This paper considers cost-effective policies to reduce greenhouse gas emissions. At the international level, tradeable carbon emission allowances are proposed. Domestically, tradeable allowances for carbon dioxide are proposed for large sources, while a carbon tax, linked to the market price of allowances, is suggested for small sources. Trading of emission reduction responsibilities among nations is encouraged to lower compliance costs, facilitate cost sharing, and provide an economic incentive for countries to become signatories to international emissions control agreements and to adhere to their commitments. National policies could target emissions fees and emissions permits at those sectors where they are most appropriate. Emissions fees are better suited to sources with relatively small emissions; tradeable emissions permits are better suited to large sources. A CO_2 emissions trading system could be extended to include methane and CFCs as well as reforestation. While economic incentive approaches to environmental control offer no panacea, they frequently do offer a practical way to achieve environmental goals more flexibly and at lower cost than more traditional regulatory approaches. They merit serious consideration as policies to address emissions of greenhouse gases are developed.

L'auteur envisage des politiques économiquement efficaces pour réduire les émissions de gaz à effet de serre. Il propose l'instauration, au niveau international, de quotas cessibles d'émission des gaz du carbone. Quant au plan intérieur, il prévoit, d'une part, un régime des quotas cessibles d'émission de dioxyde de carbone qui s'appliquerait aux importantes sources d'émission et, d'autre part, une taxe sur la teneur en carbone, liée au prix des quotas sur le marché, qui frapperait les sources de moindre importance. L'échange entre les pays de leurs responsabilités en matière de réduction des émissions est préconisé comme moyen de diminuer le coût de conformité, de faciliter le partage des coûts et de motiver, par des incitations économiques, les pays à adhérer à des ententes internationales de contrôle des émissions et à respecter leurs engagements dans ce domaine. Le choix des secteurs dans lesquels seraient établis les droits ou les permis d'émission ressortirait aux politiques nationales. Les droits d'émission sont davantage applicables aux faibles sources d'émission, alors que les permis d'émission sont plus utiles dans le cas des importantes sources. Le régime des quotas cessibles d'émission de dioxyde de carbone pourrait être élargi pour englober le méthane, les chlorofluorocarbures et le reboisement. Bien qu'elles ne soient pas une panacée, les méthodes fondées sur des incitations économiques constituent un moyen pratique d'atteindre les objectifs de protection environnementale de façon plus souple et à moindre coût que les méthodes coercitives traditionnelles. Elles pourraient donc constituer un élément important des politiques de contrôle des émissions des gaz à effet de serre.

Erik Haites is a Principal in the consulting firm Barakat & Chamberlin of Toronto.

Tradeable Allowances and Carbon Taxes: Cost Effective Policy Responses to Global Warming

ERIK HAITES*

I. Introduction

Some gases that make up only a small part of the atmosphere absorb a great deal of the heat radiated by the earth. The heat absorbed by these trace gases warms the lower atmosphere creating a greenhouse effect (Schneider, 1990, pp.13-23). Carbon dioxide is estimated to be responsible for approximately 55% of this effect.[1] Also contributing to climate warming are: methane (15%), chlorofluorocarbons (17%), nitrous oxide (6%), and other gases (7%).

Atmospheric concentrations of CO_2 have risen

* I am indebted to Tom Tietenberg for valuable contributions to an earlier version of this paper. In addition I have received helpful comments and suggestions from Ed Caldwell, Paul Centolella, Steve Deutsch, David Patterson and four anonymous referees. Any errors of omission or commission are the sole responsibility of the author.

1/ See Houghton (1990, Figure 7, p.xx). The figures are "the contribution from each of the human-made gases to the change in radiative forcing from 1980 to 1990. The contribution from ozone may also be significant, but cannot be quantified at present." Other sources that include ozone and relate to different periods give somewhat different numbers. World Resources (1990, Table 2.4, p.24) shows the contributions to global warming by human activity as carbon dioxide 50%, methane 16%, ozone 8%, nitrous oxide 6% and chlorofluorocarbons and others 20%.

by 25% since 1800 (Houghton *et al*, 1990, Table 1, p. xvi). Atmospheric concentrations of most of the other greenhouse gases, except nitrous oxide, have been rising more rapidly than that of CO_2.

Increased concentrations of the greenhouse gases in the atmosphere will raise the average temperature, although the speed, magnitude and regional patterns of the warming are uncertain (Houghton, 1990, p.xii).

To study the consequences of global warming, the Intergovernmental Panel on Climate Change (IPCC) developed four scenarios of greenhouse gas emissions to 2100 (Houghton, 1990, p.xxxiv). The "Business as Usual" scenario leads to a doubling of equivalent CO_2 concentration by 2030 and almost a quadrupling of the current concentration by 2100. These increased concentrations are predicted to lead to an increase in global mean temperatures of about 1°C above the present value by 2025 and 3°C above today's temperature by the end of the next century (Houghton, 1990, p.xxii). These increases are realized temperatures;[2] at any time we would be committed to a further temperature rise of 25 to 100% before equilibrium is reached.

Climate warming of this rate and magnitude poses serious threats to the planet.[3] The IPCC's Business as Usual scenario results in a predicted realized sea level rise of 65 cm by the end of the next century (Houghton, 1990, p.xxx). As global mean temperature rises, climate regimes move toward the poles and to higher latitudes. Forests may not be able to move fast enough to keep pace with climate change (Houghton, 1990, Chapter 10). Plant and animal species that attempt to migrate with the climate regime may encounter barriers including human land use. As a result many plant and animal species could be lost. A higher global mean temperature could also lead to poleward migration of diseases hitherto confined to the tropics and increased death rates during heatwaves (Legett, Chapter 7).

Scientists estimate that to stabilize atmospheric concentrations at current levels will require that human-made emissions of greenhouse gases, except methane and HCFC-22, be cut by at least 60% from current rates (Houghton, Table 2, p.xviii). As an **interim** target, the Toronto Climate Conference proposed reducing CO_2 emissions by 20% from 1988 levels by 2005 (Changing Atmosphere, p.5). The feasibility of this interim target has been studied for a number of countries.[4] Generally it is found to be a very challenging target.

Given the scale of the challenge, policies should be designed to minimize the costs of reducing emissions of greenhouse gases. Two types of analysis are possible. In principle, the costs of reducing emissions of greenhouse gases can be compared to damages avoided as a result

---

2/ When atmospheric concentrations of greenhouse gases rise, the atmosphere will try to respond by warming immediately. But the atmosphere is closely coupled to the oceans, so in order for the air to be warmed the temperature of the oceans must rise. Because of the thermal capacity of the oceans, it takes decades or centuries for their temperatures to rise to the new equilibrium temperature. A commitment to the new equilibrium temperature is incurred as soon as the greenhouse gas concentration changes. But at any point in time before the new equilibrium is reached, the actual temperature will have risen by only part of this amount. The actual increase at any point in time is the **realized** temperature change. The difference between the equilibrium temperature and the realized temperature is the **committed** temperature change that will be realized over succeeding decades or centuries. The relationship between realized and committed temperature change depends upon the pattern of change in greenhouse gas concentrations and climate sensitivity. The realized temperature is estimated at 50 to 80% of the equilibrium temperature depending upon climate sensitivity. See Houghton (1990, p.xxvi).

3/ The impacts depend upon the scale and **rate of change** of the climate in each area. Generally, temperatures in areas near the equator are expected to rise less than the global average, while temperatures near the poles are anticipated to rise several times as much as the global average. Temperature changes also affect precipitation patterns. Although the impacts on total precipitation are not clear, a warmer climate will reduce the proportion of total precipitation as snow and raise the proportion that falls as rain. That shift will reduce soil moisture during the growing season for many agricultural areas in the mid-latitudes.

