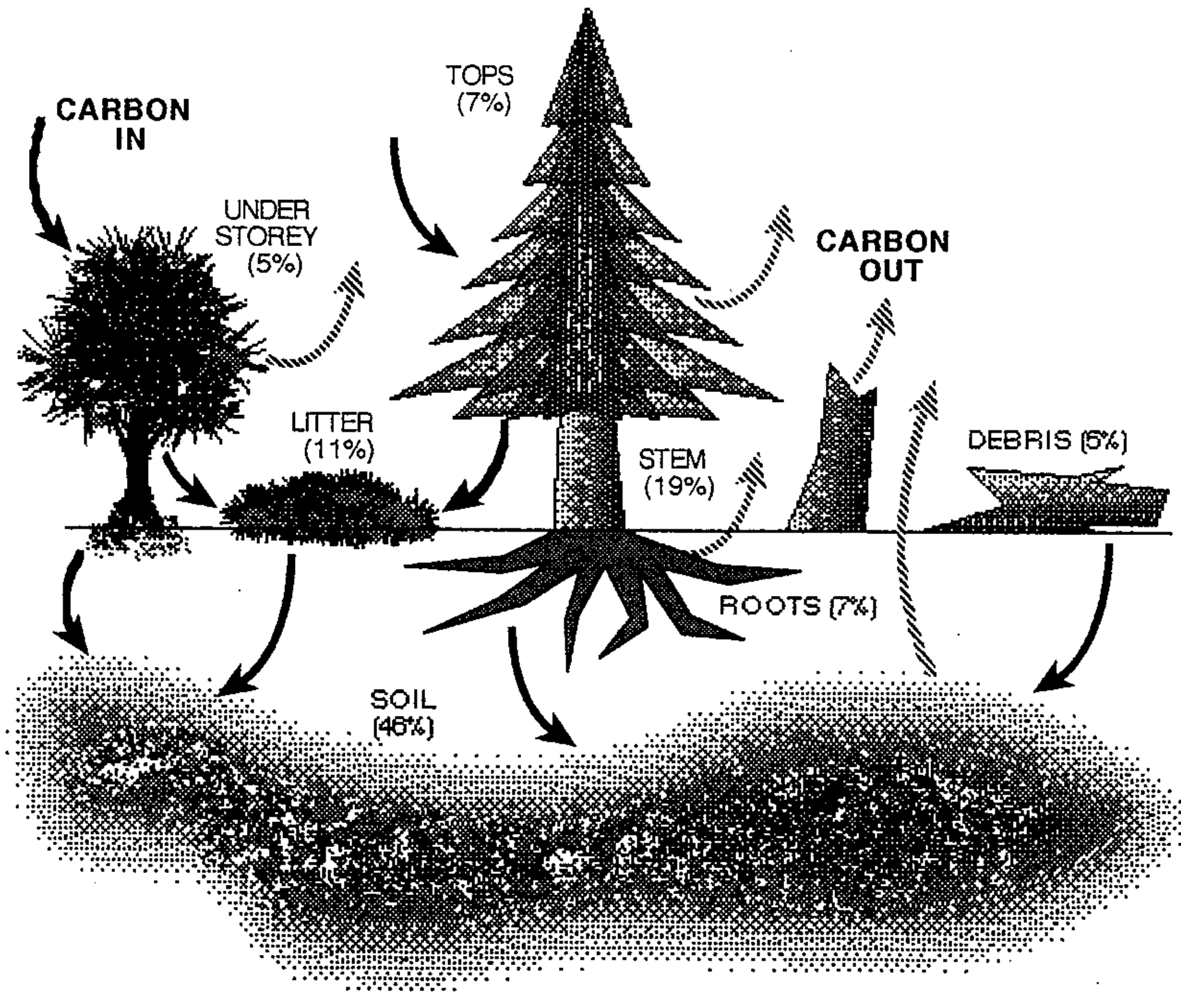
GLOBAL WARMING: POLICY ANALYSIS AND PROPOSAL FOR A

CARBON SINK SILVICULTURE PROGRAM

by Joyce C. Murray



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Abstract

Global warming results from human activities such as deforestation and energy combustion that increase concentrations of atmospheric greenhouse gases. There are many uncertainties as to how quickly warming will occur and what the impacts will be. The great majority of climatologists and informed leaders agree that effectively irreversible greenhouse gas concentrations risk environmental catastrophe. An immediate and concerted international response is needed to limit the sources of global warming.

Canada is among the highest per capita producers of greenhouse gases, largely owing to inefficient energy use. Canada is expected to experience higher than average warming resulting in environmental, social and economic disruptions. The Canadian government recognizes the need for government intervention in the market, and has made a commitment to reduce greenhouse gas emissions to 1990 levels by the year 2000. Canada is also participating in multiple international negotiations aimed at curbing the problem. The international treaties will take time, and countries need to undertake unilateral action in the interim.

The Canadian government's response policies are inadequate to achieve the emissions reduction target. Policies and subsidies still encourage the individual and corporate activities responsible for greenhouse gas emissions. Action to reduce net emissions has been delayed by concern over losing trade competitiveness and by pressure from affected industries, such as those in the energy sector. Canada's passive strategy must be changed. Inaction increases the risks, and the net costs of action are less than predicted when external and long-term benefits are properly valued. In this context, moral leadership by Canada is affordable and will encourage parallel unilateral action by other nations.

Declining global forest cover contributes to global warming since trees absorb carbon dioxide, the foremost greenhouse gas. Carbon sink silviculture - planting trees and managing forests to increase carbon uptake - is unanimously considered to be an essential part of a global warming response program. The required infrastructure already exists in Canada, as does a national timber supply crisis and a vast expanse of land available to be forested. Canadians place a high value on the many other benefits from healthy forests. Along with programs which decrease energy use and shift to less polluting energy sources, a large silviculture program should be undertaken.

Available benchmarks suggest a national program to plant fifteen billion trees over fifteen years. Incorporating the principles of environmental sustainability is crucial to its success. Policy goals and practical constraints dictate that the program include diverse components. Planting urban trees, converting marginal agriculture lands to timber and bio-fuel plantations, restoring degraded wilderness areas, and financing tropical agro-forestry projects are among the favorable options. A cost-benefit sketch of the fifteen billion tree program, in which future product values and a conservative estimate of non-consumption benefits are accounted for, suggests that the net cost of the program could be as low as one-third of the gross cost.

Dedication

To Baba, Erik and Dawn.

I love you.

Acknowledgments

Thank you Aidan Vining, John Richards and Dirk Brinkman for encouragement, assistance and inspiration. I appreciate your support.

Table of Contents

List of Tables

List of Figures

SECTION 1 THE GLOBAL WARMING PROBLEM

1.A Background

1.A.1 Canada's strategic issue

This paper addresses a seemingly straightforward question. What, if anything, should Canadians be doing about global warming? In order to answer this question a maze of complex issues must be tackled.

Global warming is acknowledged to be one of the most critical environmental problems facing humankind. The problem is vast, pervasive and confusing. The causes of global warming are tied into the basic organization and activities of human society. As a result, the dimensions of unresolved issues and ambiguities encompass every dimension of human existence: scientific, economic, social, political and moral, among others.

Scientific understanding of the greenhouse effect, and capability to predict future warming levels are characterized by uncertainty. The impacts of climate change on environments, people and economies are difficult to forecast. The wisdom of devoting resources to limiting the problem now, as opposed to adapting to the consequences later, is controversial. The economic repercussions of various potential response actions are not well understood. The merits of alternative government mechanisms for implementing these actions are unresolved. Allocating national responsibility for the problem and for mitigating it is politically contentious. The problem of free-riding by some nations on the response actions of others is difficult to surmount.

The Canadian government's response strategy needs to be coordinated within this context of uncertainty.

Consensus on some of these issues is beginning to emerge

Scientists claim that human activities augment the flow and stock of greenhouse gases which control global temperature. How big a problem is this? There are two basic sides to the argument. On the one side are those who argue that global warming is not a serious problem. There are too many scientific uncertainties, the impacts of climate warming are distant in time, the changes may well be gradual, and the effects will in some cases provide regional benefits (Idso 1989).

On the other side are those who maintain that global warming is an urgent problem. There can be no denying the risk that climate warming may occur more quickly, that even gradual warming may have catastrophic and unforeseen effects on regional climate conditions, and that climate impacts could cause serious damage. Can this risk be taken when the consequences will be irreversible? The great majority of scientists and policy-makers now agree that the risk should not be taken. This paper will argue that global warming must be controlled quickly by unilateral national actions and by international coordination. Each year delay in implementing solutions means that the actions required to accomplish any given level of net greenhouse gas limitation will need to be more extensive and disruptive.

Are Canada's policies adequate?

In order to appraise Canada's global warming response policies, another series of questions must be tackled. What is our national strategy with respect to global warming response - are our stated and actual strategies the same? Is Canada's strategy a rationale one - has the balance of costs and risks of response action and inaction been accurately assessed? Is there a more defensible strategy - if so what is it? What specific global warming response actions would be most efficient for Canada? What are the priorities, objectives and constraints? These and other issues will be discussed as a background to developing a rationale and proposal for a large-scale silviculture program as a greenhouse gas limitation measure.

First, a general understanding of the problem of global warming is required. This includes consideration of some of the underlying aspects of the market that cause the problem, and some generic problems with government that frustrate attempts to control it.

1.A.2 Human activity is amplifying the greenhouse effect

The earth's atmosphere is composed of gases that form a protective blanket around the planet, maintaining an equilibrium of heat reaching earth from the sun and heat radiating from earth back into space. This insulating blanket keeps the temperature just above the earth's surface at a comfortable level for human existence. The average global temperature is 15° Celsius, or just 33° above what it would be without the greenhouse gases.

The greenhouse effect is a natural phenomenon

The cycling of energy in the global climate system is regulated by a few gases, which function as a natural thermostat. Although minor in concentration, these greenhouse gases (GHGs) absorb much of the infrared heat radiated out from the earth, holding it in the lower layer of the atmosphere. Along with clouds, these gases provide the insulating effect known as radiative forcing, or the greenhouse effect. The climate system is a balance of interrelated elements such as this heat, atmospheric moisture, wind and ocean currents resulting from the redistribution of the solar radiation, the earth's spin, and the effects of land masses.

Astronomical rhythms, linked to changes in the orientation of the earth as it orbits the sun, and pulses in solar energy output, create regular fluctuating solar radiation cycles. The juxtapositions of these cycles and the equilibrating function of the greenhouse effect have led to cooling and warming periods during the earth's history. The correlation between atmospheric composition and climate cycles has been confirmed by the analysis of historic evidence, such as ice core samples from Antarctica, which provide a record dating as far back as 160,000 years ago (Gribbon 1990a).

The primary greenhouse gases that occur naturally in the atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor and ozone. Scientific understanding of the flows and stocks of these gases is incomplete, although CO_2 has probably been the subject of most study. CO_2 is the least radiatively effective of the gases, yet because it is the most prevalent and persists in the atmosphere for many years, it is considered to be the most important. Methane, in contrast, absorbs more heat but has a shorter atmospheric lifetime. Climatologists have attempted to come up with a common unit of measure with which to compare the radiative effects of the various gases. They have calculated the "global warming potentials " (GWPs) of each of the gases by assessing the combined effect of its absorption efficiency, indirect effects, and atmospheric lifetime, in order to have a single unit for assessing and comparing the collective effects of the greenhouse gases from various sources.[1]

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[1] GWP's are quite widely used politically, particularly for purposes of establishing a measure of relative responsibility for GHG emissions. However some caution that our lack of adequate understanding of the factors that affect GWP calculations for all the gases can lead to misdirected efforts to control them (Victor 1990).

Elevated greenhouse gas concentrations are irreversible

An atmospheric monitoring station was established near the summit of Mauna Loa, Hawaii in 1956, for the International Geophysical Year in 1957. Subsequent data analysis confirmed scientists' concerns that atmospheric concentrations of CO_2 and other greenhouse gases were steadily increasing (Boyle & Ardill 1989). CO_2 concentrations that were recorded to be 315 parts per million (ppm) in 1958, for example, had increased to 350 ppm by 1988, an 11% increase (Gribbon 1990a). Human activities such as fossil fuel combustion, industrial chemical production and deforestation have over the past century augmented the flows of natural greenhouse gases - CO_2, nitrous oxide, methane and ozone - and have added important new ones, the chloroflourocarbons (CFCs), which are by far the most potent. The total GWP increase resulting from human activities over the past one hundred years is equivalent to a 50% increase in atmospheric CO_2 concentrations (Jastrow et al 1990).

Due to the longevity of greenhouse gases, ranging up to 200 years, the excess flows are increasing atmospheric GHG concentrations. In other words, the effect of CO_2 emissions being released today is virtually irreversible, since the molecules will still have a radiative warming effect many years from now. *Table 1* below shows the respective radiative potency and duration of the gases, as well as the relative contributions of fossil fuel combustion (80%) and deforestation (20%) to the buildup of CO_2.

Table 1 **Major Greenhouse Gases and their Characteristics**

Parameter	**CO_2 (Fossil fuels)**	**CO_2 (Biological)**	**CH_4**	**N_2O**	**CFCs**
Relative greenhouse efficiency (GWP)	1	1	25	230	15,000
Current greenhouse contribution	44%	13%	12%	6%	25%
Atmospheric life (years)	50-200	50-200	10	150	65-130
Principal human sources of gas	Coal, oil, natural gas combustion	Deforestation slash burning	Fossil fuels, rice, wetlands, livestock	Fossil fuels, fertilizers, deforestation	Foams, refrigerants, aerosols, solvents

Source: Adapted from (Flavin 1989)

In the late 1980s, anthropogenic CO_2 emissions loaded between 6 billion tonnes (Hengeveld 1991) and 8 billion tonnes (Myers 1991) of carbon into the air each year. Approximately half is re-absorbed by processes not clearly understood,[2] with the balance adding to the atmospheric stock (concentration) of radiative gases. CO_2 emissions account for about half of the global increase in GWP. The other greenhouse gases collectively account for the rest. Annual emission rates are increasing globally from a low of 0.2% per year for N_2O to a high of 5% per year for CFC's. CO_2 is increasing at the rate of 0.4% per year (IPCC 1990a). These increases are shown in *Table 2* below.

Table 2 **Summary of Greenhouse Gas Increases**

Parameter	CO_2	CH_4	N_2O	CFC-11	CFC-12
Pre-industrial concentration (1750 to 1880)	280 ppmv	0.8 ppmv	288 ppbv	0	0
Current concentration (1990)	353 ppmv	1.72 ppmv	310 ppbv	280 pptv	484 pptv
Current annual increment	1.8 ppmv	0.015 ppmv	0.8 ppbv	9.5 pptv	17 pptv
Annual increase in rate (percentage)	0.4%	1%	0.2%	5%	5%

Abbreviations: ppmv/ppbv/pptv = parts per million/billion/trillion by volume
Sources: (MacDonald 1991, Flavin 1989)

Not only are we augmenting the flow of GHGs into the atmosphere each year, but we are doing so at an accelerating rate. The rate at which this will continue depends on scenarios for future population growth, economic growth rates, international response in mitigating the problem and other factors.

Developing nations will account for a larger share of future emissions

Currently the developed nations are the primary emitters of CO_2 from fossil fuel combustion, and the less developed countries are responsible for most of the CO_2 buildup from biomass burning.

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[2] CO_2 is absorbed and stored by ocean and land vegetation "sinks". It is also stored in ocean carboniferous life forms which sink into the oceans beyond reach of the circulation of currents. Recent research by Steve Ryan, climatologist at the Mauna Loa climate station, suggests that the terrestrial sinks are a far more important CO_2 sink than previously assumed (Chen & Ryan 1992).

Each inhabitant of a developed country consumes an average of twenty-two times the energy that a person in a low income country consumes, according to World Bank figures (George, in Leggett 1990). As the developing countries pursue desired economic development and growth, their per capita emissions from energy production and use are also expected to increase dramatically. Since populations in many of these countries are expanding, their total emissions will increase accordingly. Thus even though the industrialized nations are decreasing energy inputs per unit of production, average global energy use and emissions will continue to increase.

