\textsuperscript{36} These leakage rates are large enough that a European Community tax on CO$_2$ could actually boost a net increase in potential global warming.\textsuperscript{37}

Similarly, use of biomass-based ethanol as a replacement for gasoline would lower CO$_2$ but could simultaneously increase N$_2$O, if expanded corn farming to produce ethanol feedstock made heavy use of fertilizers, a major N$_2$O source. Corn is one of the most nitrogen-fertilizer-intensive crops grown today. Biomass to produce the ethanol might be grown on lands cleared of forests, forfeiting a sink to gain the alternative fuel.\textsuperscript{38}

These are simply two examples of the many environmentally self-defeating displacements that a piecemeal approach could produce. What is perhaps even more worrisome is the array of unanticipated, complex tradeoffs that seem bound to occur if we tinker with one aspect of the GHG system without taking into account the effect on the system as a whole. By contrast, a comprehensive approach would account for all the environmental effects of alternatives, forcing decision makers to focus on those measures that yield the greatest net overall environmental benefits.

Finally, the comprehensive approach offers greater flexibility to respond to new information. The science of climate will evolve. The significant new scientific insights revealed in the fall of 1991 regarding the indirect effect of CFCs on lower-stratosphere ozone illustrate the importance of flexibility.

\textsuperscript{32} Id. at 1219.
\textsuperscript{36} C. Mitchell, J. Sweet & T. Jackson, \textit{A Study of Leakage from the UK Natural Gas Distribution System}, 18 Energy Policy 809 (1990). This conservative estimate did not even include leakage from sources other than service pipelines, such as connections at wellhead and points of distribution.
\textsuperscript{37} This issue is often omitted from estimates of the effect of European Community policies on net GHG emissions. For example, it is omitted from the analysis in McKinsey & Co., \textit{Towards Reduced Greenhouse Gas Emissions in the European Communities and the United States} (1992).
\textsuperscript{38} If the biomass were sustainably harvested and if it sequestered as much CO$_2$ as the forest (including its root and soil matter), no net carbon would be lost on the sink side, and the biomass fuel would still offset combustion of fossil fuel.
New findings also indicate that sulfur aerosols produced by fossil fuel combustion have an important cooling effect on the lower atmosphere, offsetting some of the warming effect of the CO₂ produced by such combustion.²⁹ By constantly renewing attention to all the important factors, a comprehensive approach keeps policymakers from targeting policy at one aspect of the issue only to discover later that the target has moved.

B. Economic Advantages

Another lesson from the history of environmental policy in the United States is that piecemeal approaches which regulate only a part of a problem are substantially more costly than those that allow greater flexibility and expand control opportunities. Prior to the 1990 Clean Air Amendments,⁴⁰ U.S. policy for dealing with sulfur dioxide emissions focused on sulfur emissions from new sources and required at least partial use of scrubbers from all such sources. Under the acid rain provisions of the 1990 Clean Air Act,⁴¹ ambitious sulfur control requirements are extended to all utility sources. But sources are allowed the flexibility to achieve reductions in any way they choose—whether through use of scrubbers, low-sulfur coal, new combustion technologies, or reduced electricity generation due to conservation and demand-management techniques. Moreover, sources that reduce sulfur emissions further than they are required may sell their excess reductions to others who find it more difficult or costly to achieve reductions. The flexibility afforded by this approach is projected to save billions of dollars compared to an approach imposing specific, uniform controls.⁴²

The comprehensive approach affords nations similar flexibility in limiting net GHG emissions by allowing them to choose among all GHGs, their sources and sinks, in meeting GWP limitation obligations. Because of the heterogeneity of GHG limitation opportunities and costs in different nations, the comprehensive approach should yield large cost savings compared to a piecemeal approach that requires uniform controls for each gas or sink. Different nations have very different portfolios of GHGs and sinks. For example, U.S. CO₂ emissions are over six times greater, in terms of total GWP, than U.S. methane emissions. In India, by contrast, methane emissions are twice as large a share as CO₂ emissions.⁴³ More importantly, the marginal costs of net GHG limitations within a nation will vary considerably

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39. IPCC Supplement, supra note 6, at 20-21.
41. Id.
across different gases, their sources and sinks. These sector-by-sector marginal costs will also vary among nations. A comprehensive approach allows each nation the flexibility to select that combination of GHG source and sink controls that is least economically and socially costly in achieving overall GWP limitations.

What is best for one nation will not necessarily be best for another. Depending on relative marginal costs, one nation might focus more of its energies on limiting CO₂ emissions from the energy sector, another on limiting methane emissions from agriculture, a third might stress afforestation, and a fourth, concentrate on reductions in pollution that cause tropospheric (low-atmosphere) ozone. A piecemeal approach that requires each nation to achieve specific, uniform levels of control for each gas or sink ignores these variations in national GHG inventories and control costs, and is bound to increase substantially the cost of achieving a given level of limitation of GWP. The excessive costs of a piecemeal approach will be even greater if controls are targeted on particular sectors or if “best available technology” requirements are imposed.

The superior cost-effectiveness of a comprehensive approach is important because the long-term costs of significant limitations on net GHG emissions could be large.44 The amount of savings from using a cost-effective approach can be commensurately large. The cost savings associated with the flexibility offered by the comprehensive approach to address all GHG sources and sinks, rather than being compelled to obtain all reductions out of energy sector CO₂ alone, could be quite dramatic: in the United States, for example, to achieve an equivalent goal (defined in GWP) could cost as much as 90% less under the comprehensive approach than under the energy-CO₂-only approach.45