4/ Chandler (1990) reports case studies for the Soviet Union, Poland, Hungary, Canada, Japan, the United Kingdom, France and the United States. US Agency for International Development (1990) examines emission reduction options for a number of developing countries.

of lower rates of global warming. Equating the marginal cost of emissions reduction with the marginal value of the damages avoided determines the **efficient** level of emissions control. Alternatively, the level of emissions reduction can be determined by negotiation or other means. Then the challenge is to develop policies that achieve the predetermined reduction in the most **cost-effective** manner.[5]

An attempt has been made to determine the efficient level of emissions control for the United States.[6] That analysis could be replicated, and possibly improved, for Canada. However, Canada has already committed itself to stabilizing national emissions of CO_2 and other greenhouse gases at 1990 levels by the year 2000 (Canada, p.97). Given that this target has already been established, the challenge becomes one of designing cost-effective ways to achieve the goal. This paper focuses on the design of cost-effective policies to reduce greenhouse gas emissions.

The paper draws upon the experience with emissions abatement policies for other pollutants to mould a set of policies that hold promise for encouraging cost-effective, enforceable, international efforts to reduce emissions of greenhouse gases. In contrast to other discussions of this topic, I suggest different policies targeted to the areas where they work best, but orchestrated to produce the greatest reductions at the lowest cost.

The paper begins by establishing the context for the reduction of greenhouse gases; the prospects for an international agreement to reduce emissions of greenhouse gases and the principal options for lowering carbon dioxide emissions. Next, it briefly reviews the advantages and disadvantages of emission fees and tradeable emission allowances. It is then established that application of these policies is appropriate for greenhouse gases. These insights are used to propose policies that might be implemented to mitigate global warming. At the international level tradeable carbon emission allowances are proposed. Domestically, tradeable allowances for CO_2 are proposed for large sources, while a carbon tax linked to the market price of allowances is suggested for small sources. Possible extension of the system to methane, CFCs and reforestation is considered.

II. The Context

International Agreement to Reduce Emissions

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988. The IPCC organized three working groups to: assess available scientific information on climate change; assess environmental and socio-economic impacts of climate change; and formulate response strategies.

In addition a Special Committee on the Participation of Developing Countries was established to promote full participation of developing countries in its activities. Over 70 countries participated in the IPCC process. The IPCC report, published late in 1990, provides much of the background information needed to negotiate an international agreement to reduce emissions of greenhouse gases.

Negotiation of an international agreement to address climate change has begun. The agreement governing production of ozone depleting substances is expected to serve as a model. That model would result in a framework convention and a series of protocols governing emissions of

5/ Efficient control requires that the pollution target maximize the net benefits to society, while cost-effective control seeks to meet a predetermined target at minimum cost. The predefined target may or may not maximize the net benefits to society.

6/ Nordhaus (1990) presents an analysis to determine the efficient level of greenhouse gas emissions reductions for the US. His results indicate reductions of greenhouse gas emissions of between 10 and 47% are efficient for the US, depending upon the damage estimate. The analysis has been criticized on various grounds: the earth, rather than the US, is the only appropriate scale of analysis; some damages, such as existence values for species that might be lost, are not included in the estimates; and for the implicit assumption that, in the absence of emissions reductions, there would be no damage.

carbon dioxide and other greenhouse gases. Mid-1992 is the target date for signature of the framework convention.

This paper assumes that national emission limits for CO_2, and possibly other greenhouse gases, will be successfully negotiated. Various approaches have been suggested as a basis for setting the national emission targets.[7] Negotiation of them is complicated by their implications for wealth transfers.[8] Developing countries argue that developed countries have grown wealthy through the use of fossil fuels, such growth having created the current problem, and so they should bear the burden of mitigating global warming. The agreement is expected to include some form of assistance to developing countries to help cover the costs of reducing emissions. The negotiations will obviously be complex and success is not guaranteed.

At least a dozen countries have announced plans to limit unilaterally their emissions of carbon dioxide.[9] In most cases the target adopted is stabilization of CO_2 emissions at current levels by 2000. The current commitments are **interim** targets. Climate stabilization will require a series of progressively more stringent targets to cut emissions of CO_2 and most other greenhouse gases by over 60% from current levels. Control policies for greenhouse gases should recognize the need for future reductions in emissions targets and be designed to achieve those reductions with a minimum of disruption.

Carbon Dioxide Emission Reduction Options

While recognizing the contributions of other gases, the discussion will focus on carbon dioxide because it is responsible for about half of the greenhouse effect. The possible extension of cost-effective policies for control of other greenhouse gas emissions is discussed later.

The dominant human-made source of CO_2 emissions is the combustion of fossil fuels. Emissions are closely related to the carbon content of the fuel and are relatively insensitive to the combustion conditions. In other words, CO_2 emissions can be determined fairly accurately from fuel use.

Studies of options for reducing CO_2 emissions consistently show that improved energy efficiency is the most cost-effective strategy available over the next decade or two. Fuel switching can also contribute. Fuel switching covers both substitution of fossil fuels with lower emissions per unit of energy (e.g., natural gas) for fossil fuels with higher emissions per unit of energy (e.g., coal), and substitution of non-fossil energy sources (e.g., hydroelectric, nuclear, solar) for fossil fuels. However, the analyses completed to date suggest that fuel switching alone could not reduce forecast CO_2 emissions enough to meet the proposed interim targets (Chandler, 1990).

If the ultimate target is to stabilize atmospheric concentrations of CO_2, emissions will need to be reduced by at least 60% from current levels. Estimates of the potential for energy efficiency improvement are well below 60% for most energy uses. Substituting one fossil fuel for another also will not lower CO_2 emissions to the extent needed (Edmonds, p.3). Hence, to go beyond the interim targets will require greater reliance on non-fossil energy sources.

Atmospheric concentrations of carbon dioxide can also be lowered by increasing the amount of carbon stored in natural "sinks". Carbon is stored in oceans, soils, vegetation and a variety of other natural sinks. Analyses of the potential for increased use of carbon sinks focus on forestry because of the relatively long life of trees and the ability of humans to manage forests.

Protection of existing forests and reforestation have been proposed as ways to offset projected

---

7/ See, for example, Krause (1989), Part II, and Flavin (1989). The Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency is using national models to estimate emissions targets that would have the same marginal cost of control in each country (ETSAP News, 1990).

8/ Whalley and Wigle (1990) explicitly analyses the redistributional implications by examining the incidence of a global carbon tax and alternative formulae for redistributing the tax revenues.

9/ Austria, Australia, Canada, Denmark, France, Germany, Italy, Japan, The Netherlands, New Zealand, Norway, Sweden and the United Kingdom.

CO_2 emissions. Reforestation is limited by the amount of land available. While it can make a contribution, it is not capable of offsetting current CO_2 emissions, let alone reducing atmospheric concentrations below current levels (Krause, 1989, pp.I-3-39 to I-3-51).

Policies to reduce greenhouse gas emissions will need to encourage adoption of the optimal mix of energy-efficiency improvements, fuel switching, reforestation and other measures if the interim and ultimate targets are to be achieved at the lowest overall cost.

III. Cost-Effective Pollution Control

Economic Regulatory Mechanisms

What policies will be needed to reduce carbon dioxide in a cost-effective manner? The theory of cost-effective pollution control is now well established.[10]

The conditions that cost-effective pollution control must satisfy depend on the nature of the pollutant. If the location of the emissions does not matter, the pollutants are referred to as uniformly mixed. Greenhouse gases are uniformly mixed pollutants. For such pollutants, it is enough to control the aggregate level of emissions. Cost-effective control is achieved for uniformly mixed pollutants when the marginal control cost is the same for every source in every country.

The two primary policy instruments for achieving cost-effective control for uniformly mixed pollutants are emission fees and tradeable emission allowances. These are not the policy instruments commonly used to regulate atmospheric emissions. Traditionally atmospheric emissions are controlled by passing regulations that specify maximum allowable emission rates, permissible production technologies or required control technologies. The requirements may vary by type of source and small sources are often left unregulated. The compliance costs of this traditional "command-and-control" approach can vary significantly from source to source, and so generally it does not achieve cost-effective control.