Canada ranks first in the world, in terms of CO_2 emissions per capita (Nagle 1990), and third in terms of overall global warming potential (GWP) per capita. This dubious honor is partly due to the northern climate and large transportation requirements, but is also due to inefficient utilization of energy, related to the relatively cheap price that Canadians pay for energy and the resulting wasteful use.

The increasing rate of greenhouse gas emissions and the increases in atmospheric concentrations are not a matter of scientific dispute. Rather, controversy centers on the future climate change that will result from these elevated concentrations, and on the impacts of climate change on ecosystems and societies.

1.A.3 Greenhouse gas concentrations are associated with climate

In 1886 Swedish scientist Svante Arrhenius suggested that industrial pollution might double CO_2 concentrations in the atmosphere. He postulated that over several centuries global temperatures could rise by 5^o Celsius (Boyle & Ardill 1989). In the late 1930s, researcher G.S. Callendar also observed the connection between CO_2 concentrations and climate. Calculating the probable CO_2 increase from fossil fuel use over the previous several decades and comparing it with temperature records, he wrote a series of papers analyzing the magnitude of the temperature rise that could be expected from future emissions. More recent analysis of carbon isotopes in ice core samples reveal annual CO_2 levels going back 160,000 years (Gribbon 1990a). CO_2 levels recorded in these ice cores correlate closely with global climate cycles.[3]

[3] The ratio of the different carbon isotopes enables scientists to identify the relative sources of CO_2 emissions each year since the isotope produced by living carbon (biomass burning) differs from the one produced by fossil carbon (fossil fuel combustion).

The reality of climate warming is now established

The average global temperature is a difficult measure to take. It compresses into a single measure seasonal variability, daily temperature changes, and variations due to different latitudes, geographical configurations, and altitudes. This complexity is one reason there has been so much debate over whether the global climate is indeed heating up. Researchers agree now that the global climate has warmed by about 0.5°C since mid-last century. This calculation has been adjusted to account for an urban "heat island" effect which skews temperature readings taken from stations close to urban areas (Michaels 1989). 0.5° is a lower increase than predicted, given the GHG concentration increases during that period. Some researchers explain the modest increase as being due to the thermal lag caused by ocean heat absorption, some speculate that a solar cooling cycle is responsible (Gribbon 1990a), and yet others claim this to be evidence that future warming predictions are greatly inflated (Idso 1989).

In 1989 climatologists revealed that the six hottest years of the past century occurred during the 1980s. Since then the trend has continued. According to three major measures of global temperatures, 1990 was the hottest year on record (Kerr 1991), and 1991 was the second-hottest (Anonymous 1992). The incidences of hot weather and droughts in the 1980s magnified prior concerns about the greenhouse effect. One of the acknowledged scientific "gurus" of climate warming, James Hansen, announced at a Congressional hearing in 1989 that he was 99% certain the predicted global warming had begun (Jastrow et al 1990).

Future warming predictions are controversial

What can be expected in the future? Climatologists in several countries are using sophisticated global circulation models (GCMs) to predict future climate change for various emission scenarios. The validity of the models is corroborated with test runs that demonstrate the ability to predict past climate cycles with relative accuracy. Results from different GCMs converge fairly closely for overall climate warming. A large uncertainty arises due to feedback effects. The main ones that have been identified are changes in sea-ice mass, the effect of clouds, ocean carbon cycling and recent concerns that the thawing of tundra peat could release significant CO_2 and methane emissions. These effects could feed into the climate system in ways that diminish the greenhouse effect or, as is more likely, in ways that reinforce and accelerate it (Gribbon 1990a). These feedback effects may not be accurately modelled for a long time and constitute the main risk wild card.

A small minority of scientists claim that basic inadequacies in the GCMs mean they are totally inadequate to properly simulate world climate, and as a result the future warming predictions are greatly inflated (Idso 1989). They accuse researchers of squashing the views of the dissenting scientists (Michaels 1989). Others claim that while some uncertainties do exist, the greenhouse effect is one of the most scientifically well-established theories in the atmospheric sciences (Boyle & Ardill 1989).

The IPCC process

In the fall of 1988, the Intergovernmental Panel on Climate Change (IPCC) was established under the auspices of the United Nations Environmental Program and the World Meteorological Organization. The panel's mandate was to provide a framework for international collaboration on the global warming issue, and to attempt to resolve some of the controversy. Three Working Groups (WGs) were charged with the task of reporting the current state of analysis of the scientific aspects of global warming (WG I), the impacts of increased temperatures (WG II), and potential policy responses (WG III). Many of the world's foremost climate change researchers devoted two years to this project (Schneider 1991). Each of the Working Groups tabled a report in June 1990. The information and conclusions in these reports are generally accepted world-wide. Naturally, some researchers claim that the estimates err on the side of conservatism, and others accuse them of being inflated.

Warming is predicted to occur to a level and at a rate unprecedented in climate records

Geological records indicate that the previous fastest rate of climate change was 0.1°C per decade. Various GCMs have predicted future rates of warming from 0.2° to 0.5° per decade. The working figure adopted by the IPCC Working Group I is 0.3° per decade (IPCC 1990a). This rate implies that average temperature, under a "business-as-usual" scenario, is expected to increase 1° above the present period by 2025 and 3° by the end of the next century. Double current CO_2 concentration ($2xCO_2$) equivalent is the atmospheric concentration of greenhouse gases that has become the benchmark for climate warming and impact predictions. In a "business-as-usual" scenario this level is predicted to be reached by roughly the middle of the next century. 2.5°C is the IPCC best estimate for warming at the $2xCO_2$ level mid-next century (Jastrow et al 1989). This increase is in addition to the temperature increase from pre-industrial levels to the present.

The range of uncertainty is still quite large. Warming could be 2°C or as high as 5° by the end of the next century. Even this is not the total outcome. The estimates concern realized (actual) temperatures. At any given time the earth would be committed to a further temperature increase toward an actual equilibrium temperature.[4] The magnitude of eventual equilibrium warming will be about twice the magnitude of the realized temperature increase.

The sceptics who challenge the GCM results have made alternative predictions based on the amount of warming experienced to date, adjusted for other variables. One of the most conservative predictions is the scenario of a slow increase of 1.6°C by the year 2300, based on atmospheric greenhouse gas concentrations equivalent to a tripling of CO_2 levels by that time (Idso 1989). Scientists at the Marshall Institute predict an increase in temperature ranging from 0.4° to 1.8°C by 2050, assuming a $2xCO_2$ concentration level (Jastrow et al 1990).

Temperature increases are predicted to be higher than the global average in the northern latitudes, and greater in winter than in summer. The models also predict changes in rainfall levels and patterns. Greater precipitation levels ranging from 3% to 15% are predicted, due to increased ocean evaporation (Dornbusch & Poterba 1991). Drier climates are expected in the continental interior of temperate areas. Higher incidences of climate anomalies, heat extremes, and violent storms are also predicted. *Table 3* on the next page shows some global circulation model estimates of the average global change, and the regional impacts at a concentration of $2xCO_2$.

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[4] The lag between actual temperature and eventual equilibrium temperature is related to the slow rate of heat uptake by the ocean mass. The time that will elapse before equilibrium is reached, and the exact ratio between actual and equilibrium temperature levels that will result from a given concentration of greenhouse gases, depends on the rate at which climate is warming.

Table 3 **Range of Estimates from GCMs for Global Warming Impact on Major Variables.**

Variable[a]	Probable global average change	Distribution of regional change	Confidence in the Prediction:[b] Global average	Regional avg.
Temperature	+2° to +5° C	-3° to +10°	High	Medium
Sea level[c]	+10 to +100cm		High	
Precipitation	+7 to +15%	-20 to +20%	High	Low
Soil Moisture	?[d]	-50 to +50%	?[d]	Medium
Runoff	Increase	-50 to +50%	Medium	Low
Severe storms	?[d]	?[d]	?[d]	?[d]

Source: (Nordhaus, in Dornbusch & Poterba 1991:38)

[a]. Warming at $2XCO_2$ equivalent greenhouse gas concentrations.

[b]. The "confidence in prediction" is a subjective estimate of experts of the confidence that the range of estimates provided is accurate. These estimates are based upon formal models, historical analogy, and other experience.

[c]. Increases in sea level are the average of the global rate. Sea-level rise in particular locations will be higher or lower than this figure depending upon local geological conditions.

[d]. No basis for forecast of this variable.

Global circulation models predict a warming ranging from 2° to 5° by the year 2050. The IPCC prediction is for 2° to 5° by the end of next century. The difference reflects the conservatism of IPCC conclusions.

Uncertainties confound climate change predictions

The capability to predict climate change accurately is limited by the uncertainty levels of inputs into the climate models. The unknowns mentioned previously are summarized below.

Emissions uncertainties

Difficulties in accurately forecasting global future energy demand, fuel combustion technologies, population growth rates, changes in land use practices, mitigation efforts and other activity inputs, make it difficult to estimate future greenhouse gas emissions.

Solar cycle uncertainties

The natural astronomically influenced climatic cycles increase the complexity of predicting future climate. Some climatologists are concerned that a natural cooling cycle, tied into the double pulsebeat of minor climatic cycles of 80 and 180 years, has been in effect. This may have mitigated the warming that would otherwise have occurred during the decades from 1950 to 1980, when the predicted greenhouse warming trend was not evident in temperature records. This natural solar cycle is predicted to enter a new phase, and to begin to augment greenhouse warming for the next 25 years. Consequently, climate models may be underestimating the magnitude of warming that is in store for us (Gribbon 1990a).

Regional climate uncertainties

The vast volume of data needed to simulate small ecosystem components and weather effects within a global circulation model, the lack of understanding of feedback effects, and current computer limitations prevent the GCMs from predicting regional climate change with much certainty. This severely hampers our understanding of what to expect in actual communities and local economies. Policy-makers should not wait for accurate regional information, cautions climatologist Steven Schneider, as this will not be available for several more decades (Schneider 1991).

Wild card uncertainties

Wild card uncertainties are by definition the ones that we don't even know that we don't know of. Climate systems are complex, nonlinear and a classic example of a system exhibiting mathematical "chaos". If an unprecedented rate of ecosystem change occurs in a system in which so many life-sustaining systems are interconnected, there could conceivably be wild card effects. For example there is an incomplete understanding of the rates of uptake of the emitted gases by various parts of the global system. The thresholds beyond which absorption will not occur are not completely understood. The growth of ocean phytoplankton, an important link in the oceanic carbon sink chain, could be dramatically reduced by ozone thinning and other greenhouse effects. If so, the ratio of CO_2 emissions currently absorbed by sinks (50%) would correspondingly diminish and atmospheric concentrations increase. This poses the threat of runaway warming that could occur if carbon sinks are seriously disrupted (Gribbon 1990a).

1.A.4 Climate warming could cause extensive damage

The Intergovernmental Panel on Climate Change (WG II) concludes that the physical impacts of climate change will likely be considerable (IPCC 1990b). A minority of researchers hold the view that the net impact of climate change will be small or even beneficial (Brookes 1989). The latter view has been largely discredited (Gribbon 1990b). A recent study by Charles River Consulting in Washington D.C., for example, uses a substantial report by the U.S. National Academy of Sciences to support its assertion that climate change will occur gradually, allowing opportunities for gradual and relatively low-cost adaptation as it occurs. Critics of the reports point out that neither study fully justifies its assertions, and that the reports themselves admit that evidence now available gives little basis for choosing which is more likely - scenarios that generate catastrophic impacts or those that generate benign impacts. In other words the risk of catastrophe exists (Sundt 1992a).

Estimates of damage impacts are imprecise

Since the assessment of physical impacts leans on climate change data, it is not surprising that there are uncertainties, especially at the regional level. Some localized impacts could be beneficial. For example, new areas will become climatically suitable for agriculture, and certain plant species will enjoy increased growth rates from CO_2 fertilization. Yet the net effect overall could be highly disruptive and costly. The major physical impacts predicted for the warming resulting from a doubling of CO_2 concentrations are listed below:

- Sea-level rises will result in flooding and salination of low-lying areas;
- Urban areas will have higher incidences of extremely hot days;[5]
- Agricultural areas that experience hot and dry summers 30% of the time will experience them 70% of the time (Gribbon 1990b);
- Incidence of climate anomalies such as violent storms and hurricanes will increase; and
- Forest productivity will decline due to temperature stress, fire losses and pests. Extent of forests will decrease as climatic zones shift northward faster than species can shift.

Predicted impacts could be worse than expected. Examples of other plausible threats are the disruption of oceanic currents[6], major shifts in Arctic and Antarctic glaciers leading to much

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[5] A NASA computer model predicts that with a 4°C warming, 8 geographically representative cities in the U.S. can in aggregate expect to experience days >90° F 679 times a year compared with 307 currently; and days >100° F 183 times a year compared with 28 currently (Lyman 1990).

[6] Scientists speculate that the conditions governing the Atlantic ocean current that currently brings warm tropical water and air up the European coast (resulting in a far warmer climate than is otherwise found at that latitude) may be upset to the point of being disrupted. The consequence could be a European climate similar to the one in the last ice age, despite average warming experienced elsewhere (Calvin 1991).

greater sea-level rise, extensive desertification of continental grain belts, and higher human, animal and plant disease rates as pests from tropical countries invade now-warmer areas where indigenous populations lack resistance.

The economic impact of climate change effects may be extensive

How might climate warming affect national economies? The productive sectors most affected by climate warming will be the primary resource industries such as agriculture, forestry, fishing, and wild animal harvesting as well as the primary manufacturing industries that depend on these resources for factor inputs (Ireland 1989). Increasing flood control costs, loss of value of beach front residential and commercial properties, and the incalculable cost of lives lost from storms, floods and tidal waves are some other damages that can be expected.

Economist William Nordhaus, a former member of the U.S. Council of Economic Advisors, has estimated a low, medium and high value for annual aggregate global economic damages, assuming a 3°C average increase in temperature associated with greenhouse gas concentrations equivalent to $2xCO_2$. His low damage estimate of 0.25% of global income (approximately US$50 billion per year) ignores non-market costs for which adequate data are not available, and ignores values for species loss and other aesthetic and social values which are difficult to monetize. His medium estimate, in which the aforementioned exclusions are included, is 1% of global income (US$200 billion). His high estimate is 2% of global income (US$400 billion) (Nordhaus 1990). Nordhaus himself, and others, consider this range relatively conservative (Gerelli, in Dornbusch & Poterba 1991). Damage estimates for the capital cost of dealing with sea-level rise of 1 meter, for the U.S. alone, range from US$71 to US$111 billion (Gribbon 1990a). Some examples of the kinds of economic impacts that are expected to contribute to these damage costs can be found in Appendix 2.

The federal Ministry of Environment claims that the risks posed by uncontrolled climate warming are as serious for Canada as they are for the world as a whole (Government of Canada 1990). Some areas of Canada will become more habitable with a warmer climate. However, the magnitude of climate change is expected to be much greater in Canada than the global average, and some severe negative impacts and adjustments must be anticipated.

Developing Nations are expected to be the biggest losers

Northern latitudes are expected to experience the highest average climate change. Yet because many people in developing countries live closer to the margin, and because their economies are more closely tied to the sectors most impacted by climate change, the repercussions for these countries will be more severe.

Nations such as Egypt and Bangladesh with heavily populated flat coastal areas will lose large portions of habitable lands. Especially threatened are several low-lying island nations such as the Maldives. This entire nation measures less than 2 meters above sea level, and its population of 177,000 people is threatened with catastrophe from rising sea levels. Developed nations contribute the most greenhouse gas emissions, yet poorer nations will experience much of the damage. This has implications for the difficult international climate change negotiations.

1.B Forests Play a Unique Role

1.B.1 Forests contribute to the problem and to the solution

The connection between global warming and forests is worth singling out. Forests are an important component of all of the world's continents except Antarctica, and provide many well recognized benefits for humans and other life forms. One-third of the earth's surface is covered by forests, and approximately 85% of land phytomass is contributed by forests (Myers 1984). An impressive portion of the world's biotic carbon reserves can be found in Canadian forests, which account for 12% of global closed forest area (Dixon et al 1991).