45. As an illustration, DOE estimates that to reduce U.S. energy-sector CO₂ emissions by 20% from 1990 levels by 2010, using a tax on the carbon content of fossil fuels, would require a tax of $3539 per metric ton of carbon put in place after 1990 and would impose a total economic cost of $128 billion per year in 2010. To reduce U.S. net GHG emissions from the energy sector by the same degree, using a GWP-weighted tax on fossil fuels, would require a tax of $180 per metric ton of carbon-equivalent and would impose a total economic cost of only about $30 billion per year in 2010. See Bradley et al., supra note 44. Hence even when constrained to act only within the energy sector, broadening from CO₂ to all GHGs reduces costs by about 75%. Broadening beyond the energy sector to a full net GHG emissions approach reduces costs further: applying the GWP tax and in addition allowing a refund for reforestation activities that sequester CO₂ would lower the total cost in 2010 to about $6-10 billion—over 90% less than the CO₂-only, energy-only policy. Id. at 8.4, 8.12. Note that these figures should be taken only to illustrate the likely range of cost savings, since they depend in part upon the IPCC’s 1990 GWP figures.
In particular, a CO2-only approach would ignore some of the most promising, lower-cost opportunities for reducing net GHG emissions. For example, reducing CH4 leakage itself may be a cost-effective means to reduce contributions to potential warming.\textsuperscript{46} CH4 is itself the product being transported and sold in natural gas systems, providing an economic incentive to capture fugitive CH4 emissions,\textsuperscript{47} but leakage will persist where energy markets are not competitive or where the cost of capture exceeds the revenue that the capturer can gain from the recovered CH4. Leakage from landfills, coalbeds, and ruminant animals might also be recovered for use as fuel, or otherwise reduced.\textsuperscript{48}

\textbf{C. Promoting the Likelihood of International Agreement}

Reaching international agreement on GHG limitations will be difficult because of differing national interests.\textsuperscript{49} Some nations, such as low-lying island and coastal nations or nations in Africa already threatened by desertification, may feel more immediately and severely threatened by global climate change than others. Nations where little temperature change is expected to occur,\textsuperscript{50} or where the costs of adaptation would be small,\textsuperscript{51} may have little incentive to limit emissions. Meanwhile, the burdens of different types of GHG limitations will be different in different nations. Countries like the United States and Canada with low population densities who rely heavily on fossil fuels, and the OPEC nations who sell such fuels, would probably be disproportionately burdened by limitations on CO2 emissions. Nations that rely on forest clearing to feed their populations or generate export income would be disproportionately burdened by specific controls on reductions of CO2 sinks. Nations relying heavily on agriculture would be affected, in differing degrees, by limitations on N2O and CH4 emissions.

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\textsuperscript{46} E.g., Rabchuk & Ilkevich, \textit{supra} note 33, at 12, calculate that recovering 1/2 to 2/3 of the gas leaking from main pipelines in Russia would cost about 50-90\% of the cost of equivalent new production.

\textsuperscript{47} Hogan, Hoffman & Thompson, \textit{supra} note 34, at 181.

\textsuperscript{48} Id.

\textsuperscript{49} See James K. Sebenius, \textit{Negotiating a Regime to Control Global Warming,} in Greenhouse Warming: Negotiating a Global Regime (World Resources Institute, 1991).

\textsuperscript{50} Relatively less temperature change is expected in the tropics, perhaps disinclining tropical nations to limiting emissions. William R. Cling, \textit{Comments,} in Dombusch & Poterba, \textit{supra} note 1, at 225-26.

\textsuperscript{51} Industrialized countries may face small costs from gradual warming. See William D. Nordhaus, \textit{Economic Approaches to Global Warming,} in Dombusch & Poterba, \textit{supra} note 1, at 40-44; Schelling, in Dombush & Poterba, \textit{supra} note 1, at 201-02.
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Faced with controls that would limit their economic development, the developing countries will likely argue that there should be no (immediate) application of limitations to them, and that the industrialized nations have already “filled up the global commons” with more than their fair share of GHGs.

These differing interests are likely to be reflected in the various equity arguments advanced by different nations in the negotiations over the structure of a limitations agreement. Some will emphasize current emissions as a starting point. Others will argue that the right to emit should be allocated by population, by development needs, or by energy efficiency. No single principle will win assent. Any agreement will be the product of tough bargaining, compromise, and convergence among different allocative principles.52

Use of a comprehensive approach in any GHG limitations agreement would advance the chances of an agreement, for two reasons. First, the superior cost effectiveness of a comprehensive approach will lower aggregate compliance costs compared to a piecemeal approach. By reducing the social and economic burdens of limiting GHGs, it should make all parties more willing to incur limitation obligations.

Second, a comprehensive approach establishes an equitable position for all nations at the table. Because of the differences among nations noted above, a piecemeal approach inevitably favors some nations while disproportionately burdening others. Nations who would be penalized by a proposed piecemeal measure will resist its adoption because of the distributional inequity involved and fears that the relative international competitiveness of its industry will suffer. A comprehensive approach provides a more equitable “level playing field” that does not favor some nations relative to others. It is therefore likely to increase the chances of international agreement on GHG limitations.

IV. PRACTICAL CHALLENGES IN IMPLEMENTING A COMPREHENSIVE APPROACH

The initial reaction in the international community to the Bush administration’s advocacy of a comprehensive approach was generally, though not uniformly negative. Because a comprehensive approach would involve more complexities and uncertainties than an approach limited to fossil-based CO2 emissions, and because it would take time to resolve these problems, many saw the proposed comprehensive approach as a smokescreen for inaction and delay. Today, there is growing recognition of the environmental and economic advantages of a comprehensive approach. Even many of those

52. See generally Duane Chapman & Thomas Drennan, Equity and Effectiveness of Possible Carbon Dioxide Treaty Proposals, 8 Contemp. Pol’y Issues 16 (1990).
advocating early binding agreement on targets and timetables for limiting GHG emissions now advocate a comprehensive approach.\footnote{E.g., Norway, Canada, Australia.}