An emission fee or tax is a fee per unit of pollutant emitted into the atmosphere. The fee raises the "price" of emissions, often from zero, and so provides an incentive to reduce the quantity of the pollutant emitted.

A tradeable emissions allowance system establishes an overall limit on emissions. Permits equal to this total are distributed to those responsible for the sources of emissions. Each source must hold sufficient permits to cover its actual emissions. Permits not required by a source can be sold to other sources whose emissions exceed the permits originally allocated to them. Instead of putting a price on emissions and allowing the quantity to adjust (the concept behind emission fees), emissions permits set quantity limits on emissions and allow the price to adjust.

Systems of emissions taxes and tradeable emissions permits are, in principle, substitutes for one another. In practice each approach has characteristics that makes it more suitable for some applications. Those characteristics are discussed below. First, it is useful to compare both of these economic regulatory mechanisms with command-and-control regulation of emissions.[11]

As already noted, a command-and-control approach generally does not achieve a cost-effective allocation of control. The regulations involved often restrict the options for achieving compliance, while economic regulatory mechanisms allow any measure that lowers emissions. Achieving compliance with command-and-control regulations removes almost all incentives to cut emissions further, while economic mechanisms always provide an incentive to lower emissions further. Economic mechanisms also provide an incentive to develop and implement better control technologies. The emissions reductions achieved lower the emission fees that

---

10/ See Baumol (1975), and for a textbook treatment, see Tietenberg (1988). Recall that the focus is on policies to meet a predetermined target at minimum cost, not determination of the most efficient level of control.

11/ For discussions of the advantages of economic incentive measures see US Department of State (1990), US Department of Energy (1989), Opschoor (1989), Anderson (1990).

must be paid in the one system or yield saleable permits in the other. All regulatory approaches lead to a redistribution of wealth.[12]

Emission Fees

An emission fee or tax is a fee per unit of pollutant emitted into the atmosphere. Polluters faced with an emission fee minimize their costs by controlling discharges until the marginal cost of control is equal to the per unit fee.[13] This implies that forcing all polluters to face the same per unit fee on emissions results in an allocation of the control responsibility that is cost-effective; the marginal costs of control are equalized for all sources by polluters acting to minimize their own costs.

How is the emission fee established? With a predetermined target, such as a negotiated national limit on carbon dioxide emissions, the fee that will yield the target level of emissions must be estimated.[14] It is likely that the estimated fee will not achieve the target precisely. In the case of greenhouse gases, the environmental consequences of excess emissions in a particular year are not severe, provided that offsetting reductions in target emissions are achieved in subsequent years.

A fee designed to reduce CO_2 emissions is usually set on the basis of the carbon content of the fuel and is generally called a carbon tax.[15] The fees needed to achieve appreciable reductions in CO_2 emissions generate large revenues.[16] The manner in which those revenues are used becomes an important consideration in the redistribution of wealth caused by tax.

Emission fees have a significant disadvantage from the viewpoint of the polluter. Under traditional command-and-control regulation, sources pay only for the required pollution control measures. With emission fees they have to pay for the control equipment, but they also have to pay fees on uncontrolled emissions. Emissions taxes can create problems where sources on opposite sides of a border are taxed at a significantly different rates.

While steps can be taken to reduce the financial burden of emissions fees (tax rebates or taxing only emissions above a certain level), these tactics have not been very successful in deflecting political opposition.[17] In Europe concern over the financial burden has not been sufficient to prevent emission fees from being instituted, but it has served to keep the rates lower than economists believe they need to be to achieve

12/ Imposition of an emissions tax leads to higher product prices, lower returns to shareholders and possibly lower returns to employees and suppliers due to lower demands for their services and products. The manner in which the tax revenue is used or redistributed also affects the distribution of impacts. Command-and-control regulations have impacts similar to those of an emissions tax, except that there is no revenue to redistribute. In the case of emissions permits the impact on the distribution of wealth depends heavily on the manner in which the permits are allocated. If the permits are sold by government, the distributional impacts of the use of the revenue have to be considered. Free distribution of permits may confer net benefits on polluters.

13/ More control would raise costs unnecessarily because the cost of the additional control would exceed the cost of simply paying the tax. Less control would also result in an unnecessarily high cost, because the tax paid on uncontrolled emissions would exceed the cost of eliminating those emissions.

14/ If the emissions target is the efficient pollution level, then the fee is set equal to the marginal benefit of reduced emissions. If the target is set on some other basis the fee corresponding to that level of emissions must be determined through trial and error, although good estimates can be obtained from economic models.

15/ Sweden has announced an emissions tax for carbon dioxide.

16/ Montgomery (1990, p.xii) indicates that a tax of $100 per ton of carbon in the US would yield revenues of $110 to 120 billion. Whalley and Wigle (1990) estimate that a tax of approximately US $450 per ton of carbon would be needed to reduce global carbon use by 50% relative to their base case. The present value of the tax revenue over the period 1990-2030 is estimated at $43 trillion dollars, which is about 10% of the gross world product for the period. Edmonds (1990, pp.16-17) lists carbon tax rates estimated by various authors which range up to US $450 per ton of carbon.

17/ Emission fees have been labelled, incorrectly, "licences to pollute." The right to pollute is no greater than under traditional command-and-control regulation, and fees must be paid on all emissions.

their environmental goals. Emission fees have also proven to be relatively difficult to adjust when higher levels of control are needed.

Tradeable Emissions Allowances

In the US, cost-effective pollution control has taken the form of tradeable emissions allowances. Permits corresponding to a predetermined national or regional emissions target are created. The permits can be auctioned or be allocated free of charge to individual sources, usually in proportion to historic emission levels. In any case, each regulated source must obtain enough permits to cover its actual emissions. Allocated permits not used by a source can be sold to others. The quantity of permits issued can be reduced over time to meet a specified reduction target.

Tradeable emissions permits share with emission fees the characteristic that they result in a cost-effective allocation of control. Cost-effectiveness is achieved because sources that can reduce their emissions most cheaply do so and sell their surplus emission permits to others. In these transfers the price of the emissions permit plays the same role as the emission fee; it encourages reallocation of control until the marginal control costs are equalized across all sources.

A smoothly functioning market is critical to achieving the most cost-effective allocation of control with a tradeable emissions permit system. If the number of buyers or sellers is small, or if the conditions on trading permits are onerous, the market may not function smoothly. A limited ability to trade permits, or permit prices different from those that would prevail in a perfectly competitive market, will result in an allocation of control that is not the most cost-effective.

One of the most significant characteristics of the emissions permit approach is the opportunity it offers for cost sharing. In effect emissions permits separate the financing of emission reductions from the actual implementation of those reductions. With tradeable permits a source is free to choose to reduce its emissions and to use revenue from the sale of surplus permits to help finance the cost of control. Alternatively, a source may choose to purchase additional permits to cover its total emissions if this is cheaper than reducing its own emissions.

Some Lessons[18]

We now have quite a bit of practical experience with using emission fees and transferable emissions permits, and it is possible to extract some lessons from that experience. In theory environmental objectives can be achieved equally effectively using emissions fees or tradeable emissions permits. In practice, each approach works better under some circumstances.

Emissions permits integrate smoothly into any policy structure based on quantitative emission reduction targets. Transferable permits are better than emissions fees in situations where excess emissions during any period could have significant environmental or health consequences. Emission fees are superior when the policy target can be expressed in monetary terms, such as a revenue target or a marginal damage estimate, or when the objective is to raise revenue for environmentally benign projects or to replace other revenue sources.

Transferable emissions permits can work well for large sources provided that the transactions costs are not onerous and that there are a sufficient number of sources to allow active trading. The greater the range of compliance costs across sources, the larger the potential gains from trade. Emissions fees are superior when transactions costs associated with permit transfers are high or when the conditions needed to sustain a competitive market are not present. Emissions fees are also superior when sources face similar marginal control costs so that the gains from trade are small.