Historians have noted the past connection between many early civilizations' control of forest reserves, and their growth, prosperity and political power. The decline of these political empires and civilizations was often associated with the eventual over-harvest and destruction of their forest resource (Perlin 1991). In today's world, ease of trade for forest goods diminishes this close relationship between healthy forests and national social well-being. Still, the world's forest land base of 6 billion hectares has been reduced over the past century to about 3 billion hectares. In many countries deforestation has resulted in a less hospitable climate and increased the struggle for economic development and, in some cases, for survival.

Climate warming could have serious impact on forest health and mass.

Forest researchers are identifying a number of impacts that climate warming will have on forests. Tree species are adapted to specific climate parameters. Climate warming, with its attendant changes in temperature extremes and precipitation patterns, will result in millions of hectares of forests no longer thriving in their present location (Berry & Lertzman 1991). The increase in physiological stress will augment tree vulnerability to pests such as bark beetles and budworms. Since the duration of drought conditions is the single best predictor of area burned by wildfires (in Canadian forests), the increasing frequency of dry years will augment the risk of large forest fire losses. Ecological succession patterns may change due to the differences in species responses to elevated concentrations of carbon dioxide. Some tree species experience a fertilization effect and improved productivity from increased CO_2 concentrations. However, some studies suggest that those plants which do grow faster are more susceptible to insect damage.[7]

Forests have migrated in the past in response to changing climates. Unfortunately the warming increase is projected to occur at a rate that is far faster than forests are capable of adapting. The average rate of migration of tree species in Europe and North America during the ice ages was approximately 0.3 kilometers a year. Warming estimates will result in ecosystem displacements by mid-next century at rates that are ten times greater (Graham et al 1990). There are absolutely no precedents for forests adapting at that pace. Human intervention (planting) will be needed to assist in extending forests into northern margins in which the climate may become suitable. Even this will not prevent net forest losses, since thin soil cover in some of these areas will be inadequate for the plantation requirements (Lyman 1990). Global warming has particularly grave implications for Canada's boreal forests, which account for a large percentage of Canadian total forest cover, and are threatened with massive dislocation and decline.

[7] The fertilization effect is still poorly understood. While it may increase growth rates in some species, this effect will not occur when another aspect of the tree's growing conditions such as soil nutrition, light or moisture is its limiting factor. An isolated plant's response to elevated CO_2 appears to not necessarily translate into increased growth for the entire community. Recent research indicates that the value of the fertilization effect may be overrated (Bazzaz & Fajer 1992).

Forest use practices is one of the primary sources of CO_2 emissions

Global forest cover is diminishing at an increasingly rapid pace. In 1989 the volume of carbon released into the atmosphere by deforestation was 41% higher than the volume emitted a decade earlier (Myers, in Leggett 1990).

Most of the deforestation is occurring in tropical countries, for agricultural uses such as ranching, smallholder agriculture and commodity crop plantations. Population pressures are leading to more and more deforestation from shifted cultivators, squeezed out of established farmlands, who head for "unoccupied" forest lands. These are usually uneducated farmers with little understanding of how to use forests sustainably. This trend is worth mentioning because shifted cultivators now account for more tropical forest destruction than all other agents combined, and because their forest clearing method is normally slash-and-burn, releasing CO_2, methane and nitrous oxide into the atmosphere. Unfortunately, even the more productive alternative uses for these former forests compare poorly with the potential value obtainable from sustainable harvest practices (Dixon et al 1991).

A recent survey analyzed forest cover loss by deforestation in 34 tropical and other countries. Losses total 14.2 million hectares per year (Myers, in Leggett 1990). In much of this area secondary forest growth is not occurring, because soil conditions are degraded. When the additional biomass lost through partial deforestation and degradation is added, the total is closer to 17 to 20 million hectares per year. The deforestation rate is still increasing, and is expected to reach 30 million hectares annually within several decades, if present trends continue.

While the bulk of CO_2 emissions from forest misuse occurs in developing nations, industrialized countries such as Canada cannot claim exemplary records. Further losses in forest biomass are resulting from forest declines attributed to inadequate forest management practices, acid rain pollution, and urban and industrial development. Despite Canada's comparative wealth and recognition of the need to manage forests sustainably, 18 million tonnes more biomass is removed annually from the nation's forests than is replaced through forest and plantation growth (Kurtz & Apps 1991).

CO_2 absorption by forests is the main terrestrial sink for CO_2 emissions

Trees are the primary terrestrial carbon sink. They remove CO_2 from the atmosphere and convert it into biomass, 50% of which is carbon on average. *Figure 1* below shows the cycling of carbon in a forest ecosystem.

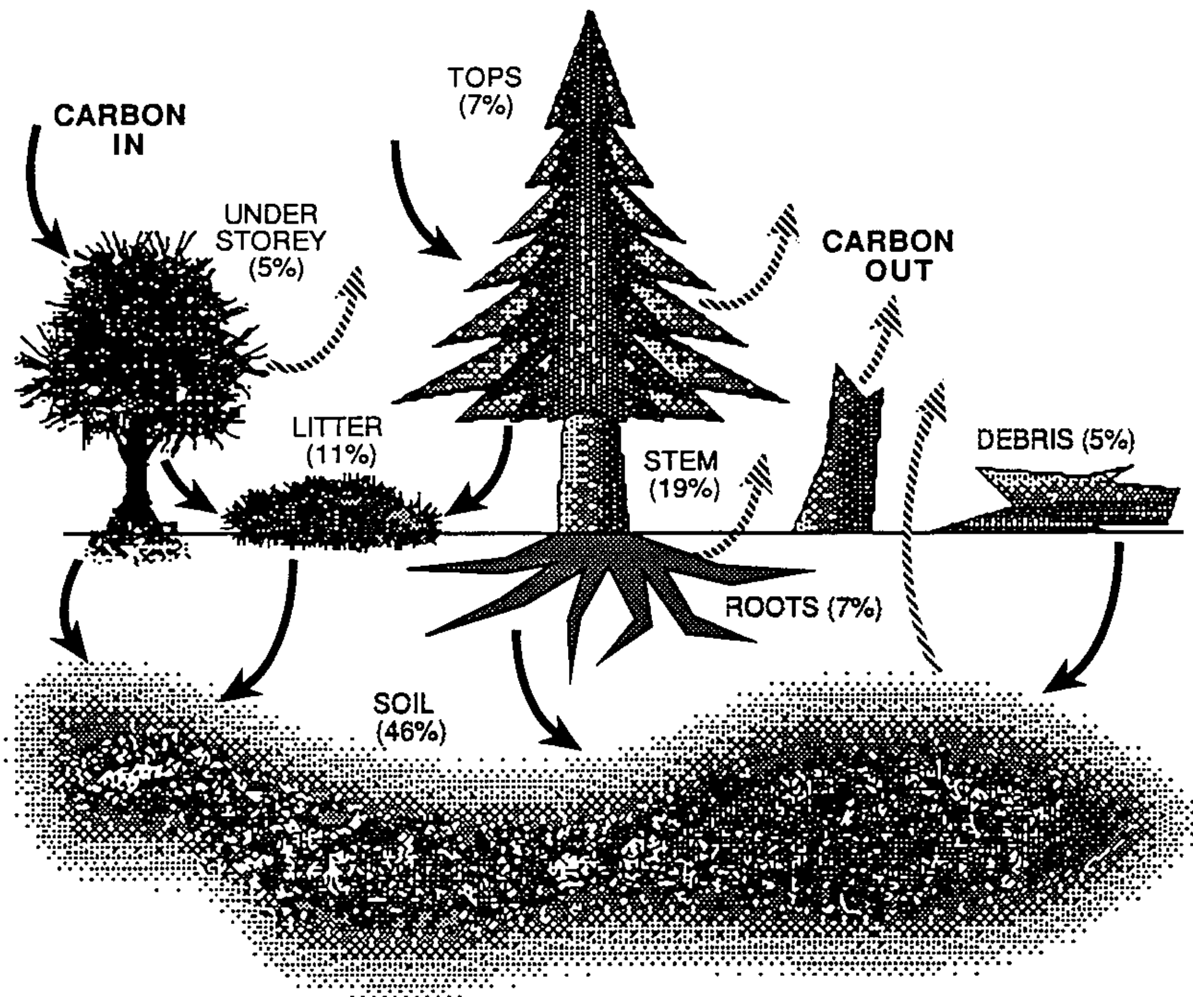

Figure 1 Carbon Banks in the Forest
Source: (Nagle 1990:6)

The loss of forests is a double negative in its disruption of the carbon cycle balance. Harvest and combustion contribute to the greenhouse effect; and the same forest is no longer a part of the global carbon sink. A tree plantation can absorb an average of 10 tonnes of carbon per hectare each year. This sums to 1,000 tonnes per km^2, with large variabilities depending on species, site condition and ecosystem. Planting 1 million square kilometers could result in the uptake of 1 of the 4 billion excess tonnes of carbon collecting in the atmosphere each year. The large scale planting of trees could significantly cushion the impact of fossil fuel combustion while the world figures out how to deal with the problem of greenhouse gas emissions (Myers & Goreau 1991).

1.C Action is Needed

1.C.1 The scope of required action is controversial

It is too late to prevent temperatures from rising at least 1°C further, no matter how ambitious the mitigation measures (Gribbon 1990b). Developed nations would have to reduce their CO_2 emissions by an estimated 60-90% just to achieve a stabilization of current global atmospheric concentrations of greenhouse gases and limit warming to a further 1°C. (Canada. Environment Canada 1992a). If we leave aside the issues of who should be responsible, and how action should best be implemented to ensure global cost efficiency and equity, there is still controversy about how much action is needed, if any. Experts disagree whether action should be weighted toward improving research (and reducing uncertainties), toward mitigating the net GHG increases, or toward preparing for the inevitable climate change.

A critical factor that needs to be included in estimates of costs of action is the costs of delay. At the current rate of emissions GHG concentrations are increasing by 8% every five years. The rate of flows and the size of the stock (concentrations) of emissions are both increasing. This means the speed with which mitigation efforts are put in place will clearly affect the magnitude of change that can be accomplished by a given program and, consequently, will impact the cost of future warming damage[8] (Pearce & Barbier 1991).

What should be done? Few analysts argue for a *risk taking* strategy of doing nothing to limit climate warming. The conservative Marshall Institute group recommends that the international community hedge its bets by taking a *risk neutral* approach they describe as a "no regrets" policy to retard global warming. This involves taking relatively low-cost action such as energy

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[8] For example, reducing emissions globally by 2% per year starting in 1990 would have stabilized the CO_2 equilibrium level at 390 ppm, for a temperature stabilization at approximately 1°C warmer than today. In contrast a 2% reduction starting from the year 2010 stabilizes concentration of CO_2 at 460 ppm for a temperature approximately 2° warmer than today. These estimates were derived from mitigation scenario graphs (IPCC 1990a).

conservation, shifts in fossil fuel mix and reforestation (Jastrow et al 1990). At the same time investments in improving global monitoring and mathematical modelling should be pursued to reduce uncertainties. Most other writers advocate a *risk averse* approach.

The case for more dramatic action to mitigate the climate change threat is persuasive:

1. Predictions of substantial climate change and damage costs are considered to be credible by the majority of experts, and the possibility of catastrophe of major proportions exists;

2. The greenhouse gas effects are irreversible. According to orthodox economic theory this means, in a cost-benefit analysis of alternative strategies, the net benefit of avoiding costly action must be reduced to account for the loss of future options inherent in inaction (Arrow & Fisher 1974);

3. The problem escalates as time elapses;

4. The impact of global warming is a risk that can not be pooled across a portfolio of investments to limit risk - there is only one Earth; and

5. Societies by nature are risk averse (Pearce & Barbier 1991).

The rational strategy is a risk averse one in which all nations devote considerable resources to mitigating net greenhouse gas emissions immediately.

Some specific mitigation targets are being recommended

Potential mitigation programs vary from the cautious to the ambitious. *Table 4* on the next page shows a sample of mitigation actions which have been suggested.

Table 4 **Sample of Recommended Mitigation Action**

Source	Action	Climate Change Target	Comments
Brookes (1989), Idso (1990) and others	Make no commitments await the results of future research	no target	"Business as usual" scenario
Canadian Council of Ministers of the Environment (1990)	Stabilize emissions of GHGs at the 1990 rate by the year 2000	no target	Canada's national commitment
Gribbon (1990)	Use less fuel, change fuel mix, protect forests, reforestation and improve agriculture practices	Slow temperature increase from 0.3° C to 0.1° C per decade	0.1° C is the maximum rate of climate change pre-human intervention - thus adaptation is possible
Boyle and Ardill (1989)	First a 20% reduction from 1988 CO_2 levels by 2005, then a further 50% reduction	Climate average from 1.5° C to 2° C higher than current by 2050 and still increasing	Statement of action from the 1988 Toronto International Climate Conference
Leggett (1990)	Reduction to 30% of present GHG emissions by 2020, plus extensive reforestation	Climate eventually stabilizes at 1.5° C +/-1° C above current by the year 2050	Rate and scale of change are within historic precedent

The highly respected Climatic Research Unit at the University of East Anglia in Britain analyzed simulations of four potential mitigation scenarios (Kelly 1990). The simulation assumptions and results, summarized on the following page in *Table 5*, provide more detail about the relative climate warming outcomes predicted for certain levels of action.

Table 5 Four Global Warming Response Scenarios

	Actions				Warming	Results
Scenario	**CFCs**	**GHG sinks**	**GHG sources (other than deforestation)**	**Warming rate per decade**	**Actual warming at yr 2050**	**Equilibrium warming at yr 2050**
1. Business as Usual	full compliance with Montreal Protocol; substitutes are not GHGs	linear increase in rate of net annual deforestation to 2040; 10% decline by 2050	concentration levels continue based on future modest economic growth globally	0.26° C+/- 0.12° C	2.6° C +/- 1.1° C	3.6° C +/- 1.8° C
2. First Step	elimination of CFCs by 1995; substitutes are not GHGs	a halt to net area of forests lost, by year 2000	concentration levels continue based on future modest economic growth globally	0.22 +/- 0.1° C	2.4 +/- 1.0° C	3.2 +/- 1.6° C
3. The 50% Solution	elimination of CFCs by 1995; substitutes are not GHGs	a halt to net area of forests lost, by year 2000	reduction of CO_2 emissions to 80% of 1988 level; further 50% reduction by 2030	0.16 +/- 0.08° C	2.1 +/- 0.8° C	2.6 +/- 1.3° C
4. Global Warming Halted	elimination of CFCs by 1995; substitutes are not GHGs	same as above; + 160×10^6 hectares additional reforestation by 2020	same as above; + reductions in CH_4/N_2O to 75% of expected concentrations in 2050	0.04 +/- 0.03° C (rate by 2050)	1.7 +/- 0.8° C	2.0 +/- 1.0° C

The scenarios outlined in Table 5 make no mention of technological "fixes". These are various scientific and engineering proposals for reducing climate warming by using large-scale technological interventions. One example is the proposal for dumping iron into Antarctic waters in order to boost the production of microscopic algae, thus increasing CO_2 absorption capacity of the algae. A new study has refuted the viability of this option (Reisner 1991). Another example is the artificial seeding of cloud cover to reflect away incoming solar heat. Technological fixes are appealing to some since they hold the promise of solutions which avoid inconvenient life-style changes. They are generally rejected since the effect of the intervention on other environmental variables is uncertain, and the cure could be worse than the disease (Gribbon 1990a).

The most intuitively sensible to the lay person are targets which reduce the risks inherent in unprecedented rate and scale of warming. At best, nations collectively will aim to achieve the level of emission reductions required for the eventual leveling of atmospheric GHG concentrations. This will lead to stabilization of climate equilibrium at a level several degrees warmer than today by mid next century, the Global Warming Halted scenario in Table 5. At least, nations need to aim for mitigation targets that will slow warming to a pace that is within the 0.1°C per decade historic precedent, even though warming may continue to increase.