A. Addressing Practical Challenges

Faced with current difficulties in measuring all the various GHG emissions sources and sinks, some have urged a "phased comprehensive" approach: agreement on fossil CO\(_2\) limitations now, and "later" enlargement of this agreement to include other gases and sinks as knowledge and monitoring capacities improve.\footnote{Rafe Pomerance of World Resources Institute has quipped that waiting to take any action until every emission of every GHG is precisely measurable would be a "compulsive comprehensive approach." Rafe Pomerance, in a discussion at the Project 88/Round II Workshop on "Market-Based Policy Mechanisms for Addressing Global Climate Change" (Washington, D.C., Mar. 12, 1992). This caricature is instructive, but no one has made this proposal. Meanwhile the proposal billed as "phased comprehensive" under which we "proceed gas-by-gas, starting with energy sector CO\(_2\) and address the other GHGs 'later,'" is really "costume comprehensive." "Later" is undefined, illusory and fails to grasp the real policy problems and dynamic incentive implications. As we argue below, the practical middle ground is to establish a framework for full accounting and for cost-effective actions that is coextensive with the broad scope of the environmental issue, and that provides appropriate incentives for improved measurement.} Based on today's knowledge, technology, and data bases, it probably would be administratively easier to implement a limitations agreement restricted to fossil CO\(_2\) emissions than a comprehensive agreement. Our capacity to monitor fossil-based CO\(_2\) emissions from the important activity sectors—energy, transportation, and industry—is far better deployed than our capacity to monitor CO\(_2\) sinks, or emissions of many of the other GHGs. Many current studies confine themselves to energy policy alone simply for the reason that, in the words of one of the more candid analysts, "[t]his focus suggests itself because the necessary quantitative data for a least-cost analysis are far more developed in the case of energy than for other major sources of greenhouse gases."\footnote{F. Krause et al., 1 Energy Policy in the Greenhouse 1-3 (1989).}

But this is not sufficient justification for pressing forward with an immediate piecemeal agreement on CO\(_2\) emissions. First, if one is truly concerned about the potential for climate change from anthropogenic GHGs, adopting a CO\(_2\)-only approach is no solution: ignoring the hard-to-measure gases will not make them go away.

Second, looking ahead, a piecemeal CO\(_2\)-only policy would provide no encouragement to the additional research work that is needed to develop a comprehensive approach. By placing no policy value on non-CO\(_2\) emissions, it offers no reward to those who develop means to monitor and control non-CO\(_2\) gases. This monitoring work will be needed if only to be able to predict future emissions and concentrations. The design of the comprehensive approach, by contrast, ensures that the incentives for research into the
key unknowns are provided. Measuring many GHG emissions will not be easy. But it is not beyond our reach, if we focus current research efforts to support a comprehensive approach. Indeed, the IPCC and many countries, including the United States, are rapidly moving ahead to conduct this research, following a comprehensive agenda.

Third, the important issue is not what is administratively “feasible” today, but whether the costs of proceeding with a flawed piecemeal policy design are less than the costs of doing the necessary groundwork to develop a comprehensive approach. The serious defects of piecemeal environmental policy design, summarized above, suggests that pursuing such a policy may even worsen climate risks—hardly a solution that environmental advocates should espouse.

Fourth, piecemeal approaches tend to entrench themselves by favoring certain nations and economic interests that develop a vested stake in their perpetuation. Experience shows that, once adopted, piecemeal initiatives rarely evolve into a comprehensive strategy. Those interests that are competitively favored by piecemeal approaches block changes that would reduce this advantage. U.S. environmental regulatory policy, which started down a piecemeal path over twenty years ago, remains largely piecemeal today, resulting in serious economic inefficiencies and competitive distortions. For example, the Prevention of Significant Deterioration provisions of the Clean Air Act limit industrial development in many “cleaner” regions of the United States, often without substantial environmental justification. But removal of the PSD provisions is opposed by political representatives from “dirty” regions, who fear that industry will consequently migrate to the cleaner regions.

This experience is ignored by those who argue that a piecemeal approach should be adopted initially, and expanded into a comprehensive approach later on. Those nations that were favored by the initial piecemeal measures would resist development of a more comprehensive approach that would treat all nations with an even hand. The resulting entrenchment of a piecemeal approach would produce incomplete environmental protection and serious economic distortions and inefficiencies. It is accordingly essential to insist that a comprehensive approach be adopted from the start, rather than beginning with a defective design that will perpetuate itself.

Fifth, there is, in any event, unlikely to be any broad international agreement on CO2-only limitations in the near future. One of the major obstacles to such an agreement is that a CO2-only approach would disproportionately penalize some nations or groups of nations, such as the United

57. See Peter Pashigian, Environmental Regulation: Whose Self-Interests are being Protected?, 23 Econ. Inquiry 551 (1986).
States and the OPEC nations. And a CO2-only approach misses much of the environmental variable of interest, namely net GHG emissions. The adoption of a comprehensive approach is likely to be a necessary (though not sufficient) condition of any far-reaching international agreement in GHG limitations.

Sixth, as explained more fully below, one can design a comprehensive approach in ways that takes due account of gaps in our knowledge respecting some GHGs, sources and sinks, while simultaneously providing incentives to close those gaps. These gaps principally concern two items: the development of a GWP Index, and the development of reliable monitoring and data collection capacity to measure the impact of various source and sink activities on net GHG emissions.

B. Developing a GWP Index

The development of a GWP index will be a process of international scientific consensus. The extent of international scientific exchange and collaboration fostered by the IPCC, and the extent of convergence on common assessments of GHG issues, has been remarkable. The United States is currently spending well over $1 billion annually on global climate research, and the other nations of the world are together spending a like amount. At this level of effort, it should be possible to develop a reliable GWP index by the time that a binding international agreement on quantitative GHG limitations is a realistic possibility.