Transferable emissions permits allow the issue of who will pay for the control to be separated from who will install the control. This allows the regulatory policy to be designed so that the cost is apportioned across all sources regardless of their compliance options.

18/ This section relies heavily on Tietenberg (1990, pp.17-33).

There can be little doubt that the emissions trading programme in the US has improved upon the command-and-control programme that preceded it. The documented cost savings are large and the flexibility provided has been important. Similarly emissions charges have achieved their own measure of success in Europe. To be sure the programs are far from perfect, but the flaws should be kept in perspective. ... Although economic incentive approaches lose their Utopian lustre upon closer inspection, they have nonetheless made a lasting, impressive contribution to environmental policy (Tietenberg, 1990).

IV. Economic Incentives for Greenhouse Gases

Should economic incentive approaches to regulation play a substantial role in policies to control emissions of greenhouse gases? That question will be answered affirmatively if regulation of greenhouse gases by economic means is environmentally sound and if economic regulation produces advantages not available via other regulatory approaches.

Greenhouse gases are uniformly mixed gases for which economic regulatory approaches are appropriate. It does not matter whether emissions occur at the poles or the equator, the impact on the global climate is the same. The short-term temporal pattern of emissions of greenhouse gases is also not critical to the impact on climate. Having annual emissions concentrated in one season, or being over target one year and under target by an equal amount the next does not materially alter the climate impacts that will be experienced over the next several decades.

The scale of reduction in greenhouse gas emissions required to stabilize atmospheric concentrations at current levels is very large. The costs are also estimated to be large relative to other environmental controls. The relatively high cost is a compelling argument in favour of cost-effective regulatory policies — emission fees and transferable emissions permits rather than traditional command-and-control approaches. The costs of achieving greenhouse gas emissions reductions targets will be unnecessarily high unless economic incentive approaches are adopted.

The ability of tradeable emissions permits to separate the cost of compliance from the reduction of emissions is another important advantage. It enables the cost of compliance to be apportioned equitably over all sources while enabling actual reductions to be made where they can be obtained at the lowest cost. The scope for cost-effective reductions is not evenly distributed across sectors or regions.

Figure 1 shows estimates of the forecast emissions of carbon dioxide by sector in Canada before and after implementation of the cost-effective mitigation measures. Each sector is indexed with 1988 = 100. In the absence of control measures, CO_2 emissions from the residential sector in 2005 would be 20% higher than in 1988.[19] If all cost-effective control measures were implemented, CO_2 emissions from this sector would be 70% of the 1988 level. The figure suggests that the scope for cost-effective reductions is substantially greater in the electric utility sector than the industrial sector. The same study found similar discrepancies in the scope for cost-effective reductions by region within Canada.

The data in Figure 1 suggest that there are significant differences in marginal control costs across sectors. That in turn implies the existence of economic advantages as a result of trade in emissions permits. It is interesting as well that the discrepancies appear to be most pronounced in the industrial and electric utility sectors, precisely the sectors most likely to offer and purchase large quantities of emissions permits.

Larger trading areas should allow more sources to participate in the market for transfer-

19/ The assumed annual rates of growth of CO_2 emissions, which are closely related to growth of energy use as forecast by Energy, Mines and Resources using its IFSD model, are 1.08% for the residential/commercial sector, 1.78% for the industrial sector, and 2.00% for the transportation sector. Emissions due to electricity generation rise at a rate of 4.31% per year as a result of the declining real price of electricity, with rising real prices of natural gas and petroleum products, and a shift to coal for electricity generation because it is assumed to have a constant real price.

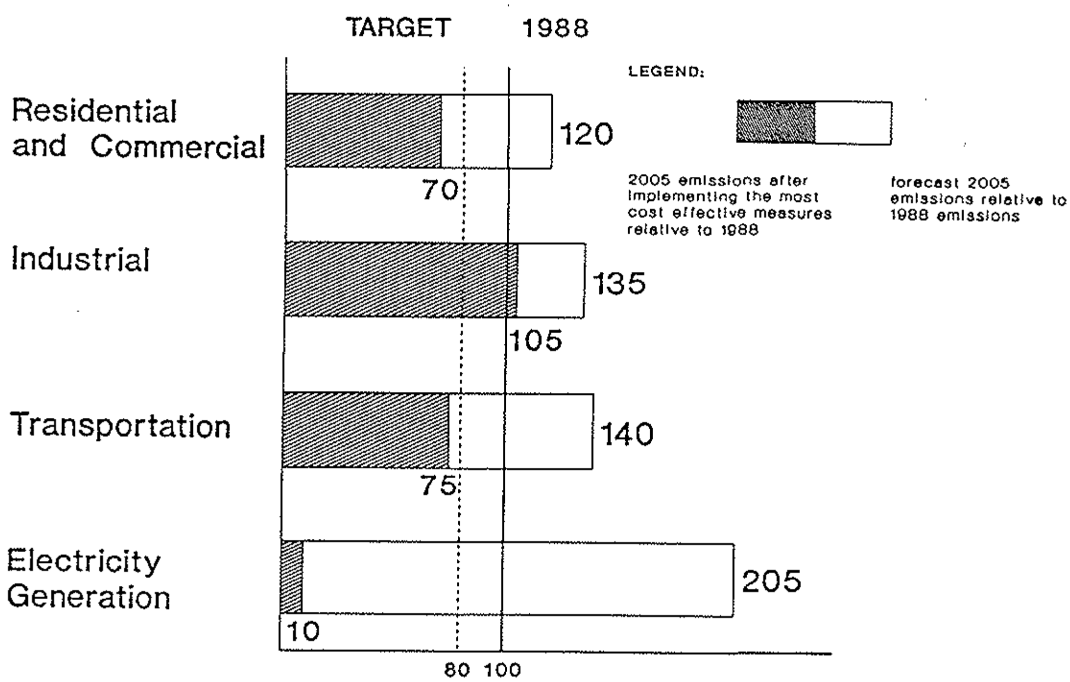

Figure 1: Impacts of Most Cost-Effective Measures

Source: Calculated from The DPA Group Study on the Reduction of Energy-Related Greenhouse Gas Emissions, March 1989.

able emissions permits. This augurs well for the use of emission permits as part of the strategy to control global warming because the natural trading areas are large. Greenhouse gases could involve trading areas that are at least national and, preferably, global in scope.

V. International Trade of Emissions Permits

The approach proposed here involves a two-tiered system of greenhouse gas emission controls. The first tier governs the allocation of emission reduction responsibilities among the nations of the world. The second tier allocates the national responsibility for emission reductions among the sources within a nation.

This division has some appealing features. The first tier is handled by international agreement and is subject to international enforcement. The infringement of national sovereignty is limited to the total amounts of greenhouse gases emitted in a country each year. How each country chooses to reach its national targets is left to its discretion. The second tier policy is determined independently by each nation and is likely to vary significantly from country to country.

National Emissions Targets

As indicated earlier, I believe that an international agreement on global warming is likely within the next few years and that it will contain specific annual emission targets for greenhouse gases by country with deadlines for compliance. The basis for the national targets is not material to the analysis. The national targets are likely to be lowered several times during subsequent decades before the climate is stabilized. Compliance procedures will require updated emissions inventories sufficiently detailed to be verified.

It is likely that the national targets embodied in the international agreements will not distribute the control burden among countries in a cost-effective manner.[20] One possibility that has been discussed, for example, is to set targets for developing countries above current emission levels. To achieve a given global reduction, developed countries would then need to cut their emissions by more than the overall target.[21] This implies zero marginal cost of emissions reduction for developing countries and positive marginal costs of emission reduction for developed countries. However fair this approach is, it certainly does not equalize the marginal cost of control across all sources and so is not cost-effective.