1.D Failures in Market Forces and Government Explain Mitigation Delays

1.D.1 Market transactions fail to account for certain "external" costs and benefits

Virtually everyone is engaged in the transactions that emit greenhouse gases into the atmosphere. With the current level of understanding of the threat to climate, why are people not reducing these activities? Because current behavior is rational when the cost of polluting is "free".

Impacts from the production or consumption of goods that affect someone who did not consent to it are known as externalities. These impacts are usually not costed into transaction prices. Classic economic theory of supply and demand predicts that the quantity of a good or service demanded will be greater (less) than the socially efficient quantity, when these social costs (benefits) are not included in the price.

The word economics stems from the Greek works Oikos - "house" and nemein - "manage". Most societies today, underpinned by traditional economic systems, take a narrow view of house management. Costs and benefits encountered today are weighted far more heavily than those expected in the future. Investment analysts typically use discount rates of 10% or higher, which favors projects with short-term benefits and long-term costs. An investment that will lead to serious environmental damage in the future may appear economic while a project that will generate returns far in the future will appear uneconomic. The effect of this traditional cost-benefit methodology is to transfer environmental costs to future generations. Implicit in this system is the assumption that future generations will be indifferent to receiving a legacy of man-made capital or one consisting of natural capital. This assumption does not hold up when global environmental problems are as serious as they are today, and are interdependent with the economy (MacNeill et al 1991). The excessive discounting of future costs and benefits is known as myopia, and is a primary reason that externalities such as greenhouse gas emissions are ignored.

Myopia leads to the exclusion of external costs from pricing structures

When market prices for activities that contribute to global warming fail to include the cost of climate impacts, there is no incentive (other than conscience) to limit consumption. The price paid by an automobile driver, for example, of getting from *a* to *b* is certainly less than the total cost to society. The individual is unlikely to take this external cost into account in making the decision whether to drive or take transit, even though in the long-term pollution may make the area unlivable. Industry is under pressure to produce short-term returns and is not yet required to include in its cost structure the future cost of climate warming. The petroleum industry, for example, has little incentive to invest in innovations to mitigate environmental damage, when environmental costs can be ignored by the producer.

Myopia leads to a depreciation of positive externalities

The positive external effects of some activities are undervalued, resulting in the under-production of these activities. Silviculture and sustainable forest use are good examples. When making land use decisions, a Brazilian farmer does not include in his or her calculations the decrease in CO_2 absorption capacity, or the environmental sustainability of this same land in the future. (S)he will tend to opt for the use with the more immediate returns.[9] Magnified by economic and population pressures, the resulting over-consumption of forests becomes a particularly intractable problem.

[9] Environmentally sustainable use results in higher, albeit longer term returns. For example the net present values for future yield from an Amazonian forest in Peru are: $6330/hectare if harvested sustainably for fruits, latex and resins; $3184 if converted into a managed pulpwood plantation; $2960 if converted into agriculture/pasture land; and $1000 if clear cut for timber (Dixon et al 1991).

Developed nations are also guilty of short-sightedness in the pricing of public forest resources. The value of non-priced amenity services generated by the standing forest tends to be excluded from forest management decisions (Wernerheim 1986). The over-emphasis on immediate returns leads to under-investing in silviculture, for which the pay-off is long-long-run.

Information asymmetry compounds the failure of markets to account for the externalities

Markets are efficient when participants are well informed of the costs and benefits, and buyers and sellers have the same information about the good being traded. Here this is not always the case. Global warming is a relatively recent concern, since until the mid-1970s scientists were predicting the opposite problem - a coming ice age. There are still many controversies and unknowns, and the set of information that is available is spread very unevenly. Information asymmetry has the greatest potential for creating inefficient consumption levels of post-experience goods - ones where the consumer has difficulty in recognizing the causality between consumption and some of its effects (Weimer & Vining 1989). Greenhouse gas emissions are a post-post experience good.

Most people, for example, have little idea whether their houses are well-insulated, nor how efficient their fixtures and appliances are. People rarely know what savings new insulation, furnace replacement, thermal windows or efficient appliances will bring them. They are even less likely to know the future impact on the environment of their energy use. By contrast, electricity generators do know the thermal efficiencies and pollution emissions of their power stations and can forecast the repercussions of changes in demand (Helm 1990).

This market failure means that a higher level of GHG emissions are produced than if information about the problem were more unambiguous and more evenly available.

1.D.2 Government intervention is also subject to inefficiency

The nature of a market activity in which significant costs are external, and in which future costs and benefits are excessively discounted, is to sustain inefficient levels of polluting transactions. The solution is for governments to intervene to distort private decisions toward what is deemed to be socially desirable. Potential government intervention in the global warming problem can be segmented in several ways.

Categories of government intervention

Segmentation of possible action by governments can be based on economic categories. A risk neutral strategy involves taking only actions which are effectively costless since there are benefits other than greenhouse mitigation which justify the policy. Examples of this are programs such as energy demand management, treeplanting or elimination of CFCs. The second category is the risk averse strategy in which actions are also implemented which require investments with fewer external benefits or a longer pay-back period. Examples are conversion of energy facilities from high CO_2 fuels such as oil to lower CO_2 emitting fuel such as natural gas, and investments to improve renewable energy sources that are not economically viable at present. Canada's Green Plan, discussed later in the paper, reflects this segmentation in its global warming response (Government of Canada 1990).

Another segmentation scheme for government intervention is characterized by time - the rate at which the action can effectively be implemented. Potential short-term changes include energy efficiency regulation; medium-term results can be achieved by reforestation programming; and long-term action includes the development of renewable energy power generation. An array of response actions in each category is typically recommended in a risk averse strategy due to the scope of action needed to meet GHG limitation targets (Green 1991).

Segmentation can also be based on fiscal mechanism (Weimer and Vining 1989). Governments can choose policies to *facilitate markets*, for example by creating new marketable goods such as tradeable pollution permits. They can use *taxes and subsidies* such as carbon taxes or subsidies to encourage conversion to low-emission farming practices. They can *establish rules* such as energy efficiency standards for housing, automobiles and household appliances. Governments can *supply goods through non-market mechanisms* by allocating funding to increase reforestation programs. Finally, they can *provide insurance* in the form of disaster relief funds. This segmentation scheme is used later, when considering Canada's potential response options.

Governments have the mandate to intervene when inefficient market conditions lead to social costs such as global warming. Why are governments not intervening adequately?

Mitigation of greenhouse gas emissions is a global public good

The main stumbling block to government actions to ensure efficient levels of emission-producing activities is the perceived cost of programs. The transfer of valuable resources - from other activities to limiting global warming - produces environmental benefits which are a global public good. Definitionally a public good is one which, to some extent, meets the following criteria: 1. The benefits of the action are non-rivalrous. In other words the amount of benefit enjoyed by one individual or country does not reduce the amount enjoyed by others; and 2. The benefits are non-excludable. This means no person or country can exert control or ownership over the benefit (Weimer and Vining 1989).

Mitigation of global warming is a classic public good. The mitigation action will cost the acting government disproportionately to the benefits received, since the benefits are diffused over the globe in the atmosphere. There is strong incentive for a nation to free-ride on beneficial actions of other concerned nations, without taking similar action itself. This leads overall to a lower level of production of global warming mitigation than is socially efficient.

The strong trends toward global business strategies and increased international trade and competition magnify governments' concerns about free-riding. Politicians fear that taking action will result in decreased competitiveness and threaten the economic well-being of the nation and its citizens. The incentive therefore is to stall until international agreements are in place to limit free-riding.

Interest group pressures contribute to government inertia

Industry interest groups have large investments in the status quo, such as existing energy sources and technologies. To protect the interests of their various stakeholders these industries resist government measures that could depress demand for their products, or that require major investments in new process and plants. Stringent standards can in the long term lead to the development of innovations that create competitive advantage. In the short term the added burden of tighter standards is resisted. Corporations may also assume, based on government track records to date, that concerns for energy security and the economic viability of national industries will take precedence over environmental concerns (Meade 1991). In the absence of other incentives they will continue to pressure governments not to intervene.

Myopia in decision-making limits mitigation action

Myopia, the excessive discounting of future costs and benefits, distorts global warming response policy. Electoral cycles are short relative to the future costs of warming and payoffs from greenhouse mitigation expenditures. Consequences fifty to one hundred years from now strain political decision-making geared to immediate crises. Politicians are aware that the electorate will be measuring them relative to budget allocations, such as health care, social security, and job protection, which have immediate individual benefits. Political decisions are driven by economic indicators such as the Gross National Product, which reflects activity flows and ignores the wealth or depletion of environmental and natural resource capital.

Problems with bureaucratic supply further thwart effective action

Government bureaucracies are notoriously inefficient large organizations. They are well able to resist structural change, particularly the scope of change needed to avert global warming. In countries such as Canada a further layer of complexity results from decentralized decision-making. Important decisions require consultation and buy-in by federal, provincial, municipal and other levels of government. At each level there may be numerous agencies or departments such as Forestry, Energy, Environment, External Affairs and Finance, involved in the response strategy. Programs and regulations in the various sectors will need to be coordinated, but this implies a loss of autonomy that will potentially be resisted.

The public good aspect of mitigation actions and the failures inherent in governments are practical challenges that governments must surmount in order to implement a risk averse strategy to respond to the threat of global warming. The next section of the paper analyzes how well Canada is doing in this regard.

SECTION 2 CANADA'S SITUATION

2.A Global Warming is Canada's Problem

2.A.1 Canadians contribute disproportionately to global warming

Canada is responsible for close to 2% of world greenhouse gas emissions, an amount that is disproportionate to our relative population. Canadians are tied with the U.S in producing the largest volume of CO_2 emissions per capita. Despite already high levels, the federal government forecasts that economic growth will cause CO_2 emissions to increase by 1.6% each year (CCME 1990).[10] Estimates developed by the Dutch government show that Canadians will need to reduce CO_2 emissions from 5.5 tonnes per capita (1984 level) to 0.7 tonnes by the year 2025 if we aim to achieve an equitable rate of emissions compared with the rest of the world (MacDonald 1991).

2.A.2 Canada will be affected by climate change

Climate models predict a much higher level of climate change for Canada than the global average. Compared with an average warming of 3.5^{o} C expected at $2xCO_2$ concentrations, Canadian climate models predict a 4.8^{o} increase in the southern parts of the country and increases in the northern areas ranging from 0^{o} to 6^{o} in the summer and 8^{o} to 12^{o} in winter (Hengeveld 1991).

This level of warming is expected to cause environmental and economic losses. Consequences for Canadian forests are likely to be severe, especially along the southern margins and low soil-moisture limits of each species. A net loss of 100 million hectares of boreal forest is predicted, although some of this could develop into mixedwood forests where moisture is abundant (Hall 1991). Eventually, Canada's $20 billion annual forest products trade surplus will be jeopardized.

Impacts on agriculture will be mixed. Growth potential in some areas will improve. In prime agricultural regions such as the Prairies and southern Ontario and Quebec, increased heat and drought conditions will cause major crop stress and economic losses.

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[10] This could be an optimistic projection, given that our CO_2 emissions increased 4.6% in 1987 and 6.6% in 1988, according to a report published by the Carbon Dioxide Information Analysis Center (MacDonald 1991).

Water levels in the Great Lakes system could drop by one-half to one meter or more on average, and water flowing from the St. Lawrence River could drop by 20%. Shipping and recreational activities will be affected. Ecologically important wetlands will disappear and aquatic habitats and species populations will be disrupted.

The rise in sea level will affect major population centers along the Atlantic and B.C. coasts, necessitating large investment in improved protective barriers. Rural areas will also be affected with salination of farmlands and increased flooding of rivers upstream of the coast.

Canadians will also be affected by climate warming damage in other countries. Disruptions of trade patterns, increased incidence of international conflicts, and pressures on Canada to augment emergency relief funding are a few of the consequences expected (Hengeveld 1991).

In order to understand Canada's global warming strategy the following sections summarize Canada's involvement in international negotiations, our domestic response actions, and the range of available policies. This is followed by an analysis of the current strategy, concluding that there is a strong rationale for a more aggressive approach to meeting global warming limitation targets.

2.A.3 The Canadian government recognizes the need for response

At the highest levels, the Canadian government has recognized the seriousness of the global warming problem and the need for action. A former federal Environment Minister, Charles Caccia, publicly affirmed that global warming is the number one environmental problem facing the nation (Prins & Roberts 1990). He is convinced that developed nations such as Canada need to take action, for political as well as environmental reasons. While in office, Caccia wrote that "[domestic] action taken by OECD countries to reduce CO_2 emissions is of key importance if a global climate change strategy is to be taken seriously [by other countries], developed and successfully implemented" (Caccia 1991:2).

Greenhouse gas limitation targets

The federal government has committed Canada to an initial "first step" target of reducing CO_2 and other greenhouse gas emissions to the 1990 level by the year 2000. It claims that further reductions to greenhouse gas (GHG) emissions are required. The government supports the global principle, articulated at the Second World Climate Conference in Geneva in 1990, of stabilizing GHG concentrations at a level that would prevent dangerous human interference with climate. To this end the government plans to examine the implications for trade as well as technical and cost feasibility of complying with the first step target recommended by participants at the international 1988 Toronto Conference on Climate Change: a 20% cut in CO_2 emissions from 1988 levels by the year 2005 (Government of Canada 1990).

The House of Commons Standing Committee on the Environment recommends that Canada adopt the more stringent Toronto Conference target immediately, and expand it to include other GHG emissions (MacDonald 1991). This reduction level is in itself insufficient to stabilize atmospheric concentrations soon enough to avoid doubling of CO_2 concentrations, and the attendant impacts on climate and economies. Despite questions about its adequacy, the Toronto target is seen to be an achievable initial goal and remains the focal point of international discussions.

What do these goals mean in terms of emission reductions? If the predicted 1.6% annual increase in CO_2 emissions occurs, Canada will need to cut emissions by 17% from the levels otherwise expected for the year 2000, in order to achieve 1990 levels. The Toronto goal, a 20% reduction from 1988 levels by 2005, would require a 40%-50% reduction from levels projected for 2005 based on forecasts for future energy use by the Department of Energy, Mines and Resources and by the National Energy Board (MacDonald 1990, Hengeveld 1991).

Domestic and international components to Canada's response

Canada's National Action Strategy for global warming concludes that there is significant scope to improve our emissions record in ways which are economic or achieve other objectives; and Canada needs to do this to act on our responsibility as a developed nation and at the same time further our own economic interests. However another fundamental conclusions of the NAS is that, as Canada accounts for only 2% of global emissions, "Canada alone, therefore, can have no meaningful impact on reducing world GHG emissions. We clearly will have to work at the international level to help resolve the problem of global warming" (CCME 1990: 5).

This position reflects the pragmatic recognition that the threat of global warming merits domestic action to limit the problem. But at the same time, at the international level, action to reduce GHG emissions is a public good. The Canadian government considers it necessary, before making significant investments in limitation initiatives, to ensure an international contract is in place to prevent free-riding of other nations.

2.B Canada's International Involvement

2.B.1 Canada has been a leader in the international forum

Is the strategy of pursuing international agreement one which will result in achievement of Canada's targets? To assess this question, some information about international negotiations which concern global warming is reviewed.

International cooperation

The international community recognizes that the global public good aspect of response action creates dis-incentives for individual nations to respond to global warming. A "world government" or other supra-national agency delegated with the authority to prevent free-riding and to obtain solutions at the net lowest global social cost is not a realistic near-term option (Piddington 1989). Instead international negotiations are being pursued, with the goal of eventually achieving global treaties which will delineate national responsibilities.

Canada has had an active role in initiating these negotiations, and appears to be committed to fostering international agreement to limit global warming. The Canadian government prefers to finance activities that constitute an international public good, in the presence of a mutual contract with the other beneficiaries of the good. A prescedent for this exists in Canadian expenditures for North Atlantic Treaty Organization (NATO) defense activities over the past several decades, for example.