Difficulties are undoubtedly presented by the estimation of atmospheric residence time. Because of gaps in knowledge regarding sink removal and recycling rates and atmospheric reactions, there is uncertainty about exact residence time for key GHGs. These uncertainties seem to be greatest for CO2, which cycles in and out of the atmosphere every few years, and is not actually "retired" into the deep ocean or soil matter for over 100 years. Relative residence time has important policy implications, for it is presumptively more valuable, all other things being equal, to limit emissions of a GHG with a long residence time as compared with one that has a shorter residence time, because the longer-lived gas will contribute to the global warming effect for a longer number of years. But how much weight should be given to this factor? Is reduction of one GWP unit of a GHG with a 100 year residence time equivalent to reduction of 10 units of a gas with a 10 year residence time?

60. A further consideration is reversibility. An erroneous underestimate of the severity of global climate warming is harder to reverse if the gases being emitted are relatively long-lived.
A related issue has to do with the “time horizon” over which the GWP is calculated. On conventional economic analysis, adverse effects occurring 100 years from now should be discounted much more steeply than effects occurring ten years from now. Presumably the relative damage of a unit of warming 100 years from now will be less than the same unit of warming today, because we will have learned better ways to adapt and will have more resources with which to do so in the future. An alternative to straightforward annual discounting is to use a fixed time horizon in constructing an index, taking into account only the radiative forcing exerted during that time horizon. The longer the time horizon, the greater the relative weight given to longer-lived gases. The IPCC is using time horizons of 20, 50, 100, 200 and 500 years. The choice among these is, however, primarily a question of policy rather than science. A shorter time horizon (higher discount rate) reflects greater concern over the short-term rate of warming, whereas a longer time horizon (lower discount rate) reflects greater concern over ultimate equilibrium temperature levels.

A third difficulty is presented by differences in GHG reactivities and other atmospheric interactions that indirectly affect global climate. Reactions are important sinks for some GHGs, such as methane. Other gases, such as NOx, CO, and VOCs are precursor gases; although they are not important GHGs themselves, they react in the atmosphere to form tropospheric ozone, which does exert a radiative forcing effect. Hence, their GWP is indirect. NOx and CH4 have other indirect effects that are being intensively studied. For example, CH4 reacts in the atmosphere to produce tropospheric ozone, stratospheric water vapor, and CO2. The difficulties in estimating the “indirect” component of the CH4 GWP are being aggressively pursued, and may be substantially resolved by the time this article is published.

Significant and rapid progress is being made in resolving the relevant uncertainties. There is no reason to suppose that a workable GWP index for all GHGs cannot be developed by the time that a broad international agreement on GHG limitations is likely. Moreover, absolute precision is not needed for practical use. Just as “uncertainty is no excuse for inaction,” the existence of some residual uncertainty is not a sufficient justification for restricting a limitations agreement to a single gas, such as CO2. Such a policy would, in effect, establish a GWP index that implicitly assigns a weight of zero to all other GHGs. This error is far greater than any that would be made in including them. Some weighing system, implicit or explicit, is inevitable in any policy response to GHG emissions. It is preferable that the weighing

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62. This feature of the time horizons is well recognized by the scientific community. See WMO, Ozone Depletion, supra note 9, at 7.4 to 7.5.
63. IPCC Scientific Assessment, supra note 2, at 28.
be made explicit, and that the relevant science be pushed forward to make that weighing as accurate as practicable.

Nor is a different conclusion warranted by recent scientific developments that indicate that CFCs in the aggregate may have no net effect on global temperature. Removing CFCs from the analysis makes CO$_2$ relatively more important, but it simultaneously increases—in the same proportion—the importance of the remaining GHGs, including methane, N$_2$O, and the HCFCs being developed to replace CFCs because of concerns about ozone depletion. Accordingly, use of a comprehensive approach is as important as ever. In addition, if CFCs have no net warming effect, then net GHG emissions during the past decade were about 25% lower in GWP than previously thought. Because the pressures on the commons have been less severe than we thought, the case for immediately pushing forward with a piecemeal approach is weakened. 64

Finally, as detailed above, eventually it would be desirable to include environmental effects other than GWP in the construction of a more complete GHG index, in order that policy measures be directed at all of the environmental effects of concern. Ignoring those other effects could reduce overall well-being by restricting GWP but also forfeiting other benefits or exacerbating other ills.

C. Measuring Net Emissions

In order to implement and verify compliance with any emissions limitation agreement, one needs reliable methods for estimating the amount of net GHGs resulting from various activities. It will generally not be feasible to measure emissions of GHGs directly. As is so often the case in environmental regulation, policy measures must be addressed to variables that are proxies or surrogates for the environmental agent of ultimate interest. Even in the case of fossil-based CO$_2$ emissions, emissions are indirectly calculated on the basis of the carbon content of fuel and combustion characteristics, although the methodology and data involved are highly reliable. Because of existing regulatory controls on emissions of VOC, HC, and NO$_x$, their emissions can be monitored with considerable reliability, at least in the industrialized countries. HCFC production can also be determined fairly easily. But the necessary methodology and data are less developed for emissions of methane and nitrous oxides, for emissions of CO$_2$ from deforestation and land use, and for CO$_2$ sink uptake and storage.

In order to close this gap, emissions factors should be developed. Take methane, for example. Leaks from natural gas pipelines can be estimated without great difficulty, given incentives to do so. But diffuse, non-point

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64. On the other hand, the GWP reductions that had been expected to result from the phase-out of CFCs may no longer be in prospect.
sources present greater difficulties. Methane emissions from an acre of a given type of rice paddy, or a cow of a given type with a given feed, could be measured. These measurements could be used to construct a factor index that allows one to calculate emissions from a rice farm of given size or a herd of given numbers. In order to develop the data base needed to use this index, one must inventory the amounts of different types of rice paddies or cattle and feed. Similar steps must be taken to develop indices and data bases for N₂O emissions and for different types of sinks. For example, the capacity of different types of forests to store carbon differs substantially, depending on the soil and terrain, species, survival rate, and local climate.65 These differences must be embodied in workable emissions factors and reflected in inventories.66

Substantial work on solving these problems is already underway. A comprehensive understanding of the sources and emissions rates of all GHGs and of uptake by different GHG sinks is needed for reasons independent of the scope of any international agreement limiting net GHG emissions. The development of accurate global climate models requires an accurate determination of existing baselines and future trends in net GHG emissions. A better understanding of net emissions and source-sink balances is also needed in order to reduce uncertainty regarding atmospheric residence times and thereby develop a more accurate index of the comparative GWP of different GHGs. The likely emergence of a “national strategies” approach in an initial framework GHG convention will provide a further impetus to the development of better techniques and data to measure net GHG emissions resulting from different human activities.