Nations with the lowest cost means of reducing emissions would not be able to fully exploit those opportunities. Many countries which have low marginal costs of emissions reduction also have few resources to devote to environmental protection. In other words, the affordability of emissions reduction measures is a problem for many countries quite apart from the wealth redistribution issue noted above.

Internationally Emissions Permits are Better than Emission Fees

While in principle either emissions fees or transferable emissions permits could address the problem, I believe that emissions permits have the edge internationally. Since they are quantity based, emissions permits are completely and immediately compatible with the national targets assumed to be negotiated and incorporated into an international agreement.

Emissions trading can also facilitate international cost-sharing in a manner which encourages the full participation of developing nations. If the carbon dioxide reduction targets for developing countries are less stringent than those for developed countries, emissions trading creates an economic incentive for Third World countries to become signatories to the international agreement.

Each country that signs the international agreement to reduce CO_2 emissions agrees, by doing so, to limit its emissions to a specified quantity each year. If the actual emissions are below the specified limit, permits corresponding to the difference could be banked for future use or sold to countries whose actual emissions exceed their agreed limits. Countries whose actual emissions exceed their agreed target must use banked emissions permits, or emissions permits purchased from other countries to meet their international commitments.

To demonstrate how international trade of carbon dioxide emissions permits would work, consider an example. Suppose Malawi can reduce CO_2 emissions for US $100 per tonne, while Canada could reduce emissions for US $400 per tonne. Suppose that according to the international agreement, Malawi is in compliance, while Canada needs further reductions to meet its target.

With international trading of emissions permits, Malawi could reduce its emissions more than required by the international agreement and sell the excess to Canada. Sale of the emissions permits, say at US $250 per tonne, would supply Malawi with more than enough funds to cover the additional cost of control.[22] Canada would also be better off. By purchasing these credits at US $250 per tonne it eliminates the need to spend US $400 per tonne to meet its requirements. The costs of compliance have been substantially lowered and both countries benefit economically.

The trade has addressed the affordability issue since the price of the permits exceeds the cost of

---

20/ The targets being estimated by IEA's ETSAP project are an exception. They are being estimated so that the marginal cost of control will be equal in every country.

21/ If the global target is a 20% reduction from 1988 emissions by 2005 and the emissions of developing countries rise, those of the developed countries must fall by more than 20%.

22/ The trade could be made between the respective national governments, private organizations in the two countries or any combination thereof. However, given the wealth transfer involved, the selling government would likely wish to be a party to the transaction in order to capture some share of the wealth transfer.

reducing emissions in the selling country. A transfer of wealth equal to the difference between the sale price and cost of control has also been effected. Yet these objectives have been achieved in a manner that benefits the purchasing country. Neither national governments nor an international agency need be involved in the transfer of funds.

International carbon taxes could also do the job, but an international mechanism for collecting and redistributing the fee revenue would need to be established (Whalley, 1990). The scale of the fees needed to achieve the likely emissions reduction targets will diminish national enthusiasm for participating in the agreements, not only for developing countries, but for the US and other countries with demonstrated aversions to tax increases.

Cost-effective control would require that the same tax rate be applied throughout the world. The world carbon tax would be set so as to achieve the global carbon dioxide reduction target. If national emission reduction targets are agreed to, the carbon tax needed to achieve each country's target would probably be different. In that case the result is not a cost-effective allocation of control responsibility. Affordability and wealth transfer are handled through distribution of the carbon tax revenues collected.

Tradeable permits are preferred to international carbon taxes because they are easier to integrate with the national emission targets likely to be negotiated and require countries to yield less sovereignty. Carbon taxes involve greater infringement on national sovereignty since they require an international taxing authority to set the tax rate and redistribute the revenues.

Certification of Emission Permits

A country must be in compliance with its international obligations to reduce greenhouse gas emissions if the emissions permits it exports are to be valid.[23] A country whose combined actual emissions and emissions permit exports are greater than its agreed target is not in compliance. Ensuring that all signatories comply with their emissions reduction obligations is a problem regardless of the policies adopted by different countries. With international emissions permit trading, compliance can be enhanced through international certification of permits or through trade restrictions on nationally certified permits.

In principle an international agency could be designated to certify emissions permits for international trade. A country would need to demonstrate that its emissions were below its agreed target, and hence were available for sale. This approach entails a considerable surrender of sovereignty by participating nations and the creation of an international bureaucracy.

The alternative is to rely on each country's own certification process. This gives rise to the concern that the process will not be equally rigorous in all countries.

Each country that participates in the international agreement to reduce emissions of greenhouse gases will need to establish its own process for measuring its emissions and monitoring performance against its target. A country that wishes to export emissions permits needs this same information to determine the quantity that can be traded.[24] A country that wishes to purchase permits could ask to inspect the documentation supporting the permits to be purchased. The intensity of the inspection is likely to vary by country.

The analogy of inspection standards for foodstuffs is appropriate. Each country decides

23/ Compliance will obviously need to be addressed in the negotiations that establish the national emissions targets. Carbon dioxide emissions can be estimated fairly accurately from data on energy use and forest growth. Relatively good international statistics on energy use are available for most countries. Forest growth can be estimated from satellite photographs. Small, short-term violations of emissions targets do not create immediate health or environmental dangers, only long lasting impacts on climate. *Ex post* monitoring of emissions with a requirement to reduce future emissions by the amount of past violations may well be sufficient.

24/ A country does not need to have a national emissions permit system to participate. Assume that a country relies entirely on command-and-control regulation domestically but keeps its actual emissions below the agreed target. Permits equal to the difference between actual emissions and the target could be created by the national government for purposes of international trade.

which foodstuffs can be imported on the basis of the inspection system in the country of origin. In some cases the importing country relies entirely on the system used by the exporting country. In other cases the importing country randomly inspects products or processing plants in the exporting country. In yet other cases, all products are inspected at the border. Similar arrangements would likely evolve for international trade in CO_2 emission permits.

The integrity of national certification processes for emissions permits is enhanced by the threat of trade sanctions. Importing countries will wish to inspect the systems and documentation supporting the permits they purchase. If the documentation provided by a particular country is unsatisfactory, imports of emissions permits from that country could be prohibited.[25] If enough importers prohibit purchases from a given country, its surplus permits will have little value on the international market. This provides a financial incentive, at least for countries that are exporters of emissions permits, to adhere to their agreed national targets.

Reliance on the domestic certification processes is likely to be the more appealing alternative. An international agency to register, but not control, trades of emissions permits would be useful under these circumstances.

VI. Cost-Effective National Policies

Each country that signs the international agreement to reduce greenhouse gas emissions must limit its emissions to its authorized target plus the net amount of emissions credits purchased from and sold to other countries. It is my belief that cost-effective policies for reaching the national emissions limits should combine emissions fees (a carbon tax) and tradeable permits rather than rely exclusively on either policy. The policy best suited to each sector is reviewed below.

Throughout it is assumed that revenues raised from emissions fees and the sale of emissions permits by government are used exclusively to reduce revenues collected using other taxes. In addition, affordability concerns and wealth impacts are assumed to be addressed in a manner deemed to be equitable by the national government through redistribution of emissions fee revenue and conditions on the distribution of emissions permits.

Transportation Sector

In the transportation sector carbon dioxide emissions vary with the type and quantity of fuel used. To influence fuel use so as to obtain a cost-effective reduction of emissions in this sector, there are three options: emission fees; emission permits for consumers; or emission permits for fuel distributors. These are discussed below.

It should first be noted that energy efficiency standards for vehicles are not a substitute for emission taxes or emission permits. Emissions are related to total fuel use, which is the product of vehicle fuel efficiency and distance travelled. Fuel efficiency standards do not regulate the distance travelled and so have only a partial influence on emissions. An emission fee or emissions permit is needed to influence distance travelled.