The Montreal Protocol was essentially the first treaty negotiated which limits a greenhouse gas. Canada played a key role in organizing the series of negotiations leading to the 1987 Montreal Protocol and was one of the first signatories. Subsequently Canada was the first country to ratify a strengthened Protocol, the Helsinki Declaration (signed by 81 countries all told), which in 1989 called for the complete phase-out of CFCs by the year 2000 (Government of Canada 1990). In March 1992, the government declared its commitment to eliminate CFCs by 1995.

2.B.2 The "Earth Summit" addresses global warming

Canadian diplomatic efforts since 1988 have been mainly directed at preparing for the United Nations Conference on Environment and Development (UNCED), also known as the "Earth Summit", scheduled for June 1992. The Secretary General of UNCED is Maurice Strong, a Canadian businessman, formerly Chairperson, President and CEO of major Canadian corporations. Mr Strong is well-known for his participation with the Bruntland Commission, as well as for high-profile positions in other development and environment organizations (Hauser 1991a).

The "Earth Summit" is a widely publicized attempt to put in place international contracts to reduce negative environmental externalities. These contracts will provide incentives for countries to invest in environmental action by limiting free-riding by other nations. According to Secretary General Maurice Strong, the primary goal of UNCED "will be to lay the foundation for a global partnership between developing and more industrialized countries, based on mutual need and common interests, to ensure the future of the planet [and] to find a viable and equitable balance between environment and development" (Hauser 1991c:2).

Multiple agreements at the "Earth Summit"

The conference organizers hope to achieve an impressive array of international agreements, crafted and negotiated over the past several years, and prepared for signature by heads of state at the UNCED in June. A large range of non-government groups are also participating in the UNCED negotiations, both by input into national positions papers, and separate from individual national interests.

The agreements include a Charter of global principles, an action Agenda and several Framework Conventions. The Earth Charter is the basic statement of a global moral framework for environment and development. Agenda 21 is an international action plan for governments and international organizations such as the UN and the World Bank. Agenda 21 will include chapters dealing with categories of activities such as national policies and actions, data gathering and regional and international cooperation. The agenda covers all the main environment/development sectoral and cross-sectoral issues. Preparation for the Agenda 21 recommendations was organized into three Working Groups (WGs). WG I covers issues involving the atmosphere, land, bio-diversity protection, and safe management of bio-diversity. WG II covers fresh water, marine and waste disposal issues. WG III deals with strengthening environmental law, and reforming national and international instruments for implementing UNCED decisions (Hauser 1991a).

Within the auspices of UNCED, there are several Framework Conventions, including one dealing with climate change. The goal of the Climate Change Convention is to identify the primary climate change principles and obligations; to gain the adherence of the largest possible number and a wide balance of nations; and to establish a process for subsequent negotiation of the treaty protocols which will outline quantitative objectives for climate change responses over a specified time period (IPCC 1990d). This framework convention covers topics also being considered in the WG I 'Atmosphere' sub-section of Agenda 21 discussions.

Climate change issues will be addressed as well in the Forestry Framework Convention, a proposed set of international principles and protocols governing conservation and sustainable forestry management. This Convention is also expected to be signed by heads of government during the UNCED (Maini 1991). Since three sets of negotiations bear directly and indirectly on the topic of global warming, the agreement documentations need to reflect the linkages with other agreements, while delineating the objectives of each and avoiding overlap.

The scope of negotiations being undertaken for the "Earth Summit" is truly impressive. The down side is that the complexity of negotiations may retard a satisfactory outcome. The ambitious timetable naturally stretches the resources of knowledgeable people needed to research, formulate and coordinate national positions on the myriad topics.[11] Inadequate preparations will compound the difficulties inherent in getting global agreement on touchy issues, and could contribute to watered-down agreements reflecting the lowest common cooperation denominator.

2.B.3 The interests of developing and developed nations are divergent

The international activity leading up to global warming agreements is a very dynamic process, with multiple negotiations currently underway. Signing agreements at the June conference will follow several years of work by the international negotiating teams that are crafting the agreement documents.

The negotiations process

The UNCED negotiating teams, made up of delegates from member states of the United Nations (UN), have held a series of meetings to negotiate the issues that underpin the agreements. These meetings are known as Preparatory Committee (PrepCom) sessions. The fourth PrepCom, including negotiations toward the Forestry Framework Convention which comes under the UNCED umbrella, was held in March 1992 in New York. The Climate Change Convention is

[11] A Canadian attendee of interdepartmental meetings, held to formulate Canada's position for UNCED, was interviewed for this paper. She confirmed that achieving a coherent national position seemed to be a major challenge. There were 20 government departments represented at one meeting which was "floundering, fuzzy - it was scary - people didn't even know their department's position on the issues" (Plexman 1992).

organized on a separate track from UNCED, as is the Bio-diversity Framework Convention, which also covers issues linked to both forestry and climate change concerns. The most recent Climate Change negotiations were held in February, and a final round is scheduled for April 1992.

UN negotiations typically have involved "blocs", groups which have formed for the purpose of ensuring the proper geo-political representation and for building coalitions around issues important to the group. One of the three basic blocs is WEOG (Western European and others), which includes the European industrialized countries, the U.S., Canada, Japan, Australia and New Zealand. Another is the Group of 77, which includes developing countries and newly developed nations. The Eastern Bloc consists of the nations that formerly were part of the USSR as well as the Eastern European nations (Hauser 1991b).

The speed with which issues and positions change, and the secrecy inherent in the negotiating process make it difficult to pin down what is really happening. As negotiations get down to the wire, domestic and international political pressures could lead to last minute shifts and compromises before the documents are signed by the politicians. The summary which follows gives an overview of some potential problems, as of early April 1992.

Potential barriers to progress

Impressive progress is being made in identifying issues, organizing and collating the research and preparation needed for meaningful negotiations to take place, and giving voice and participation to a large number of nations. There are however difficult areas of contention that challenge the Agenda 21 as well as the Framework Convention negotiations. The barriers are primarily centered around the different interests and views of the industrialized versus the developing nations.

1. The right to development.

Climate change limitation focuses on reducing energy use as well as reducing the shrinkage of forest carbon sinks. The developing nations are asserting their right to exploit their energy and forest resources in order to develop their economies and future standard of living, in the same way that the industrialized countries have done in the past. Jose Goldemberg, a minister in the Brazilian government, argues that during the period of building a national economic infrastructure, the use of resources constitutes a "capital" investment which creates a heavy draw on resources. Once the infrastructure is in place, the nation incurs normal "operating" costs and the draw on resources will diminish. He claims that developing nations need to be allowed this period of infrastructure building unimpeded, during which time developed nations should expect to bear the total responsibility for limiting greenhouse gas emissions (Goldemberg 1990).

The developed nations wrestle with a dilemma. While many of the development expectations of developing nations are legitimate, the present urgent environmental threats call for environmental sustainability to be factored into development plans worldwide.

2. Differentiated responsibility between developed and developing nations.

The developing nations insist that industrialized nations admit to having the greatest share of responsibility for creating the global warming problem. They consider developed nations responsible to undertake and finance the changes needed to prevent future global greenhouse gas emission increases. Developed nations claim that every nation contributes to the current problem and must therefore take responsibility to correct it by committing to limitation targets.

3. Assistance.

The developing nations are demanding a transfer of dollars and technical resources on favorable and preferential terms to finance global warming response actions and for other development needs. Developed nations resist tying agreements about climate change to agreements to supply aid. They fear that this could create the precedent for a potentially endless draw on their resources from the seemingly intractable financial problems of developing countries.

4. Splits in negotiating blocs.

When nations in a negotiating bloc cannot agree amongst themselves, achieving agreement with other blocs with even more divergent views is made more difficult. A group of small island nations that are threatened by the projected sea level rise resulting from climate warming has a much greater incentive to see concrete action emerge from the negotiations than do some of the other members of the Group of 77, and are therefore pressing for a more conciliatory approach.

In the WEOG bloc, the U.S. is playing the "villain" role in contrast to the European Community which is adopting the "hero" stance (Gerelli, in Dornbusch & Poterba 1991). The European Community (EC) has agreed to freeze GHG emissions at the 1990 level by the year 2000. To improve its credibility, the EC has been working to reach internal agreement on a Community Strategy based on concrete policies for limiting emissions and improving energy efficiency. The group aims to have this Strategy signed by the EC Council of Ministers in May 1992, prior to the U.N. Conference on Environment and Development (UNCED) (Sundt 1992b).

US negotiators have not agreed to the need for establishing emissions targets and dates, and claim there is not enough science to justify costly action. Furthermore, they argue that domestic programs already implemented to reduce air pollution under the Clean Air Act, along with CFC reductions, are adequate to achieve any net emission reductions the U.S. is prepared to make at this juncture. There are some recent signs that the U.S. is moving from this position. Observers speculate that difficulties with his 1992 election campaign, coupled with the environmental concerns of U.S. citizens, are likely to prompt President Bush to attend the UNCED, and thus perhaps to moderate the U.S.'s rebel stance.

2.B.4 International negotiations will not produce a timely solution

What is the prognosis for the June conference to achieve adequate and workable agreements? The Canadian Delegation Reports published after the fourth and fifth UNCED PrepCom sessions, in December of 1991 and March 1992 respectively, were not optimistic. The Delegation reported that "Sessions were marked by very slow progress and minimal movement by major players. Splits are developing within negotiating blocs. [There was] little evidence that delegations were ready to compromise, [but were seeking] to defend entrenched positions" (Environment Canada 1992a:2). The Environment Minister from Germany confirmed, in a speech at the Globe 92 Conference in March 1992 in Vancouver B.C., that the outlook for successful negotiations in Brazil is poor ("Globe '92 speaker urges world leaders to show courage" 1992). The Earth Charter has reportedly been abandoned because negotiators could not agree on a statement of principles. Delegates are described as having taken "a giant step backward" at the latest Forestry Convention negotiations ("Earth Talks Sputter" 1992).

Agreements will certainly be signed in June. How successful they will be in moving the world substantively toward effective limitation action remains to be seen. Once limitation principles and other equity issues have been negotiated, there are still other key criteria required for successful implementation (Helm 1990). There must be consensus on the scientific accuracy of procedures for assessing the global warming potential of each nation's emissions. Second, measures must be in place for impartially monitoring compliance with the agreement.[12] Last, the penalty for non-compliance must be more costly to the nation than the benefits of free-riding. Reaching agreement on these implementation criteria may also take time. The most recent report by the Canadian delegation warns that developing nations are taking a strong position against monitoring (Canada. Environment Canada 1992b).

It may be a long time before international contracts on the global warming issue can provide members of the international community with the confidence to act in the global common good. Roughly a decade was required to achieve international agreement - among a smaller number of nations - to reduce the production and use of CFCs. It will take a further decade to implement the reductions. Compared with ozone thinning, the causes of global warming are far more pervasive and integral to present lifestyles. Agreements will be harder to achieve, and action will take longer to implement. If Canadians wait until international contracts are in place before taking action, our limitation targets will not be met. To carry out other than a clearly risk taking strategy, we must in the interim take unilateral action.

2.C Unilateral Action to Limit Global Warming

2.C.1 Canada's domestic program

Are Canada's domestic response actions sufficient to realize our greenhouse gas limitation commitments? Before answering this question, the background to Canada's internal response strategy needs to be considered.

Canada's global warming response strategy is a combination of a conceptual framework for response policies, a national action plan, and a collection of various programs being undertaken in different jurisdictions and government departments.

The National Action Strategy

A framework for responding to global warming was formulated by parallel committees of the Environment and Energy Deputy Ministers of all the provinces. This document, commissioned

[12] A 1990 conference on climate change discussed the possibility that the General Agreements on Tariffs and Trade (GATT) could provide an institutional model for monitoring climate agreements (Bush 1990). The enforcement and dispute resolution mechanisms would certainly need to be more effective than those of the GATT.

by the Canadian Council of Ministers of the Environment, is entitled the National Action Strategy on Global Warming (NAS). Issued in November 1990, the NAS is a strategic framework within which governments will develop and coordinate specific measures in their areas. Canada's response strategy is recommended to have three components: 1. Limitation of greenhouse gases (GHGs); 2. Adaptation to climate change; and 3. Improvement of scientific understanding and predictive capability (CCME 1990).

With respect to the Limitation component, four principles are recommended:

1. A comprehensive approach. This means that responses to the problem must address all the major GHGs, and must include sinks as well as sources;

2. An international context. This principle recognizes the global character of the problem, which cannot be resolved by one or a group of countries but requires a concerted international response;

3. Flexibility. Uncertainties inherent in the global warming problem dictate that an appropriate response is one that is phased and progressive, gives flexibility to respond to new information, and uses a range of options and instruments; and

4. Regional differences. Limitation initiatives should vary from region to region to accommodate extensive regional differences.

The Green Plan

Following an extensive consultation process, in 1990 the federal Environment Minister issued Canada's environmental action plan, the Green Plan. The Plan deals with a number of environmental issues, including Global Warming, and claims to commit an additional $3 billion in incremental funding over a five year period to environmental initiatives. The section of the Plan dealing with global warming follows the framework and principles established by the National Action Strategy, and outlines action plans for putting three strategies in place: 1) Limiting Net Emissions; 2) Anticipating and Preparing for Global Warming; and 3) Improving our Understanding of Global Warming.

The Plan promises a range of initiatives under the Limiting Net Emissions strategy, including federal-provincial planning, improving energy efficiency, promoting alternative energy, informing and challenging Canadians, tree planting and limiting GHGs in agriculture. Initiatives are primarily informational and emphasize process rather than specific outcomes. Research, education, discussion processes, generating progress reports, partnership building and public information campaigns are prominent in the Plan (Government of Canada 1990).

Other responses

Canadian provincial and municipal governments have been following individual agendas with respect to global warming. The City of Toronto, for example, has adopted the Toronto Conference targets as its municipal target. Vancouver has not taken a stand. The Alberta provincial government has financed research into the problem and published informational reports pertinent to the province (Lilley & Webb 1990). The Ontario government is preparing a global warming strategy (Bennett 1992). Unfortunately, awareness is not necessarily translated into action. For example Ontario, Canada's highest greenhouse gas emitter amongst the provinces, has progressively reduced its commitment to reforesting logged areas. Now nearly half of the area harvested each year is not being naturally or artificially restocked, leading to a steady decline in CO_2 absorption capacity of Ontario's forests (Brinkman 1992).

The province of B.C. is a late-comer in taking an interest in the problem of global warming, and has only recently initiated a process to examine possible provincial strategy. However B.C Hydro, the provincial utility, is a pioneer among Canadian utilities with its PowerSmart demand management program to promote energy efficiency. Ontario Hydro is experimenting to determine the feasibility of using mill waste and bio-fuel plantations to produce fuel for power plants.

While inter-jurisdictional competition can accelerate the adoption of innovative programs and technologies, goals and programs must be coordinated. Ministry of Environment targets for reducing the carbon intensity of energy sources will not succeed if other ministries actively subsidize carbon-intensive industries such as coal and petroleum. Currently Canada's practical response to global warming is disorganized.

2.C.2 Domestic policy options

Large cuts in net CO_2 emissions are required in order to meet Canada's target of stabilizing emissions at the 1990 rates by the year 2000. The gases which represent the other half of the problem must be reduced as well. There are many actions that could be taken.

A range of potential policy options is available

Energy

The needed improvements in energy use can be approached from the supply side. Energy generating facilities can be converted to use lower net emission fuels such as natural gas or wood instead of higher emission fuels such as coal and oil. The economic viability of renewable energy sources such as bio-fuel, solar wind and wave-power energy can be developed. These measures could be accomplished by the use of a national carbon tax, tradeable emissions permits, emissions offsets,[13] subsidies for renewable energy and conservation, the removal of existing subsidies from polluting fuels, or regulations.

Wasted energy and pollution problems need also to be attacked from the demand side. Improved building construction and insulation methods can reduce heating energy requirements. The efficiency of energy-using fixtures and appliances can be increased. Energy-wasteful production processes can be eliminated by technological and process improvements. Accomplishing these tasks may require appropriate energy efficiency standards, consumer and industry subsidies, tougher building standards in the National Building Code and provincial Building Codes, and rewriting regulations governing monopoly energy pricing.