As in the case of GWP indices, perfection is not necessary. It is far better to use somewhat rough but workable emissions factors and data rather than to ignore significant components of the GHG problem entirely. To the extent that substantial deficiencies in the development of indices or in data remain if and when an international agreement on binding quantitative emissions limitations is in prospect, the resulting uncertainties can be handled by conservative accounting methods. A nation claiming credit for limitations on activities that emit GHGs or for sink expansion would receive credit towards compliance with its emission limitation obligations only to the extent of net CO₂-equivalent emission reductions found, by an international process of scientific consensus such as that created under the framework convention,

to be adequately verified by method and data. For example, if estimations of methane emissions from rice paddies have an estimated error of plus or minus 50%, one might give less than full credit for the limitation claimed, discounting it by 25% or even 50%.

This "discount" approach would give those nations, and those relevant industries, who have an interest in claiming credit for such emissions reduction measures a powerful incentive to accelerate the research and data collection needed to resolve the uncertainty and receive full credit. Of course, all emissions factors and data banks would have to be revised in light of ongoing advances in scientific knowledge. But the alternative—a "phased" approach in which the international community determines that CO2 reductions alone will receive credit until some later date at which other GHGs will be recognized—is counterproductive. In addition to the danger of entrenchment, as discussed above, such an approach provides no incentive for improved measurement of the ignored GHGS.

In addition, a climate change convention should establish a process for collection by an international body of self-reported data on the activities of nations in limiting GHG sources or reducing or enhancing sinks. This inventory will be necessary in order to analyze global emissions trends and their relation to climate change. They will also provide publicity that will encourage signatory states to adhere to their obligations. Ideally, these reports should be audited through on-site inspections, satellite observation or other methods of remote sensing, and other techniques, although the use of such techniques by an international authority will be controversial.

V. INTERNATIONAL EMISSIONS TRADING

Assuming an international agreement to limit net GHG emissions on a comprehensive basis, there are a variety of policy instruments that could be used domestically within any given nation to achieve its obligations. These include command-and-control regulations, government ownership or management of relevant resources, charges and taxes, tradeable allowances, and various forms of subsidies. Nations should have the flexibility to use whatever combination of instruments they wish in order to meet their obligations. There is, however, increasing interest in the use of economic instruments to deal with environmental problems generally and GHG emissions in particular. The United States has already successfully used trade-

67. The use of some policies, e.g., subsidies, may be limited for trade policy reasons.
able emissions allowances to deal with several environmental problems. It is gearing up to apply emissions trading on a broad scale to reduce sulfur emissions; this program will also have the indirect benefit of reducing CO₂ emissions. The European Community is considering a carbon tax to reduce fossil-based CO₂ emissions.

In the international context, the advantages of a comprehensive approach can be most fully realized if any agreement on GHG limitations allows different nations or facilities in different nations the flexibility to invest in GHG reductions wherever in the world those investments are most cost-effective. This flexibility would minimize the cost of any global effort to limit emissions while directing investments to their most valuable uses. Since GHG emissions mix globally in the atmosphere, what matters is the change in the net global flux of GHGs, and not where reductions are obtained. A kilogram of GHG emissions avoided in Poland or India is as climatologically relevant as a kilogram avoided in Paris or Indiana. Yet, the cost of avoidance may vary widely, so that an investment in the least-cost location would deliver much more emissions reduction than the same investment elsewhere.

A. Types of Trading: Formal and Informal

The benefits of flexibility could be captured through "formal" or "informal" trading mechanisms. If an agreement establishes quantitative limits on each nation's net GHG emissions, the agreement could in effect give each nation an allowance of emissions up to the limit. A "formal" trading system would allow a nation with unused allowances, or firms within such nations, to sell those allowances outright to other nations or to firms in other nations. This system would enable emissions-reducing projects to be undertaken where they are most cost-effective. If the international agreement contains no overarching quantitative limits but an obligation on nations to develop

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71. By allowing firms the flexibility to adopt the cheapest measures to reduce SO₂, the act will encourage energy conservation. See Dudek, LeBlanc & Miller, supra note 26. But see McKinsey & Co., supra note 37, at 8 (expressing a "skeptical" view).

72. See supra text accompanying note 61.

73. There is thus no significant risk of local "hotspots" in the GHG context, as there might be in trading emissions of, say, a toxic pollutant. In the toxics example, flexible location of reductions might in theory lead to bunching all the emissions at a very few locations, at which local toxicity levels might cross a threshold that might increase damages beyond the aggregate maximum goal. The major GHGs are probably less vulnerable to this problem than any of the several pollutants already regulated using emissions trading (e.g. lead, SO₂), though certain minor GHGs that also happen to be local pollutants (e.g. CO, NOₓ) might pose hotspot issues.
national strategies to limit net GHG emissions, a kind of "informal emissions trading" could be allowed: through "cooperative arrangements" or "joint implementation," nations could invest in overseas net emissions limitation efforts as part of their national strategies. In both the "informal" and "formal" cases, these investments or allowances could be expressed in carbon equivalents using an index like GWP.