Thus energy efficiency standards are compatible with, but not a substitute for, emission fees and permits.[26] Efficiency standards move vehicle design in the direction needed to achieve the substantial reductions in CO_2 emissions believed to be needed in the long run.[27]

An emissions fee (carbon tax) raises the cost of fuel and so reduces the distance travelled. An energy tax (a gasoline tax) also raises the cost of

---

25/ The quality of a country's certification procedure will affect the market for its permits, thus creating an incentive to improve certification.

26/ It can be argued that higher fuel costs may be needed to make the energy efficiency standards effective. A carbon tax would raise fuel costs and so could make energy efficiency standards more effective.

27/ Non-fossil transportation fuels — ethanol from biomass, electricity and hydrogen — contain less energy per unit weight or volume when stored in a vehicle (e.g., a charged battery) than gasoline or diesel fuel. Improvements in vehicle fuel efficiency will allow vehicles to operate in the manner that owners expect (e.g., trip length and refuelling frequency) with less total energy, thus minimizing the disadvantage of the non-fossil fuels.

fuel and so reduces carbon emissions. However, the impacts are quite different and the carbon tax reduces CO_2 emissions at lower cost.[28]

Carbon dioxide emissions are related to total fuel use. An emissions permit for one tonne of CO_2 is equivalent to a coupon for fuel with a carbon content of one tonne.[29] To constrain CO_2 emissions in the transportation sector to its share of the national total, a system of fuel coupons would be needed. Fuel coupons could be distributed to, and traded by, consumers.[30] The fuel coupons are more likely to serve as a basis for allocating available transportation fuels than as a means of achieving further reductions in CO_2 emissions.

The carbon dioxide emissions of the transportation sector could also be controlled by limiting the supplies of transportation fuels — gasoline, diesel, aviation turbo, propane for vehicles — at the distributor level. Since the objective is to reduce CO_2 emissions, the quantity of fuel supplied must be reduced from current levels. The result would be periodic shortages or price increases for transportation fuels.[31]

Distributors of transportation fuels could purchase emissions permits from other sectors to enable them to supply larger quantities of fuel. The prices of the permits would be passed on to customers in the form of higher fuel prices. In equilibrium the cost per unit of fuel of the emissions permits purchased should be equal to the emissions fees needed to achieve the same reduction.

A carbon tax appears to be the best option. It can achieve the desired reduction in CO_2 emissions alone or in combination with legislated fuel performance standards with virtually no added administration. It also leads vehicle design in the direction needed to achieve further reductions in emissions beyond the interim target and shifts land use patterns as transportation costs rise.

Residential Sector

In the residential sector carbon dioxide emissions are dominated by the use of fossil fuel for space heating and, to a lesser extent, space cooling and water heating. Use of electricity for appliances has an indirect impact on CO_2 emissions through electricity generation.

The options for reducing the carbon dioxide emissions of the residential sector are analogous to those discussed for the transportation sector. Fuel coupons would be needed to control the emissions of individual households. The coupons would reduce fuel use from current levels. Poor management on the part of the homeowner or unusual weather patterns could leave individual households without fuel during cold weather or heat waves, with possible health consequences for young children, the sick and the elderly. The consequences of fuel shortages, even if due to poor planning by the homeowner, are likely to be publicly unacceptable.

Instituting emissions permits at the distributor level would require that they purchase permits from other sectors to meet the demand for home heating fuels. If distributors buy the necessary permits and incorporate this cost in the fuel price, the result is the same as a carbon tax. If distributors choose not to purchase carbon permits the result is fuel price increases and possible shortages.[32]

A carbon tax, alone, or together with energy efficiency standards for residential buildings

---

28/ Chandler (1990) compares a carbon tax and a gasoline tax that raises the same revenue. Jorgenson (1990) compares the impacts of a carbon tax, an energy tax and an *ad valorem* energy tax, all designed to achieve the same reduction in CO_2 emissions.

29/ Approximately 1,556 litres of motor gasoline. Fuel coupons would, of course, need to be issued in more convenient denominations such as 1, 5 and 10 litres.

30/ Implementing fuel coupons at the consumer level would require an equitable system for distributing coupons. The distribution system for fuel coupons gives rise to a number of issues. For example, should coupons be distributed to drivers or to vehicles? Should commercial drivers/vehicles receive larger allocations?

31/ A price increase due to a limited supply of fuel would accrue to the oil companies.

32/ A carbon tax will increase the price of home heating fuel. This tax revenue goes to the government which, I assume, reduces other taxes by an equivalent amount. Price increases imposed by distributors of home heating fuels accrue to these firms. The implications for income distribution are quite different.

and appliances, can reduce energy consumption in the residential sector. The target reduction in CO_2 emissions can be achieved with little administration through such taxes. The carbon tax and energy performance regulations would help move building and equipment technology in the direction needed to achieve further reductions.

The best option for the residential sector, as with the transportation sector, appears to be improved energy efficiency through a carbon tax alone or in combination with energy efficiency standards.

Commercial Sector

Fossil fuel in the commercial sector is used primarily for space heating and cooling. A carbon tax alone, or in combination with energy efficiency standards for buildings and equipment can achieve significant reductions in fuel use and carbon dioxide emissions. Commercial sector installations can be large sources of CO_2. The possibility of emissions trading may be attractive for such sources.

Commercial facilities above a specified size (annual energy use or fossil fuel consumption) could be allocated CO_2 emissions permits and be eligible for a refund of the carbon taxes paid on their fuel purchases. Many of the measures that could be applied to reduce fossil fuel use in the commercial sector involve increased use of electricity. This might raise the CO_2 emissions of the electric utility. A commercial facility that implements such changes could be required to offset any increase in CO_2 emissions imposed on the electric utility or other energy supplier by transferring the appropriate emissions permits.[33]

Industrial Sector and Electric Utilities

Industrial plants above a specified size and fossil-fuelled electric generating stations are obvious candidates to participate in an emissions trading program. With a diversified industrial sector there is likely to be a wide range in the marginal cost of compliance. Since sources throughout the country could buy or sell permits, it is likely that there would be enough participants to establish a competitive market.[34] The key requirement is to design the system so that the administrative costs of executing trades are low.

Each existing industrial plant and generating station would be allocated CO_2 emissions permits in proportion to its emissions in a designated base year.[35] These permits would be allocated free of charge for the estimated remaining life of the plant.[36] Surplus permits could be banked or sold. New plants, as well as those that continue to operate beyond their estimated remaining life, would need to purchase the permits they require. An industrial facility that implements changes that impose increased CO_2 emissions on the electric utility or other energy supplier could be required to transfer the appropriate quantity of permits to the affected supplier.

33/ The offset is a policy choice. The commercial firm could sell its surplus permits and the electric utility could purchase the additional emissions permits it needs to meet the added demand. Due to the conversion losses incurred when generating electricity from fossil fuels, a measure that displaces fossil fuel with electricity could increase overall emissions of CO_2. Requiring a transfer of permits equal to the added CO_2 emissions imposed on the electric utility helps ensure that only measures that achieve a net overall reduction in emissions are implemented.

34/ With international trade of CO_2 emissions permits, firms could also be allowed to buy or sell permits internationally subject to government approval.

35/ Permits could be issued for each plant or firm (multiple plants). If they are issued on a firm basis, the firm can "trade" emissions internally without having to obtain approval for or register the trade. The difficulty that can arise in setting targets on a firm basis is that the national target may be apportioned among provinces and plants may be located in different provinces.

36/ Emissions permit systems are sometimes criticized on the ground that they create a "property" right; namely the right to discharge pollutants. Existing sources already exercise that right. A command-and-control system recognizes this right by allowing continued emissions, although at the reduced rate needed to ensure compliance with the emissions regulations. This proposal also recognizes the right of existing sources to continue their emissions at a reduced rate for the remaining life of the facility. These rights are lost when the facility ceases to operate or reaches the end of its estimated remaining life.