Forestry

Federal and provincial governments are just beginning to consider carbon management in their forest management strategies and regulatory frameworks. Agreements which allocate property rights to the public's forest resource can incorporate carbon storage targets in addition to necessitating adequate forest renewal. Incentives for landowners to invest in plantations on private land can be improved. Governments can fund incremental plantation programs to increase the size of the forest carbon sink. Possible policy mechanism implied by these options are strengthened regulations, changes to provincial Forest Acts, subsidies and government supply.

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[13] Emissions offsets requirements are being proposed for new energy plants in the U.S. Energy utilities building new plants will finance a carbon sink (tree-planting) program that sequesters an amount of CO_2 equivalent to the amount that will be produced by the facility over its lifetime, as a condition of receiving its permit (Dudek & LeBlanc 1990).

Transportation

A decrease in the carbon intensity of transportation fuel emissions is essential. The government can stimulate the private sector to improve, through innovation, the fuel efficiency of gasoline-powered vehicles. Vehicles can be designed to incorporate new low-carbon fuel technologies, as a longer-term option. GHG implications can be incorporated into public transportation decisions (such as the decision over a rapid rail link in the Windsor-Quebec corridor). Urban zoning and planning can be designed to decrease the use of commuter vehicles and encourage the use of bicycles, mopeds and motorcycles. These policies can be accomplished by legislating fuel economy standards, tax breaks and subsidies, support for innovative R&D, and changes to municipal zoning and provincial regulations.

Agriculture

Food needs will continue to grow as populations grow. Policies are needed to replace existing agriculture techniques with others which minimize methane (CH_4), nitrous oxide (N_2O) and energy use. The organic farming industry is demonstrating that there are ways of maintaining productivity while adopting more ecologically oriented farming practices such as low-tillage methods and reduced use of synthetic nitrogen-based fertilizers (Leggett 1990). Reduction of GHG emissions from the agriculture sector may be among the more difficult problems, since our understanding of CH_4 and N_2O cycles is less developed than for CO_2. The government role could be to underwrite research programs and to facilitate information transfers. Subsidies to maintain marginal agricultural lands in production could be retired. Subsidies could be re-directed to farms which convert to lower-emission activities such as organic farming and tree plantations. Permits to apply pesticides could be more tightly controlled.

Industrial production

Industrial processes are responsible for emissions of CO_2, CFCs, ozone and volatile organic compounds (VOCs) which combine to produce excess ozone in the lower layers of the atmosphere where it is a greenhouse gas. CFC production and use is being phased out. Low-GHG substitutes need to be developed since the current replacement products are also GHGs. Means to reduce permissible levels of other GHGs emitted during industrial production are needed. Taxes, subsidies tradeable permits and regulations could be employed.

Several types of government interventions are available

The preceding discussion of policy options in the various sectors outlines a number of market and non-market mechanisms that can be effective in limiting net GHG emissions. *Table 6* below summarizes some of these implementation mechanisms. Certain methods will have different political acceptability in different countries. For example taxes, which are a favored mechanism in European countries, fit poorly with the U.S. and perhaps Canadian ideological preferences for "no new taxes".

Table 6 **Mechanisms for Government Intervention to Achieve GHG Limitation**

Sector	Intervention: Facilitate markets	Taxes & subsidies	Regulations	Government supply	Insurance
Energy	•tradeable emission permits •marginal cost pricing	•carbon tax •support for development of renewables	•efficiency regs •emission offsets	•R&D for bio-energy	*Not applicable to limitation strategies*
Forestry	•resource pricing include CO_2 effects	•subsidize incremental silviculture costs	•improve prov regs and monitoring	•CO_2 sink program funding	
Transport	•internalize pollution costs of fuel	•bio-fuel development •carbon tax	•emission standards •urban zoning		
Agriculture		•shifting subsidy to low emission practices	•pesticide permit process tightened	•R&D for low CH_4&N_2O techniques	
Industrial production	•tradeable permits	•emissions tax	•CFC phase-out		

Economic research on the global warming issue lags behind environmental research due to the continuing uncertainty about climate impacts (Prins & Roberts 1990). Economists are beginning to model and debate the costs and effectiveness of these various mechanisms for achieving national targets. Some analysts are focusing on the potential of various mechanism to distribute the cost of global warming responses more equitably among the developed and developing nations. However, economic modelling of the problems and solution mechanisms present challenges that still need to be overcome. A full analysis of the relative merits of implementation methods, the effectiveness of market mechanisms verses command-and-control, and design determinants for avoiding social inequities or distortion of prices, is beyond the scope of this paper. Three potential intervention mechanisms merit a few words of discussion.

Carbon taxes

Carbon taxes are a popular option. Germany, Italy, Sweden, Norway and Finland among others have proposed or are seriously considering various forms of taxation to achieve GHG limitation (Pearce & Barbier 1991). The core of the coordinated European Community limitation strategy is the application of fiscal measures such as a revenue-neutral carbon/energy tax. The proposal calls for a tax of $46 per tonne carbon, which would generate 50 billion ECUs a year (Can$73 billion). The plan would still fall 1% short of attaining 1990 emissions levels by the year 2000. Three sets of modelling exercises have predicted convergent and generally positive results: measures will depress economic growth by only 0.05 to 0.1%; inflation might see a temporary increase of 0.3-0.5% per year; employment effects will be small; and aggregate effects on trade balance will be minimal (Sundt 1992b).

No mechanism is without problems, and some argue that carbon taxes have too many disadvantages. Elasticities of demand for different fuels, which will determine the outcomes of reduction in fuel use and generation of funds, are not well known ex ante; taxes on fuel tend to be regressive, costing poorer consumers relatively more; the tax will generate deadweight losses in overall social surplus which needs to be weighed against the advantages; and political resistance to new taxes can be expected (Pearce 1991).

Tradeable Permits

Tradeable permits are another popular option which have the feature of potentially helping to resolve concerns about developing countries' ability to finance GHG limitation programs. An example of this mechanism is detailed in a report prepared by the United Nations Conference on Trade and Development (UNCTAD) entitled "Trading Entitlements to Control Carbon Emissions: A Practical Way to Combat Global Warming" (Sundt 1992c). The fruit of eighteen months work, the report will present to the "Earth Summit" a proposed system of marketable emission permits which could be traded internationally. Under this system, entitlements would be issued to permit the emission of specific quantities and types of compounds. The entitlements would be allocated among the participating nations and could be traded internationally. Emission volumes allowed by the entitlements could later be reduced across-the-board, if necessary, to increase the effect on slowing climate change.

Facilitating markets with a scheme such as this has several advantages. It is potentially simple and efficient. The market as opposed to government sorts out the cheapest way to achieve a desired target (Helm 1990). As demand for entitlements increases, the price will increase, creating incentive for emitters to find alternate technologies or methods that pollute (and cost) less. Another advantage is that the system provides a means of shifting capital to developing countries through allocating them a greater share of entitlements than they initially need, and developed nations a smaller share.

Supply by government

The government supply of funding for large-scale reforestation has the merit of being perhaps one of the less experimental policy mechanisms. Canadian governments have financed and administered silviculture programs for the industrial timber harvest for many decades. Both direct government supply, and indirect supply by contracting-out services to the silviculture industry have been used. This mechanism of program implementation to a large extent has already been de-bugged in Canada, and will harbour fewer uncertainties or surprises.

Having discussed some aspects of Canada's international and domestic response strategy, as well as some potential policy options, the next step is to assess the adequacy of the current program in light of the threat of climate change.

SECTION 3 AN ANALYSIS OF CANADA'S STRATEGY

3.A Risk Management and Government Failures

3.A.1 Policy making under conditions of risk

The argument was made earlier that a risk averse global warming response strategy is the rational one. Since enforceable international agreements will not be accomplished in the near term, unilateral national action is needed. How do Canada's domestic programs measure up? Exploring the concepts of risk management further can help to answer this question.

Risk management is an essential aspect of global warming policy decisions. The government is faced with a choice between incurring social and economic costs associated with limiting greenhouse gas emissions in the present period, and incurring costs from climate change impacts in the future, which may be catastrophic or may be relatively benign.

The federal government risks making two types of errors when choosing its response strategy. A type I error is to incur the cost of taking action for something that does not happen. The risk averse approach is to chance making this error. A type II error is to incur the cost of failing to take action to prevent something that eventually does happen (Hengeveld 1991). Inaction is the risk taking approach. The risk neutral approach is the middle path of taking some initial lower-cost steps to retard the rate and scale of warming, while delaying substantive action until uncertainties are reduced. The government's decision will be influenced by its assessment of the probable costs of action and inaction.

The public good problem

Canada has clearly not adopted a risk averse strategy. This conclusion can be inferred from the government priorities expressed in its National Action Strategy which states that Canada "should recognize the importance of the international context. [This means] recognizing that taking certain actions out of step with other nations would have little impact and could jeopardize our competitive position internationally" (CCME 1990:iv). The argument for harmonizing Canadian limitation action with those of other nations is reiterated further in the NAS. "It must be recognized that some measures being examined could affect the competitiveness of Canadian businesses, particularly if Canada's major trading partners, including the United States, do not undertake similar actions. For this reason, policies or programs to reduce emissions must be developed through consultation with all interested parties, and must be sensitive to the policies and programs of our major trading partners" (CCME 1990:9). The public good problem has motivated the Canadian government to water down its response commitment with this emphasis on the protracted process of international agreement.

Instead, the route professed by the Canadian government could be described as risk neutral. The federal Green Plan commits to low-cost measures which reduce the risk of type II error, while keeping costs down to minimize the risk of type I error. It advocates actions that make economic sense (but have in the past been under produced due to the existence of externalities and to myopia), such as energy efficiency, tree planting, and the elimination of CFCs (Government of Canada 1990).

3.B The Effect of Government Failures

3.B.1 A critique of Canada's programs

Is the government living up to its own emission reduction commitments by putting in place the programs it advocates? Aside from efforts to eliminate CFCs, the actions needed to meet Canada's targets have not been forthcoming. Myopia, interest group pressures, and problems inherent in government bureaucracies explain the lack of effective programming.

Myopia

The Green Plan itself acknowledges that the actions set forth are not sufficient to achieve Canada's "first step" target, and recently a two-year delay in a portion of Green Plan funding was announced ("Budget gives Taxpayers a Break" 1992). Despite the government's commitment to the first step of stabilizing emissions of CO_2 and other greenhouse gases at 1990 levels by the year 2000, there is no quantification of how much of the required reduction will be accomplished by any of the initiatives in the Plan, and no standards or mandatory requirements were established (Comeau 1992). The Year I progress report issued by the federal government in 1991 (Government of Canada 1991), was not able to point to any specific progress toward achieving the emissions reduction target. The absence of any real measures suggests that the government is seeking to avoid the present costs of action and is under-valueing the future costs of inaction.

Interest group influence

Canada seems to remain committed to non-renewable and carbon-intensive activities. Budgets for conservation and renewable energy were cut by 81% since 1984, according to a brief released in 1988 by Friends of the Earth in Ottawa, and have not been re-instated. Meanwhile the federal government has financed a 25% stake in the Hibernia oil project in Newfoundland, totalling $2.7 billion in grants and loan guarantees. The total value of Green Plan initiatives for global warming, acid rain, ozone depletion and "international progress on the environment" is just $575 million in comparison. A number of recent government decisions are evidence of continuing provincial and federal support for mega-projects and for oil, gas and coal interests (Imada 1991).[14]

Critics of the federal government's strategy assert that the federal government has not taken the leadership role expected of them.[15] "Energy politics is hardball politics dominated by a handful of powerful industries and interests" (Bush 1990). In Canada government ministries tend to be, to some extent, co-opted by the industries that they were originally charged to regulate. Federal Ministers and their senior bureaucrats are critical elements of the federal government management team. Since surviving politically means building support, government decisions will give undue importance to the welfare of the individual industry stakeholders, at the expense of social efficiency.

Critics condemn the Green plan as being a charade, and assert that the scope and magnitude of policy, industrial and lifestyle changes that will be needed to accomplish Canada's targets, can not be put in place through the current process (Bennett 1992). Consulting with the interest groups composed of the emitting industries and their Ministries, and drafting plans based on the adjustments that they judge to be feasible will not lead to adequate change. Environmental groups insist the government needs to shift the question it poses industry interest groups and the public from *How much are you willing to do?* to *How will you deliver this required result?* (Imada 1992).

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[14]A coalition of environmental groups, CANet-Canada, representing more than 50 environmental groups across the country, had participated in drafting Canada's international positions on global warming through the Climate Change Convention Advisory Committee. In March 1991 CANet-Canada withdrew from the committee to protest the refusal of the Federal government to address their concerns about the lack of effective domestic climate change policies (Imada 1992).

[15] A study has revealed that Canadians are more likely to expect environmental leadership responsibility from the federal government than from any other entity including themselves, regardless of the actual allocation of jurisdiction on environmental matters (MacDonald 1991).

Changing the process requires political will. Ministries need to regulate, rather than defend industry. Policy decision-makers need to guard against being swayed by lobbying from recipients of the concentrated benefits (industry) and need to defend the inheritors of the diffuse costs (the public).

Problems with Bureaucratic supply

Greenhouse gas emissions result from activities in many aspects of Canadian life. Response policy in one sector or at one level of government will affect others and requires both cooperation and coordination. Moving ahead is a difficult challenge when the accepted and expected process involves extensive consultation and consensus-building before decisions are made. What happens if influential bureaucrats have opposing views on the urgency of global warming response? One can assume that the implementation of effective response policy will be impeded.

An example of conflicting attitudes was encountered while researching this paper. A senior bureaucrat in Forestry Canada, responsible to assist in formulating national policy recommendations on climate change, stated that global warming is not a real concern. He considers it simply to be a new platform enabling environmentalists to pressure for their favorite causes (Boulton 1992). Another status quo position is expounded in the lead article of a recent Forestry Canada publication, an interview with Forestry Canada researcher Doug Pollard. Pollard states that if models are correct, climate change is inevitable. But it should be addressed by adaptation rather than mitigation, he claims. He believes we should not change our planting programs, our protection infrastructure or our harvesting procedures. "Let's not get carried away with preserving the forest for carbon alone, there are many worthy uses of forests that can and should be incorporated into a forest-use strategy" (Blashill 1991:2).

By contrast Mr J.S. Maini, an Assistant Deputy Minister of Forestry Canada expresses a different view. In an article concerning the Forest Framework Convention he writes: "forest-related economic and environmental issues have recently emerged as a priority on the agenda of world leaders. This is because of the concern for and the need to....expand the global forest cover and forest biomass to increase the terrestrial carbon reservoir (by sequestering atmospheric CO_2) and to decrease the concentration of atmospheric greenhouse gases" (Maini 1991).

The result is low impact programs

The effect of these government failures is that adequate programs have not been formulated. An analysis of the Green Plan treeplanting program, one of the few concrete initiatives, is an instructive illustration. This program encompasses 325 million trees to be planted over seven years, beginning in 1992. How impressive is this really? Not very impressive. The program entails planting just over 46 million trees each year in all of Canada, or less than one-fifth of the number of trees planted in B.C. alone in 1990. The total area covered by the program will be 325,000 hectares over the seven years, or 46,000 hectares a year. In 1989, over 7 million hectares of forest were lost to wild fires alone (MacDonald 1991), 140 times the area that will be planted annually under this program. Each year the area that is harvested and not adequately regenerated by the forest industry averages 250,000 hectares according to Forestry Canada statistics (Canada. Forestry Canada 1990a). The Green Plan program will annually plant about one-quarter of the hectares in which we are losing productive forests each year by neglecting our industrial silviculture needs.

Matching donations from corporations must be attracted before this largely symbolic program can be accomplished. Only 20% of the estimated funding required, or $55 million, will be contributed by the government, some of which will be spent promoting and administering the program. The government is counting on receiving the remaining 80% from the private sector. The person responsible for carrying out the program for Forestry Canada admits that responses to an industry focus group process indicate that corporations "are sceptical, they think that global warming is a smoke-screen" (Gayle 1992).