**B. How Trades Could Occur**

These international investment arrangements would be wholly voluntary. Consenting adult nations would fashion agreements to meet their mutual interests. For example, the United States might offer to provide capital and technology to Brazil for the construction of a plant for manufacture of energy-efficient refrigerators. The refrigerators manufactured by the plant would reduce Brazil's emissions of CO₂ below what they otherwise would be, freeing up net GHG emission allowances that it would otherwise have had to use. In return Brazil could offer to give a portion of those unused allowances to the United States. The amount would be agreed between the United States and Brazil. The United States could then use these allowances to cover United States' emissions that would be more costly to control than investing in energy efficient refrigerators in Brazil. Similarly, the United States and Brazil could enter into an agreement in which the United States would assist in the conservation of Brazilian CO₂ sinks, in return for an agreed portion of the emissions credits thereby generated. In like fashion, other countries where the cost of limiting emissions is high, such as Japan, could invest in projects in countries where the marginal cost is low, such as China. The investor country could receive emissions allowances; the host country would receive new resources and technologies.

If the right to trade were extended beyond nations to domestic entities, a U.S. firm could, for example, provide the capital and technology for such a plant to a firm in Brazil and receive allowances as compensation. The U.S. firm could use the allowances to cover its own emissions or, more likely, sell them for cash to another U.S. firm or a firm elsewhere in the world to cover that firm's emissions. Such trades would effectively create a market in greenhouse emission allowances. Firms for which net GHG emissions reductions are relatively cheap would reduce net emissions and sell allow-

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76. Norwegian submission at the Third Session of the INC, Nairobi (Sept. 1991).

ances. Firms for which reductions were relatively costly would buy allowances. The extension of trading to firms as well as nations would substantially increase economic efficiency and stimulate environment-friendly technological innovation by creating a worldwide market in GHG limitation opportunities.

An important precedent for voluntary international trading is found in the amended Montreal Protocol, which provides (under the label of "industrial rationalization") for some CFC production trading among producers in different nations with the concurrence of the governments involved. One might expect that informal international trading would initially begin on a bilateral or regional basis, such as United States-Canada or within the European Community. Trades might also be made a feature of bilateral assistance agreements and debt-for-nature swaps. As experience with trading grew, one could expect the gradual development of a worldwide market and the emergence of a stock exchange system of trading.

C. Advantages of Trading

A trading system would have several important virtues. First, it would markedly reduce the costs of achieving a given level of net GHG limitation. Without trading, each nation can invest in emissions limitations only within its own borders. In effect, each nation must be self-sufficient in the industry of limiting emissions. Under emissions trading, however, it can invest in GHG reductions anywhere in the world, just as today nations can purchase other products in a world market and are rarely self-sufficient in major industries. The cost reductions provided by the opportunity to trade could be substantial, because the marginal cost of avoiding a unit of GHG emissions varies widely across countries.

A recent OECD study, for example, found that in order for every country in the world to reduce CO₂ emissions 20% from its 1990 levels by 2020, countries would have to impose widely different taxes: a tax in 2020 of about $950 per ton of carbon in the OECD-Pacific region (Japan, Australia and New Zealand); about $210 in OECD-Europe and OECD-North America (the United States and Canada); about $100 in the former U.S.S.R. area; and only about $60 in China. This spread in costs indicates that it is much more expensive to achieve equivalent emissions limitations in some places (e.g.,

79. U.S. EPA and Environment Canada are conducting a joint study of emissions reduction opportunities that could be pursued in concert.
80. In the United States, the Chicago Board of Trade has indicated interest in offering a futures market for sulfur dioxide emissions reduction credits created pursuant to the sulfur trading provisions of the 1990 Clean Air Act Amendments. The New York Mercantile Exchange has expressed interest in hosting a current SO₂ credits market. See Efficient Markets Pollution, Wall St. J., Mar. 2, 1992, at A12.
81. Bruniaux et al., supra note 44.
Japan) than in others (e.g., China). Allowing international trading would enable high-cost countries to invest in areas where the cost of avoiding emissions is lower, reducing the overall global cost. In the OECD model, allowing trade reduces the average global tax in 2020 from $215 per ton of carbon to $152,\textsuperscript{82} and global economic welfare falls by only 1% instead of the 1.75% drop estimated to occur from the CO₂ limitation without international trading.\textsuperscript{83} The flexibility to invest internationally thus achieves about a 40% reduction in total economic cost.\textsuperscript{84}

Second, trading would enhance the chances of a broad international agreement on limitations by further lowering the costs of achieving a given level of limitations. It would also ameliorate one of the largest obstacles to securing such an agreement: the simultaneous insistence by the developing countries that they need high GHG allowances in order to industrialize, and resistance by the ICs to any limits on their emissions that entail high compliance costs. By reducing ICs’ compliance costs by expanding the portfolio of limitation opportunities, trading should make ICs willing to give DCs a relatively larger initial allocation of allowances.

Third, trading would help address a central problem: in the decades ahead the greatest potential increases in GHG emissions will occur in the DCs as they strive to industrialize. Already the divergence in emissions growth is striking: from 1975-85, CO₂ emissions grew barely at all in OECD countries while they grew at over 5% per year in China and over 2% per year elsewhere.\textsuperscript{85} While CO₂ emissions are projected to grow at about 1% per year in the OECD from 1990-2020, they are projected to grow at about 2.2%-4.7% per year in China and 2.2%-3.5% elsewhere over the same period.\textsuperscript{86} Key DCs such as India and China have enormous coal reserves that they want to use for industrialization. Meanwhile, the deforestation contributing 10-30% of net GHG emissions is occurring almost wholly in DCs.\textsuperscript{87}

In this context, limiting emissions in the ICs alone would not make much of a dent in future global net GHG emissions. Yet DCs do not want to restrain their economic growth. In order to continue growing on a path that does not entail high GHG emissions of the sort experienced by current ICs, a flow of capital and technology from the ICs will be required to help the DCs “leapfrog” to a low-emissions development path. It is therefore unsurprising that DCs are demanding, as a condition for signing a GHG limitations agreement, substantial transfers of capital and technology from the ICs.