Summary

In summary, emissions permit trading is best suited to large commercial, industrial and utility sources. Existing sources of carbon dioxide emissions are treated as having a right to continue emitting at a reduced level for the remaining life of the facility. They are awarded permits to emit specified quantities of CO_2 each year. The total quantity of permits issued each year will decline in order to meet the national emissions reduction target. However, the permits available in each year are allocated in proportion to actual emissions during a designated historic base year. Permits may be used for actual emissions, held for future use, or sold to other sources.

Each source must provide the government with permits equal to its actual CO_2 emissions. New sources will have to purchase their emissions permits from other sources or the government.[37] As existing facilities go out of service, a larger proportion of the permits to be issued each year will be owned (and sold) by the government.[38] Government gradually becomes the principal source of permits and it can limit the supply to meet future reductions in the target for CO_2 emissions with a minimum of disruption.

A carbon tax, alone or in conjunction with energy performance standards, is the best means of reducing CO_2 emissions from the numerous small sources in the residential and transportation sectors. Emissions fees are notoriously difficult to implement and, once implemented, to change. I suggest that the carbon tax for the residential, small commercial and transportation sectors be linked to the market price for emission permits in the industrial, utility and large commercial sectors. For example, the price of emission permits, expressed in dollars per tonne of carbon, during the second and third quarters of one year would determine the carbon tax for the first half of the following year. This ensures that all sources face the same marginal cost of control.

VII. Extension to Other Greenhouse Gases

Assuming an emissions trading system is operating nationally for carbon dioxide, should it be extended to other greenhouse gases or to reforestation? This section addresses those questions.

Methane

The principal man-made sources of methane are: rice paddies; cattle and other ruminants; petroleum and natural gas production, transmission and distribution; biomass burning; seepage from landfill sites; dissociation from coal as a result of mining activity; and sewage treatment. Collection and combustion of such fugitive methane reduces the greenhouse effect because methane is more potent than CO_2 in terms of its climate impact.

Currently measures to control methane emissions apply primarily to the petroleum and natural gas industry. Natural gas is essentially pure methane, so there is an economic incentive to reduce emissions. Methane emissions are lost product and hence lost revenue. Regulatory authorities in producing areas have strict rules governing release of natural gas during testing and as a by-product of oil production. Transmission and distribution systems are carefully monitored to detect leaks because they can cause explosions.[39]

Regulations governing methane emissions from

37/ To facilitate planning on the part of firms that need CO_2 emissions permits, a market for CO_2 futures will probably arise. The 1990 *Clean Air Act* in the US provides for tradeable sulphur dioxide allowances. The Chicago Board of Trade promptly announced that it will develop a futures market for sulphur dioxide allowances.

38/ The **proportion** of permits reflects actual emissions during a designated historic base year. Initially, almost all permits will be allocated to participating facilities that existed during the base year. As these facilities cease operation or reach the end of their remaining life their entitlements revert to the government. The total **quantity** of emissions permits is set each year to meet the overall national target. The estimated CO_2 emissions of sources subject to the carbon tax are subtracted from the national target to get the quantity of permits available for larger sources. That quantity could be adjusted by international purchases or sales.

39/ Concentrations of methane in air of 4.5 to 14.0% are explosive.

coal mines, landfills, sewage treatment plants and other sources can also be found. These regulations are aimed at preventing the accumulation of explosive or toxic concentrations of methane. Where fugitive methane is collected to comply with such regulations it is usually vented or flared. Markets for fugitive methane from these sources are scarce, since it generally does not meet quality standards for natural gas fuel. An emissions permit system could provide an economic incentive to collect and use fugitive methane from these sources. An emissions permit system could also provide an incentive to reduce methane emissions in the agricultural sector.

To extend the CO_2 emissions permit system to methane, it is necessary to measure the reduction from allowable emissions actually achieved and to establish a global warming equivalence between CO_2 and methane.

Tradeable emissions permits could be issued for reductions in methane emissions or for fugitive methane recovered and used. Permits could be issued annually for the methane emissions reduced or recovered during the previous year. A base emission rate must be established before, or at the time of, participation in the system because the rate of methane generation from some sources can be manipulated. Limiting the emissions permits to the base emission rate would prevent abuse of the system.[40]

The methane eligible for a tradeable emission permit could be converted to a CO_2 equivalent. Establishing the global warming potential (GWP) equivalents of various gases is not a simple task. Working Group One of the IPCC developed GWPs based on the current atmospheric composition and time horizons of 20, 100 and 500 years (Houghton, 1990, Table 3, p.xxi). Economic approaches to developing GWPs have also been proposed.[41] Despite the difficulties it is likely that GWPs can be agreed upon as part of the international agreement, or as part of a domestic policy, to reduce emissions of greenhouse gases.

Chlorofluorocarbons

Chlorofluorocarbons (CFCs) are a large contributor to the greenhouse effect as well as the major cause of the depletion of the stratospheric ozone layer. An international agreement — the Montreal Protocol — has been negotiated to phase out all production and consumption of CFCs in high per capita consumption countries by 2000 and in low per capita consumption countries 10 years later.[42] Including CFCs in a CO_2 emissions trading system would provide an economic incentive to reduce those emissions even more quickly.[43]

All CFCs are man made; there are no natural sources. Incineration is the only commercial destruction technology for CFCs.[44] The Montreal Protocol reduces emissions of CFCs by restricting their **production**. To include CFCs in an emissions trading system, a tradeable permit could be based on lower than permitted production. Since the Montreal Protocol only defines production **ceilings** for specific dates, a more precise definition of allowable production each year would be needed to determine the tradeable emissions credits. The foregone production

40/ If fugitive methane emissions are included in the emissions trading system, new sources, such as new landfills and sewage treatment plants, should be required to purchase emissions permits for the full extent of their emissions in the same way that new sources of CO_2 would need to buy permits to cover their emissions.

41/ See Eckaus (1990) and Reilly (1990).

42/ The Montreal Protocol was signed in September, 1987 and significantly strengthened in June, 1990. These are the revised provisions which have been accepted by 65 countries. The revised agreement also establishes a fund of at least US $160 million contributed by developed countries to ease the financial burden of compliance for developing countries.

43/ The US already has a tradeable permit system for CFC production to facilitate the phase out. It could easily be integrated with a CO_2 emissions permit system by agreeing upon a CFC equivalence of CO_2.

44/ "The environmental concerns surrounding incineration — such as the potentially hazardous products of incomplete combustion and the corrosive acid and/or halogenated gas emissions that may be formed — need to be resolved. A number of other technologies are considered to have potential for destroying CFCs but none of them have been demonstrated commercially for this purpose." See Harmon (1990, p.8).

would be assumed to be the least potent of the CFCs. If a commercial destruction process is developed for CFCs, tradeable emissions permits could be issued for the quantities collected and destroyed.

The objective of the current international agreement on CFCs is to reduce the destruction of the stratospheric ozone layer. Soft CFCs help achieve that objective, but they still contribute primarily to the greenhouse effect.[45] A switch to HCFCs and HFCs means that these gases contribute primarily to the greenhouse effect, rather than ozone depletion. The revised Montreal Protocol includes the intention to phase out HCFCs no later than 2040. This is another reason for including CFCs, HFCs and HCFCs in a CO_2 emissions trading system.

Whether based on foregone production, actual destruction, or both, tradeable emission permits could be issued annually for actual performance during the previous year. The equivalence of CFC emissions would be based on the agreed GWPs for the various CFCs, HFCs and HCFCs.

Nitrous Oxide and Tropospheric Ozone

Two significant contributors to global warming (nitrous oxide and tropospheric ozone) do not lend themselves well to inclusion in a greenhouse gas emission trading system. Not enough is known about the sources and possible control technologies for nitrous oxide at this time to provide a basis upon which permits can be issued.