3.B.2 Canada's global warming response strategy

In both the National Action Strategy framework document and the Green Plan the *stated* strategy of the Canadian government is to put in place low-cost initiatives to achieve our target of 1990 emissions levels by 2000, while negotiating internationally toward further actions. The actual strategy is different. The *actual* strategy is to postpone substantive action to limit emissions until international contracts are in place preventing other nations from free-riding on Canada's limitation investment.

In other words the government's domestic policy consists of choosing to risk a type II error, not taking action and risking the consequences of catastrophic climate change impacts. This is a risk taker strategy.

Uncertainties make this issue especially susceptible to government failures

Why do Canada's actions fall so far short of the actions being signalled? Part of the answer lies in the government failures described above. However, the nature of the problem makes effective policy more difficult to devise than with many policy issues. The global warming decision problem is of the type known as "wicked" since all outcomes from a given action and the state of the world are unknown, plus the relationship between a given action and its outcomes is unknown (Brumelle et al 1988). The complexity of a wicked decision problem tends to cause decision-makers to simplify the problem by focusing on dimensions of the problem which are most expedient, or those with which they have the greatest personal experience.

Two predominant dimensions seem to underlie decisions about global warming response. One is the cost of up-front investment in making changes now, which generate present social costs. The other is the uncertainty of future imports.

This simplification ignores the many other dimensions which may be difficult to include when modelling the problem. The social welfare losses from ecosystem damage, losses of species diversity, and other climate impacts may be difficult to quantify, yet are real costs. Policy makers have rarely addressed the intergenerational equity issues stemming from the fact that our generation benefits from delaying costly action today while the next generations face the future costs.[16] Aggregation of global damage estimates can obscure the regional social and economic damage impacts in sectors for which the net global impact may be minimal.[17] The social and

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[16] A discount rate is used in making investment decisions since, in principle, a person receives more utility for a dollar today than for a dollar in the future. But is it just to employ any discount rate in a cost/benefit decision about global warming when it's use implies that the risks to the future generation are to be given less weight than the benefits our generation receives now by avoiding the cost of mitigation? (Miller 1991).

[17]For example, decreases in agricultural production in the North American grain belts may be balanced by increases in the productivity of Siberian farmlands or areas covered by northern forests. Theoretically, climate change may globally have a low net impact on food production capacity. Regional impacts could be massive.

international security impacts of eco-refugees, populations which live on the margin and will not be able to adapt to adverse climate changes, are difficult to predict.

The difficulty of including all relevant dimensions to the problem decreases the efficiency of government response.

The complexities of the issue call for courageous leadership

Environmental responsiveness by the Canadian government is perceived favorably by voters. Notwithstanding this, the public has a hard time grasping the global warming issue and should not be counted on to drive the social and economic changes needed to reduce net GHG emissions. The problem goes beyond the complexity of the problem, to the lack of compelling incentives for individual lifestyle change. Leadership on the part of the federal government is needed for the sector by sector net emission reductions which must be made by individuals, organizations and other levels of government.

3.C A Change in Strategy is Rational

3.C.1 The government's cost-benefit assessment is flawed

In light of the public good problem and other impediments to adopting a risk averse or risk neutral strategy, why should the federal government change its current passive position? There are two strong sets of arguments for taking unilateral action now to limit GHG emissions, instead of relying solely on cooperative international agreements. 1. The net costs of action are less than presumed; and 2. The current passive strategy is increasing the risk of catastrophic future costs.

1. The net costs of action have been over-estimated

Two aspects of the cost of action are examined. One category is the actual economic cost of the action itself, net of the economic benefits. The other is the economic cost resulting from decreased trade competitiveness.

Cost of Investment

The Canadian government acknowledges in its Green Plan that a number of effective actions will bring benefits equal to or greater than costs. According to the third in a series of reports issued by the House of Commons Standing Committee on the Environment, "most members continue to believe that the Toronto target - a 20% reduction in 1988 emissions by the year 2005 - is feasible without disruptive effects on the Canadian economy or lifestyles. [A submission to the hearings asserted that] if Canada were to implement the most cost-effective measures to achieve the target, we would achieve a net benefit of $100 to $150 billion in energy saving alone" (MacDonald 1991:48,49). Northern Telecom is reputed to have invested $2 million in a new technology to replace the use of CFCs and to have gained a net savings of $150 million to date from using the new product.

Reforestation investments can also result in a positive return. A study reporting returns from managed plantations in the U.S., over the period from 1956 to 1984, concluded that timber investments realized higher real rates of return than financial investments (Thomson 1991).[18] Weyerhauser Canada has voluntarily invested in forest regeneration and captured returns that are similar to those from the U.S. plantations (Tolnai 1991). A Canadian study analyzes means for maximizing the net present value of repeated harvests of douglas fir forests. The data indicates that, using a 5% discount rate, silviculture investments can increase the site value, unless logging conditions or soil fertility are poor (Heaps 1985).

Admittedly, in many cases the investment takes a long time to generate returns. Taking a long-run view will result in a more accurate estimate of the true net costs of these potential actions and correct the problem of myopia.

Cost of trade competitiveness

The potential for trade losses is clearly considered to be a cost by the federal government. The government is concerned that GHG limitation measures will increase the cost of the products produced in Canada, and firms will lose business to international competitors. This could lead, in turn, to the potential outflow of investment capital and production if foreign firms pull out operations and close Canadian branches.

The cost of losing competitiveness, by taking stronger action than our trade partners, may be over-estimated. Losing competitiveness by burdening the economy with mitigation costs should only be considered a problem if Canada's major trade partners are doing less than Canada. This is not the case. The US, while it is unwilling to publicly agree to limitation targets, is actually taking more domestic action than Canada. The U.S.'s new Clean Air Act, which is expected to

[18] Mean returns during this period were: pine plantations - 5.62%, oak - 4.6%, gum - 5.1%, ash - 7.85% and standard financial market assets of common stocks (S&P) - 4.85%.

impose costs of $20 billion annually on the US economy when fully implemented (Gerelli, in Dornbusch & Poterba 1991); the "America the Beautiful" Program, which has the goal of protecting, maintaining and planting 1 billion trees per year over ten years; and the "National Conservancy" Program, which provided government incentives for land owners to convert, in 1990 alone, 422,000 acres of marginal agricultural lands to tree plantations (Winjum et al 1991), are examples of recent U.S. programs which will mitigate GHG emissions and provide other benefits.

Ambitious action relative to Canada's is planned by European Community trade partners (Pearce & Barbier 1991). Eight countries, including Australia and Germany, have proposed or committed themselves to domestic cuts of at least 20% (Imada 1991). The Netherlands, which discharges a modest 0.7% of global CO_2 emissions compared with Canada's 2%, has adopted a target comparable to Canada's stated target but is taking effective measures to achieve it. In fact the promised rate of reduction has been surpassed, and the Dutch government now expects to achieve emissions stabilization at 1989/90 levels by 1994/95, with potential for additional reductions of 5% by the year 2000 (MacDonald 1991). *Table 7* on the next page shows that Canada ranks 20th out of 23 countries in terms of its commitments to reduce net greenhouse gases.

Table 7 Estimated Decline in Greenhouse Index Scores from 1988 to 2005

Country	Decline in greenhouse gas emissions (percentage)[a]	International standing (1=best, 23=worst)
Australia	34.9	11
Austria	46.5	3
Belgium	34.7	12
Canada	19.8	20
Denmark	43.4	6
Finland	28.2	15
France	44.5	5
Greece	42.4	7
Iceland	20.1	19
Ireland	33.2	13
Italy	43.4	8
Japan	26.0	16
Luxembourg	19.6	21
Netherlands	37.6	10
New Zealand	26.8	17
Norway	8.5	22
Portugal	57.4	1
Spain	48.3	2
Sweden	25.6	18
Switzerland	43.6	9
United Kingdom	33.2	14
United States	5.1	23
West Germany	45.8	4

Source: Adapted from (Hammond et al 1991:15)

a. Based on planned stabilization, decreases, or increases in greenhouse emissions and total recycling of CFC-11 and CFC-12 in 2005.

Most of the other countries are undertaking more significant adjustment than Canada. Not only are their commitments to reduction greater, but their per capita emissions are lower to begin with so reduction will on the margin be more costly to achieve.

Benefits to trade competitiveness, due to innovations emerging from response action, may be under-estimated in the cost calculations. Economist Michael Porter asserts that implementing strong environmental standards is a smart national competitive strategy (Porter 1991). In the

National Action Strategy, the Committee of Deputy Ministers of Energy and Environment confirm the view that taking action can produce benefits of increased national competitive advantage in various technologies developed to meet net emission targets. There can be no doubt that there will be a global market in the future for processes and technologies that can be applied to the GHG limitation problem. Once again, this requires taking a longer view of investment pay-back than is typical in either government or private firms.

2. Canada's current strategy is increasing the risk of catastrophe

The probability of catastrophic type II error (not taking action to prevent something that eventually does happen) is dynamic, rather than fixed. The risk of high damage costs from global warming is not independent of the government's choice of strategy, but increases in opposite proportion to the scale and immediacy of limitation actions. By adopting the strategy of delaying domestic GHG limitation action until international contracts are in place, Canada is daily worsening its own chance of the no-action gamble paying off.

Time is against us

The risk of catastrophe increases as response is delayed. Over time, the scientific uncertainties will be reduced and the decision problem will become less "wicked". Time is not available. Climatologists admit that it could take several decades before regional climate modelling is relatively accurate. Policy development and implementation is also a lengthy process, especially at the international level. In the meantime, atmospheric GHG concentrations are increasing each year, and as Canada delays, a given mitigation action will have less effect on the eventual equilibrium temperature than if it had been taken earlier.

Developing nations are watching

The actions of the industrialized nations will have a large impact on the cooperation of developing countries. Without this cooperation, total greenhouse gas reductions will be lower and the risk of future catastrophe higher. The developing nations' share of CO_2 emissions from fossil fuel combustion is projected to rise from 25% today to 44% by 2025 (Boyle & Ardill 1988). Since they account for the largest growth in projected CO_2 emissions, their commitment to limitation is especially important to achieving global reductions. Low-income nations are being asked by industrialized nations, which have contributed the bulk of the fossil fuel related GHG emissions over the past century while building their economies, to forego opportunities to follow the same development route. Can poorer nations be expected to sacrifice when richer nations with the most wasteful energy practices are stingy with commitments to respond to the problem? Probably not.

Internationally, Canada is expected to reduce energy use, to reduce carbon intensity of energy choices, and to increase CO_2 sinks through aggressive reforestation programs, according to the Canadian Climate Program Board (Canada. Environment Canada 1991a). Presently we are followers rather than leaders on many fronts including energy efficiency, auto emission controls, renewable energy technologies, and maintaining forest area. Our former international reputation on environmental issues is threatened by our apparent reluctance to act on CO_2 emissions.

Canada's decision to continue in its passive stance will have a negative psychological impact on nations from the Group of 77, and will further entrench the gap between the positions of developed and developing nations. As a result more time will elapse before agreements are achieved, and lower levels of action will be promised by developing nations. Canada's inaction will thus have a multiplier effect, beyond its 2% share of emissions, toward increasing the risk of high climate warming damage costs. Taking action will restore moral leadership, elicit cooperation and reduce the risk of catastrophe.

3.C.2 Precedent exists for investing in an international "public good"

Three generic bases for government policy decisions are logic, sociological impact and historic precedent. The argument for a change in global warming response policy that was made in the previous section was based on logic. Many persuasive arguments have been put forward that are based on sociological impact. For example political leaders, scientists and policy-makers at the 1988 Toronto Conference issued a statement that global warming is a threat "whose ultimate consequence could be second only to a global nuclear war" (Imada 1991). The threat of nuclear war has been reduced considerably over the past few years. The threat of global warming continues to mount.

Historical precedent also provides a good rationale for Canadians to unilaterally implement policies pursuant to GHG limitation targets. As mentioned earlier, other nations have adopted ambitious global warming response policies and create a precedent for Canadian domestic action. Canada's foreign aid program is another precedent for investing in an external public good. Despite the absence of contractual obligation, Canadian dollars are used to assist in the development of poorer nations. The external benefits are deemed sufficient to justify allocation of collective resources where market mechanisms, in the form of private donations, fail.

3.D Canada Must Adopt a Risk Averse Strategy

3.D.1 Summary of the arguments

This paper has argued that market failures distort the efficient level of production of greenhouse gases. Although the future costs of irreversible climate change are uncertain, a general consensus exists that a risk averse response by governments is warranted. Because of the public good aspect of limitation action, Canada is deferring substantial action until international agreements are in place. The minimal actions that the government has declared will be taken are in fact not being pursued for a number of reasons, the primary one being myopia. This means Canada is following a risk taker course. There are compelling reasons for the government to adopt a new strategy, and to take action to realize its emission reduction targets. A number of social and political external benefits will accompany this new position.

3.D.2 Moral leadership is needed to mobilize international action

Game theory can be used to symbolize the proposed change in Canada's strategy. Game theory is applicable to the actions of entities that are conscious their actions affect each other (Rasmusen 1990). The global warming response decision falls into the category of non-cooperative games. For the purpose of simplification, the "game" is described here as a one-off game between two players, although the global warming response is in reality a repeated game with many players.

Current strategy

To understand Canada's current response strategy, consider a simple two-person game, the Prisoners Dilemma, in which Canada is one player and other nations (O.N.) are the other player. According to the rules of this game each of the players can adopt one of two strategies, action or no action. The ranking of outcomes of the players' actions in this game are shown in *Figure 2* on the following page.

Payoff to (Canada, other nations) 3=best outcome; 0=worst outcome

	O.N. takes no action	O.N. takes action
Canada takes no action	1,1	3,0
Canada takes action	0,3	2,2

Figure 2 The Prisoners Dilemma

Since the risk of losing relative competitiveness is seen to be high, the worst outcome for a player is the one in which the player takes action and the other player does not. Conversely, the best outcome is to profit from the other's loss of trade competitiveness resulting from taking action, while not taking action oneself. If neither take action, the outcomes are equal for both. This has a lower pay-off than if both parties take action. In the case where both take action, there is no relative change in competitiveness, and environmental risk is reduced. Canada's current strategy is inaction. The dilemma arises that - while both players acting is the optimal outcome (SE cell) - inaction is the dominant Canadian strategy inasmuch as it improves Canada's position relative to the other player. This is only true, of course, if the other player's strategy is independent of Canada's, and the player does not respond "tit-for-tat".

Recommended strategy

The rules of the game are not as shown above if the relative costs and risks of action and inaction are revised according to the arguments that have been presented previously. If the costs of trade competitiveness are lower and the risk of catastrophic costs from inaction are higher, then Canada is involved in an assurance game, whose outcomes are shown in *Figure 3* below.

Payoff to (Canada, other nations.) 3=best outcome; 0=worst outcome

	O.N. takes no action	O.N. takes action
Canada takes no action	0,0	2,1
Canada takes action	1,2	3,3

Figure 3 Global Warming Response Game

In this game, there is still some disadvantage in terms of national competitiveness from taking action if the other player does not, as shown by the payoffs in the NE and SW cells. Since the risk of inaction is recognized to be more serious than it is in the previous game, the worst payoff results if neither player takes action. The logical outcome in this game is the SE cell. To obtain this outcome, a player chooses and signals its strategy of taking action to limit global warming, which encourages the other player to make the rational decision to follow suit so that both are winners.

A key benefit from taking action is the international "moral status" that will result. A practical, high-profile program that Canada can undertake is a large-scale reforestation program. Investing in a "carbon bank" will produce ongoing dividends. To fully capture the political value, the government will need to identify creative ways to signal these efforts to its citizens and to the international community. An annual accounting of the CO_2 mitigation achieved by the newly planted trees will reinforce this moral leadership.

SECTION 4 RATIONALE FOR CARBON SINK SILVICULTURE

4.A Silviculture is a Practical Emphasis for Canada

4.A.1 International consensus supports reforestation programming

The previous section argues that Canada should change its present strategy and implement effective and measurable policies to achieve its limitation targets. Achieving the targets will require action on many fronts, both in reducing the emission sources, and in protecting and increasing carbon sinks. Response programs will not be simple to design. Large-scale reforestation is no exception. However, increasing the CO_2 absorption capacity of the forest carbon sink does compare favorably with many other options for decreasing net emissions.