\textsuperscript{82} Id. at 34-36.
\textsuperscript{83} Id. at 10 (using household real income as a measure of economic welfare).
\textsuperscript{84} For comparison, the opportunity to trade SO₂ reduction credits in the U.S. acid rain program, an extremely important cost-cutting measure, is projected to cut costs by about 20-25%. See supra note 42.
\textsuperscript{85} See Bruniaux et al., supra note 44, at 27, tbl. 5.
\textsuperscript{86} Id. (summarizing projections by OECD, Manne & Richels, Edmonds-Reilly, and IEA).
Pressing further, DCs tend to demand technology on a "concessional" or "noncommercial" basis, not conditioned on emissions limitations, and a central fund from which DCs could draw financial resources.

An emissions trading system could provide a more effective and efficient way to transfer capital and technology from the ICs to the DCs, on a mutually voluntary basis, to the benefit of both. Since the growth in emissions is likely to occur in DCs and the marginal cost of achieving reductions is lower in DCs, under an emissions limitation agreement there would be an incentive for ICs to invest in emissions-avoiding projects in DCs. This mechanism would mean both lower cost to the ICs to achieve their emissions limitation and a flow of resources and technology to DCs. The OECD modelling exercise described above showed just this result: allowing international emissions trading cut total costs by 40%, with especially large savings in the OECD-Pacific countries, while generating a revenue flow to China of about $60 billion by 2020.88 Under an agreement calling for "national strategies" and allowing "informal trading" as described above, ICs would similarly be likely to invest some resources in emissions-avoiding projects in DCs.

International trading could also be used under a limitations agreement restricted to a given GHG, such as fossil-based CO₂.89 But the cost savings from trading and the potential of trades to provide needed transfers of capital and technology to the DCs are maximized under a comprehensive approach.

D. Challenges in Implementing Trading

It is often pointed out that emissions trading would require accurate monitoring of net emissions. That is of course true, but accurate monitoring will be required in order to secure compliance with any agreed-on limitations, regardless of whether trading is allowed. The additional administrative task that trading would entail is the eventual development of a registry to keep track of trades and make sure that existing inventories are consistent with the record of trades. If domestic entities are allowed to trade as well as nations, accounts must initially be kept at the national level, and then balanced on the international level. The additional administrative cost of establishing such a global "green" SEC should, however, be substantially less than the cost savings and other benefits obtained by trading, and might be funded through a nominal charge levied on trades.

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87. Intergovernmental Panel on Climate Change, Climate Change: The IPCC Response Strategies 77, 97 (1991) [hereinafter "IPCC Response Strategies"].
88. See Bruniaux et al., supra note 44, at 10-11, 34-36. Several ICs are already engaged in "technology cooperation" efforts with DCs as a part of the ICs' strategies for dealing with net GHG emissions. E.g., U.S. Technology Cooperation Related to Global Climate Change: A Selected Inventory (1991).
The design of a trading system must accommodate special concerns of the DCs that as the trading market operates, industrialized nations might "buy up" most of their allowances. Of course, the DCs would receive real resources in return for selling their allowances. The concern could be addressed by making allowances only leasable, by limiting their duration, or by limiting the percentage of any nation's allowances that may be leased. But it seems economically unlikely, since the allowances would be sought by a variety of competing ICs and could carry a significant price tag. If it is a real concern, some thought might be given to international rules of antitrust (a prospect that could implicate other commodities in international trade as well).

Perhaps more difficult is the concern expressed that, even if the trading market were competitive, future generations of DC citizens might be "sold out" by unscrupulous DC governing regimes who would take the profits from underpriced allowance sales and exit the scene. This concern besets the entire future of countries for which it is relevant, and it is hard to see how the addition of GHG emissions trading would decidedly worsen the problem. Moreover, corrupt leaders (in any country) could sell out their populations at the bargaining table on the initial climate agreement itself. But the simple answer to this concern is to make the allowances leasable, say for one-year or five-year increments, so that the DC would not irrevocably lose ownership over its allowances each time they are traded in the marketplace.

E. Emissions Taxes as an Alternative

Emission charges or taxes are another form of economic instrument that could be used to achieve cost-effective reduction of net GHG emissions in conjunction with a comprehensive approach. The GWP index and emission indices could be used to impose a CO₂ equivalent tax on all GHGs, sources and sinks. However, a tax set at levels that would provide significant incentives for substantial GHG limitations would generate enormous revenues. There appears to be little prospect that nations would give an international authority control over such revenues.

An alternative, now being explored within the European Community, is for each nation to impose such a tax in a multilaterally coordinated fashion, but for each to collect and keep the revenues itself. An immediate problem, not raised by tradeable allowances, is the need to set tax rates that are equivalent across widely different domestic tax structures and economies. A second problem is that in the context of an international GHG limitations agreement, many nations may prefer to use domestic instruments other than taxes or charges in order to achieve the emission limitations that they have agreed to. These alternatives include regulation, tradeable emission rights, and central state control of relevant resources. An internationally uniform tax or charge would greatly restrict national choice. A system of international
trading, on the other hand, would not restrict choice among domestic instruments. Still, some homogeneity among nations in the choice of domestic instruments could be desirable (though not required) under emissions trading: the advantages of international trading would be maximized if subnational entities as well as nations are allowed to trade. The ability of subnational entities to trade internationally would be greatly enhanced if a nation adopted internal trading as well.

In principle, a tax approach and a tradeable allowances approach can be economically equivalent. If both policies are set to achieve the same emissions result, the price of an emissions allowance on the allowance trading market would be identical to the marginal tax rate on emissions. But there are likely to be some notable differences in practice. For example, if the marginal cost function is not precisely known, a quantity limit could unintentionally push the economy past a point of rapidly rising marginal costs, imposing higher total cost on society than initially deemed warranted. A tax approach may provide some security against this cost-side risk; but a tax would pose the countervailing risk of inadequately discouraging emissions, for example if the price elasticity of demand for emissions-related goods and services were inaccurately estimated. Which risk of error is more important to avoid depends on one’s view of the social costs and social benefits of trying to prevent potential global warming.