Ozone is formed in the troposphere rather than emitted, so emissions trading for ozone itself is not possible. The precursors of tropospheric ozone are nitrogen oxide (NO_x) and volatile organic compounds (VOCs), but the relationship between emissions of NO_x and VOCs and ozone formation is complex. Under some circumstances, reducing NO_x emissions can increase ozone formation. The same applies to emissions of VOCs, so it is not feasible to use either or both of these precursors as a proxy for tropospheric ozone in an emissions permit system. Finally, ozone is relatively short-lived and so is more of a regional than a national or global problem.

Reforestation

Growing forests absorb carbon dioxide and sequester it until the tree decays or is burned. The rate of CO_2 absorption varies significantly by species and climate. Unless there is a commitment to maintain the forest on a sustainable yield basis in perpetuity, reforestation only sequesters the CO_2 temporarily. Temporarily in this case can be 50 to 150 years. That is a significant contribution to dealing with the mitigation of global warming.

In temperate climates reforestation is currently a relatively costly approach to reducing atmospheric concentrations of CO_2. The ability to earn tradeable emissions credits would improve the economic attractiveness of this option. Hence, efforts should be made to include reforestation in a CO_2 emissions trading system.

Permits could be based on annual or bi-annual "audits" of forest growth actually achieved and estimated CO_2 sequestered, with an appropriate discount to reflect the fact that the CO_2 probably will not be sequestered permanently.[46] Permits would be restricted to **net** increases in forest growth. For example, pulp and paper or lumber companies would need to replace all trees harvested before becoming eligible for emissions permits.[47] It might be necessary to apply this requirement on a cumulative basis from the inception of the program to preclude abuse through years of low activity followed by a period of intensive reforestation.

45/ "Soft" chlorofluorocarbons (HCFCs) contain hydrogen and/or do not contain chlorine or bromine. They react with hydroxyl radicals found in the lower atmosphere, thereby degrading more quickly, often before reaching the stratosphere. CFCs which contain only fluorine (HFCs), rather than chlorine or bromine, do not pose a threat to the ozone in the stratosphere. The HCFCs and HFCs, like CFCs, are greenhouse gases.

46/ Note that if a country's current actual rate of CO_2 emissions includes estimated emissions due to deforestation, then slowing or halting the process of deforestation would help the country comply with its international target.

47/ This same restriction would apply to other firms and individuals, such as utilities that clear rights-of-way.

VIII. Conclusions

The advantages of economic incentive approaches in helping to achieve environmental goals at the lowest overall cost are well known. They reduce compliance costs, encourage the development of more environmental benign technologies, and facilitate cost-sharing.

The problem of global warming is so serious that international action is likely. Compliance costs are high so the importance of cost-effectiveness as a policy objective is elevated. Greenhouse gases are the type of pollution problem where economic incentive approaches work best. Cost-sharing will probably be an essential component of any international agreement as the condition for participation by developing countries.

If future international agreements on global warming adopt as their *modus operandi* quantitative limits on greenhouse gas emissions from each nation, I believe that the objectives can be best achieved by adopting cost-effective policies. Trading of emission reduction responsibilities among nations would be facilitated through the use of emissions permits. Allowing responsibilities to be transferable would facilitate lower compliance costs and cost sharing. It would also provide economic incentives for countries to become signatories to the agreements and to adhere to their commitments.

National policies to achieve the internationally-agreed emissions target could target emissions fees and emissions permits at those sectors where they are most appropriate. Emissions fees are better suited to sources with relatively small emissions — vehicles, households and small commercial establishments. Tradeable emissions permits are better suited to large sources, such as large commercial and industrial establishments and fossil-fired electricity generating stations with diverse compliance options.

A carbon dioxide emissions trading system could, in my judgement, be extended to include methane and CFCs as well as reforestation.

While economic incentive approaches to environmental control offer no panacea, they frequently do offer a practical way to achieve environmental goals more flexibly and at lower cost than more traditional regulatory approaches. They merit serious consideration as policies to address emissions of greenhouse gases are developed.

References

Anderson, Robert C. (1990) *European Experiences With Incentive Mechanisms* (Washington: American Petroleum Institute).

Baumol, William, and Wallace E. Oats (1975) *The Theory of Environmental Policy* (Englewood Cliff, N.J.: Prentice Hall).

Chandler, W.U. (ed.) (1990) *Carbon Emissions Control Strategies* (Washington: World Wildlife Fund and The Conservation Foundation)

Chandler, William U. and Andrew K. Nicholls (1990) 'Assessing Carbon Emissions Control Strategies: A Carbon Tax or a Gasoline Tax?,' American Council for an Energy-Efficient Economy, ACEEE Policy Paper No. 3 (Washington) February.

'The Changing Atmosphere: Implications for Global Security' (1988) *Conference Statement,* Toronto, Canada, June 27-30.

Eckaus, Richard S., (1990) 'Comparing the Effects of Greenhouse Gas Emissions on Global Warming,' MIT-CEPR 90-022WP (Cambridge, MA: Massachusetts Institute of Technology) November.

Edmonds, Jae and David W. Barnes (1990) *Factors Affecting the Long-Term Cost of Global Fossil Fuel CO_2 Emissions Reductions,* mimeo (Washington) December.

The Energy Technology Systems Analysis Programme (ETSAP) (1990) *etsap News,* International Energy Agency, September.

Flavin, Christopher (1989) *Slowing Global Warming: A Worldwide Strategy,* Worldwatch Paper 91, (Washington: Worldwatch Institute) October.

Government of Canada (1990) *Canada's Green Plan,* Ottawa.

Harmon, Dale L. and William J. Rhodes (1990) 'Recycle and Disposal Options for CFCs and Halons,' presented at Air & Waste Management Association's 83rd Annual Meeting & Exhibition, June 24-29.

Houghton, J.T., C.J. Jenkins and J.J. Ephraums (eds.) (1990) *Climate Change: The IPCC Scientific Assessment* (Cambridge, UK: Cambridge University Press).

Jorgenson, Dale W. and Peter J. Wilcoxen (1990) *The Cost of Controlling US Carbon Dioxide Emissions,* mimeo (Cambridge, MA) September.

Krause, Florentin, Wilfrid Bach and Jon Koomey (1989) *Energy Policy in the Greenhouse,* International Project for Sustainable Energy Paths (El Cerrito, California) September.

Leggett, Jeremy (ed.) (1990) *Global Warming, The Greenpeace Report* (Oxford: Oxford University Press).

Montgomery, David and Roger Hitchner (1990) *Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels* (Washington: Congressional Budget Office).

Nordhaus, W.D. (1990) *To Slow or Not to Slow: The Economics of the Greenhouse Effect,* mimeo.

Opschoor, J.B. and H.B. Vos (1989) *Economic Instruments for Environmental Protection* (Paris: OECD).

Reilly, John, (1990) *Climate Change Damage and the Trace Gas Index Issue,* mimeo, (Washington) November.

Schneider, Stephen H. (1990) *Global Warming* (New York: Vintage Books).

Tietenberg, T.H., (1990) 'Economic Instruments for Environmental Regulation,' *Oxford Review of Economic Policy,* Spring, 6:1:17-33.

—(1988) *Environmental and Natural Resource Economics,* 2nd ed., (Glenview, IL: Scott, Foresman & Co.).

US Agency for International Development (1990) *Greenhouse Gas Emissions and the Developing Countries: Strategic Options and the U.S.A.I.D. Response* (Washington).

US Department of Energy (1989) *A Compendium of Options for Government Policy to Encourage Private Sector Responses to Potential Climate Changes* (Washington: Department of Energy).

US Department of State (1990) *Materials for the Informal Seminar on US Experience With 'Comprehensive' and 'Emissions Trading' Approaches to Environmental Policy* (Washington: Department of State).

Whalley, John and Randall Wigle (1990) *The International Incidence of Carbon Taxes,* mimeo, October.

The World Resources Institute (1990) *World Resources 1990-91* (New York: Oxford University Press).