There are common issues that must be faced under a tradeable allowances, tax, or performance-based regulatory approach. Issues of monitoring emissions and determining baseline emissions would arise with all approaches, since verifying the emissions level from each emitter would be critical to enforcing allowance limits, proper tax payments, or regulatory compliance. Issues of allocating emissions are relevant to every approach; using tradeable allowances only makes the allocation decision explicit, whereas it is implicit in every other type of limitations policy. For example, requiring all nations to stabilize (or reduce) emissions would implicitly allocate existing emissions to existing emitters in proportion to their historical output, hence “grandfathering” their current entitlement. Imposing a tax on all current emissions implicitly burdens all emissions without any “grandfathered” entitlements. A tradeable allowance approach is open to a variety of allocation schemes, including grandfathered distribution or auction. In this way the allowance approach enables efficiency (least cost) and equity (distribution) to be separable. Finally, revenue is not a unique feature of tax approaches; allowances can be sold, leased or auctioned by the government in the first instance to generate revenue.

VI. CONCLUSION

A comprehensive approach to GHG issues is the only scientifically, environmentally, and economically sound strategy. Its adoption will increase the likelihood of successful negotiation of a broad international agreement on GHG emissions. During the next decade, the development of national strategies to deal with GHG emissions under the aegis of a framework convention seems most likely. The framework convention on climate change should mandate a "net GHG emissions" approach to these national strategies. Each nation would develop an inventory of its net GHG emissions, analyze future trends on a "business as usual" assumption, develop plans for limiting net GHG emissions, and develop a tracking system to determine progress. Second, the framework convention should mandate that any future protocol for binding limitations on GHGs (if any) would be similarly comprehensive.

Third, it should guarantee some form of credit or recognition for steps taken now that limit emissions to be counted towards binding obligations if they are ever adopted. Such an "advance assurance" of a comprehensive approach would give nations the confidence to invest appropriately in limiting GHGs other than CO2, or in protecting and expanding sinks. Moreover, it would unleash the full panoply of "no regrets" actions—actions warranted for other reasons that also limit net GHG emissions—some of which nations might be holding in abeyance lest their early deployment forfeit credit against a future baseline for binding GHG reductions. Nations might then move forward with ideas they already know would be to their benefit, but are holding in the wings until GHG credit is assured, perhaps including removing policies that spur excess deforestation, internalizing the costs of energy systems and reducing energy subsidies, reducing agricultural subsidies, and making more rational use of water resources.

Guaranteeing that the convention and its progeny take a comprehensive approach would itself be a "no regrets" strategy, as it would catalyze the...

96. IPCC Response Strategies, supra note 87, at 180-87.
research effort into GHG measurement that is needed if only to understand and predict future anthropogenic contributions to radiative forcing. It would mobilize development of a workable GWP index (or other GHG index), emissions factors and inventory data banks for determining net emissions from various source and sink activities. These tools would be useful in predicting future radiative forcing, in making local technology choices, and in identifying opportunities for national strategy investments. If a binding agreement on quantitative limitations becomes ripe, a comprehensive approach would also be ready to implement with attendant cost savings and environmental benefits. These steps will enable the international response to GHGs and potential climate change to proceed on the only sound foundation: a comprehensive one.
Table 1

**SELECTED SOURCES & SINKS SUBJECT TO HUMAN INFLUENCE**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Sources</th>
<th>Sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>Fossil fuel combustion</td>
<td>Ocean biota &amp; storage</td>
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<tr>
<td></td>
<td>Land clearing</td>
<td>Forests</td>
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<tr>
<td></td>
<td>Biomass combustion</td>
<td>Soils</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>Livestock: enteric fermentation, wastes</td>
<td>Grasses</td>
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<td></td>
<td>Rice cultivation</td>
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<td></td>
<td>Wetlands</td>
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<td></td>
<td>Landfills</td>
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<tr>
<td></td>
<td>Natural gas extraction, transmission, distribution</td>
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<td></td>
<td>Coal mining</td>
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<tr>
<td></td>
<td>Biomass combustion</td>
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<tr>
<td>Nitrous oxide (N₂O)</td>
<td>Agricultural fertilizers</td>
<td>Soil removal</td>
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<td></td>
<td>Land clearing</td>
<td></td>
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<tr>
<td>Halocarbons (CFCs and related)</td>
<td>Refrigerants</td>
<td>Recapturing and destroying existing supplies</td>
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<td></td>
<td>Aerosol propellants</td>
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<td></td>
<td>Foam blowing agents</td>
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<td></td>
<td>Solvents, cleaning agents</td>
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<tr>
<td></td>
<td>Fire retardants</td>
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<tr>
<td>Tropospheric Ozone (O₃)</td>
<td>Precursors: CH₄, CO, VOCs, in the presence of NOₓ</td>
<td>Halocarbon depletion</td>
</tr>
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<td></td>
<td>Transport of strat. O₃ into troposphere</td>
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<tr>
<td>Carbon monoxide (CO)</td>
<td>Fossil fuel combustion</td>
<td>Atmospheric OH interaction</td>
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<td></td>
<td>Biomass combustion</td>
<td></td>
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<tr>
<td>Nitrogen Oxides (NOₓ)</td>
<td>Precursors: CH₄, VOCs</td>
<td></td>
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<tr>
<td></td>
<td>Fossil fuel combustion</td>
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<td></td>
<td>Biomass combustion</td>
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<tr>
<td>Volatile Organic Compounds (VOCs)</td>
<td>Fossil fuel combustion</td>
<td>Atmospheric OH interaction</td>
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<td>Biomass combustion</td>
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<td></td>
<td>Industrial processes</td>
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<tr>
<td>Sulfur oxides (SOₓ)</td>
<td>Fossil fuel combustion</td>
<td>Deposition</td>
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<td></td>
<td>Biomass combustion</td>
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