This section narrows the analysis of global warming to the response option involving the forest sector. A Canadian large-scale silviculture effort is argued to be an internationally favored, immediately implementable, attractive interim measure. Silviculture, which includes reforestation and other forest treatments, can buy time and minimize future loss of choice while providing valuable external benefits.

Silviculture meets multiple objectives

The IPCC Response Strategy Group identified the following seven criteria as being important components of the most effective potential response strategies, especially in the short-term (IPCC 1990c):

1. Beneficial for reasons other than climate change and justifiable in their own right. (better management of forests is given as an example of this).
2. Economically efficient and cost effective, in particular those using market-based mechanisms.
3. Able to serve multiple social, economic and environmental purposes.
4. Flexible and phased, so that they can be easily modified to respond to increased understanding of scientific, technological and economic aspects of climate change.
5. Compatible with economic growth and the concept of sustainable development.
6. Administratively practical and effective in terms of application, monitoring, and enforcement.

7. Reflects the obligation of both industrialized and developing countries in addressing this issue, while recognizing the special needs of developing countries, in particular in the areas of financing and technology.

With careful planning, large-scale silviculture is one of the global warming limitation programs that satisfies all of the criteria.

This view is confirmed by an economic analysis of seven possible international treaty initiatives (Chapman & Drennen 1990). The study proposes three principal criteria - effectiveness, equity and economic feasibility - to evaluate the potential climate change initiatives. The initiative which best meets the criteria is the one which includes the following features: 1. Developing country incomes increase and populations decline; 2. Energy taxation is implemented; and 3. Ten million acres are reforested annually.

Large-scale reforestation is considered to be feasible

Support for reforestation to increase the absorptive and storage capacity of terrestrial biomass sinks can be found throughout global warming literature. A massive reforestation program, that could remove the total volume of excess CO_2 produced globally, is considered to be physically possible. Finding sufficient areas of suitable land would be a challenge but not unattainable. The program would require a doubling of the present annual growth increment of forests through a 465 million hectare combination of new forests and intensive management of existing forests (Marland 1988).

The U.S. Environmental Protection Agency (EPA) is completing a $10 million, two year study to assess large-scale reforestation as a global warming response. EPA policy analysts are recommending to U.S. policy-makers that massive reforestation is a cost-effective alternative which should definitely "take its place at the table" (Winjum 1992). *Table 8* on the next page shows estimates, generated by a study commissioned by the U.S. government, of the marginal and average cost of reforestation programs to sequester a range from 5% to 30% of annual U.S. emissions.

Table 8 **Increasing Marginal Costs of Reforestation**

Annual U.S. CO_2 offset	Land area (10^6 hectares)	Total annual cost (US$$10^9$)	Marginal cost / short ton C ($)[a]	Average cost per short ton C ($)[a]
5%	36.9	0.7	n.a.	9.72
10%	70.9	1.7	16.9	12.02
20%	138.4	4.5	20.9	15.73
30%	197.6	7.7	23.6	17.91

Source: (Moulton & Richards 1990:42)

[a] One short ton equals .907 metric tonnes.

Within Canadian policy response documents the need to stop tropical deforestation and begin a global reforestation effort is also generally accepted (MacDonald 1991). Appendix 3 summarizes recommendations by the House of Commons Standing Committee on the Environment and by the National Action Strategy, with respect to reforestation.

As trees mature, the rate of carbon sequestration declines. Some writers have expressed the concern that in time these trees will die and release stored carbon back into the atmosphere (Green 1991). They claim that in order to continue indefinite carbon sequestration, mature trees will need to be harvested and plantations replaced. The volume of timber being produced could depress product prices and discourage treeplanting and forest management elsewhere. However, the increased wood supply need not enter the market as timber, but could be used to fuel power plants or be converted into liquid fuels.[19]

The plantations need not all be harvested. The mature forests will have sequestered carbon at peak rates for a number of decades, thus buying time for the implementation of other solutions. Mature forests also store much more carbon in the soil than younger plantations, which will at least partially offset the net decrease in biomass carbon storage as the forest matures (Harmon et al 1990).

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[19] Methanol and ethanol (liquid fuels from tree crops) produce relatively small quantities of CO_2 when burned. Further, technology for producing liquid fuels is well developed. A main impediment to their widespread use is raw material price (Prins & Roberts 1990).

4.A.2 Large scale silviculture builds on Canadian strengths

Canada, more than most countries, is ideally suited to undertake carbon sink silviculture as an initial global warming response. The technology and logistical expertise to begin large scale forestry are already in place. In some other sectors GHG limitation action will need to be implemented more gradually in order to avoid the potential efficiency losses from the obsolescence of large stocks of productive plant and equipment, and from industry adjustment.

A brief overview of the silviculture industry

The silviculture industry provides services to replace and improve forests, for government and forest industry clients. Close to one million hectares of land are logged each year in Canada, yielding close to 200 million cubic meters of logs. Between 60% and 70% of the logged areas are expected to regenerate naturally and 5% are seeded directly. The remaining 25 - 35% of the logged area is planted with nursery-grown seedlings. Some sites receive further silviculture treatment such as site preparation, regeneration, weeding, and stand tending. Appendix 4 shows the various operational activities in each of the four categories of silviculture, and the desired impacts on the forest of each type of activity. The 1988 demand for Canadian silviculture services was estimated to be $705 million, not including the clients' internal costs of administering silviculture projects, nor the cost of tree seedlings (Canada. Forestry Canada 1990a).

Over 90% of Canadian forest lands are publicly owned. Managing Canada's public forests sustainably has not always been a priority due to controversy about who should be responsible, the landlords or the tenants. Silviculture regulations allocating this responsibility are still not fully adequate. Over the past two decades, pressure from the Canadian public has increased government commitment to improve its record for sustainable regeneration and tending in the forests. Provincial governments are beginning to enact legislation requiring the forest industry to be responsible for establishing a free-growing plantation on areas harvested, rather than simply to administer government funds for planting trees as under the former property rights arrangements.[20] This has improved the quality of recent plantations in some provinces.

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[20] Legislation was enacted in New Brunswick and Saskatchewan in 1985, B.C. in 1987, Quebec in 1989 and Alberta in 1991.

Public pressure also resulted in massive increases in demand for silviculture services, which peaked in 1990. This demand contributed to the development of today's relatively strong and competitive silviculture industry. The silviculture industry was in its infancy twenty-five years ago. Today it is maturing and is capable of planting and managing close to one billion seedlings each year on private and public forest lands.

Silviculture program diagnosis, design and administration are the province of forest professionals and technicians, of whom there are an estimated 10,000 working in Canada, full-time or partly occupied with silviculture management (Brinkman 1991). They are educated in world-class institutions in forestry, biology, botany, ecology, soils and other related sciences. Field training and experience levels are extensive. Foresters work for government, forest industry firms, educational and research institutes, and consulting firms.

Silviculture programs are primarily delivered by over 1,000 contracting firms which employ approximately 50,000 silviculture workers, many on a seasonal basis. While about half of the work is performed by student labor, there is a large component of productive career silviculture workers who return to the field each year. The established contractors, their office and project staff, and a large portion of the labour force have built up a considerable base of valuable experience and knowledge.

The silviculture industry "diamond"

Economist Michael Porter has developed a paradigm to explain national competitive advantage, the "Diamond of National Advantage" (Porter 1991). Porter's model adds dynamic facets to the static facets that underpin traditional explanations based on David Riccardo's theories of comparative advantage. The diamond consists of six interconnected determinants of national advantage: factor conditions, demand conditions, related and supporting industries, firm strategy, structure and rivalry, government policy and chance events. The national silviculture diamond can be used to assess whether Canada provides an environment that can support high and rising levels of productivity in its silviculture industry. A strong, dynamic industry will enable Canada realistically to expand its silviculture program to include large-scale CO_2 sink projects.

Factor conditions - Strength

The primary factor in silviculture, human resources, is a strength. Labor is provided by dedicated seasonal and full-time workers who have acquired the necessary skills. Projects are managed and supervised by knowledgeable contractors and staff, and programs are designed and administered by professionals with advanced and specialized training. Provincial government/industry partnerships to coordinate training and skills-upgrade programs are being developed in several provinces. Incremental training is available from the level of the field worker to the professional silviculturist.

Related and Supporting Industries - Strength

Canadian firms have developed innovative products and processes that compare favorably with those of other forest nations. Forestry research is strongly supported by Forestry Canada and forest industry firms. Industry clusters are particularly strong in B.C. and Quebec. Clusters include the seedling nursery industry and its suppliers, and the silviculture equipment industry which supplies seedling transport equipment, tools for planting and plantation tending, and mobile camp facilities. Capacity in the seedling nursery industry is close to double current production and could easily accomodate a major expansion (Brinkman 1992). One area of weakness is in the domestic design and development of equipment for weeding and stand-tending activities. As funding for this segment increases, Canadian equipment suppliers can be expected to emerge.

Demand conditions - Mixed

The volume of silviculture demanded to sustain the Canadian forest harvest is relatively high. Despite this, demand conditions for silviculture have not been sophisticated, primarily due to the past absence of accountability for plantation performance. Responsibility to achieve free-growing plantations, coupled with budgetary pressures, are combining to increase sophistication of demand. Suppliers are now expected to add value and produce higher quality, which is leading to higher plantation survival rates. The demand for forest enhancement services, which was weak previously, is starting to increase in conjunction with concerns about the sustainability of harvest levels. On the down-side, the quantity of reforestation demanded has decreased during the past few years due to government budget deficits, forest industry financial losses and recent weakening of public pressure. This may increase prices as scale economies are lost.

Firm Strategy, Structure and Rivalry - Improving

The silviculture industry is fragmented with low barriers to entry and exit. The isolated locations and short time-frames of field projects mean that it is very difficult to monitor contractor compliance with employment standards and health, safety and transportation regulations. Past difficulties in ensuring compliance have led to the perpetuation of a segment of industry firms that prosper, despite irresponsible and unprofessional practices.

Government intervention in the form of regulations requiring "low-bid auctions", has contributed to industry weakness.[21] Competition from fly-by-night operators has reduced the resources available to legitimate firms for investing in research and innovation. This weakness is beginning to improve as governments assign responsibility for plantation results to the forest industry. As supplier-buyer relationships are enabled to develop unimpeded, contractor reputation is becoming a larger factor in buyer decision making. This is strengthening responsible firms.

Government - mixed

Landlords of the forests, provincial governments are a key factor affecting the silviculture industry. Until recently government ministries were the main buyer for silviculture and even today, government regulation requiring industry to reforest harvested sites determines demand. The aggregate volume of silviculture required by governments is a strength, but the instability of funding commitments is a weakness. Silviculture budgets tend to fluctuate yearly. Five-year plans are loudly announced and quietly reduced in size. The demand uncertainties diminish confidence and serve to destabilize the industry. For example, in Ontario where the harvest/regeneration gap is admitted to be large and increasing, the Ministry of Natural Resources has recently slashed its 1992 program by 30 million seedlings. The Ministry plans to give away or destroy the seedlings since the budget for planting them was eliminated. The advent of a carbon sink silviculture program with stable funding will improve the problem of demand uncertainty.

Chance - strength

The chance determinant is probably the most important of all. Canada's abundance of inherited forests supports the existence of a gigantic forest industry and its silviculture suppliers.

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21 In 1991 the Canadian Silviculture Association presented provincial governments with a paper outlining the damage that this interference in buyer/supplier relationships has caused to the regeneration segment of the industry by favoring firms which underestimate costs and deliver services of marginal quality. The paper makes a case for avoiding this pitfall in the younger and growing market for forest enhancement services.

The Canadian silviculture industry can handle a large carbon sink program

This assessment of Canada's national silviculture diamond supports the assertion that the infrastructure is in place to effectively undertake a large carbon sink program. The sheer size of Canada's forest products sector means the silviculture industry is strong relative to many other nations. Silviculture programs in Canada are achieving ever higher plantation survival rates at declining costs per hectare, despite some industry weaknesses. High-profile international negotiations for environmentally sustainable forestry and climate change response should heighten government commitment to silviculture, and reduce the obstacles to industry stability.

4.B Silviculture Produces a Variety of External Benefits

4.B.1 Silviculture provides economic benefits

A carbon sink silviculture program will produce direct economic benefits for components of the program targeted to growing commercial crop forests, which should be deducted from cost estimates of this alternative for reducing net greenhouse gas emissions. The positive effect of increasing timber supply for the forest industry is particularly important in light of current declines in supply.

Forestry is Canada's primary industry

Forestry has paramount importance as the largest industrial sector in Canada. There is a huge investment in productive capital infrastructure which risks being lost if the industry declines through a reduction of its raw material supply. In 1987 forestry was a $44.3 billion industry providing one job in fifteen, and was the mainstay of 350 towns (Government of Canada 1990). Canada accounts for 21% of total world trade in forestry, with the industry producing a trade surplus of approximately $20 billion each year (MacDonald 1991).

The Canadian nation was built on rents obtained by exploiting the forests. Historically Canadians have had a national competitive advantage from the abundance and low price of timber and pulp supply. Observers claim that government and the forest industry have failed to upgrade the conditions needed for sustainable industry competitiveness. This has led to diminishing competitive advantage. We are still leaning on a now-diminishing advantage in the basic supply input (Porter 1991). How secure are these timber supplies?

Increased timber supply is needed

Timber supplies are not very secure. Federal government assessment of the future timber supply in Canada concludes that there is very little potential for industry expansion in softwoods unless some action is taken to increase growth or to improve industry ability to generate returns on currently non-economic timber stands (Runyon 1991). The 1991 timber supply assessment concludes that 20% of the current harvest is not being adequately regenerated, either naturally or artificially, and consequently the backlog of not satisfactorily regenerated (NSR) areas is increasing.

A different analysis concludes that timber supply will decrease in the future without effective forest management since sustained yield calculations have in the past not accounted for the "fall-down effect"[22](Wernerheim 1986). The study claims that, given current levels of silviculture, future harvest levels are threatened by three other factors. First, the allowable cut has been based on the total quantity of legally available timber, and has not adequately distinguished the economically recoverable volume from volume where the cost of harvest is greater than the price. Second, the available timber supply will be reduced by withdrawals of forest land base from industrial forestry to other uses such as parks, residential and industrial developments, watersheds, environmentally sensitive areas, roads, agriculture and grazing lands. With the current controversy over public forest land use, the area withdrawn for park and "heritage" protection can be expected to increase. Withdrawals also occur by default when areas revert to a non-productive state through inadequate regeneration of harvests and wild fires. Third, the effects of air pollution will reduce forest growth rates and health. Air pollution is being cited as the main stress factor causing coniferous forests in Ontario and Quebec to be growing only one-third as fast today as they did three or four decades ago.

The potential negative effect of climate change on timber supply is an additional factor to the ones mentioned in the study. Large tracts of boreal forest will be lost when the migration of climatic zones increases the incidences of fires, pests and diseases. A forestry Canada study predicts that the hotter drier summers expected at $2xCO_2$ concentrations will lead to a 5% to 45% increase in burned forest area in Canada (Flannigan & Van Wagner 1989). This calculation is conservative

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22 The fall-down effect is the term coined to describe the decrease in available timber volume that will result when first-growth forests have been consumed. The future yield per hectare from second-growth forests will be less.

since it takes into account greater fire control effort, but not the possibility of longer fire risk seasons.[23]

Given these threats to timber supply and the basic economic well-being of Canadians, the forestry profession holds the view that intensive forest management is the most promising way to protect timber supply compared other alternatives, including improved utilization standards, greater protection from fire and pest losses, and harvesting of more remote stands. There is far more need for forest investment than there are funds allocated for this purpose in Canada (Wernerheim 1986). Carbon sink silviculture could fill the gap.

Other commercial forest products will provide economic benefits

The silviculture program could incorporate projects which provide bio-fuel feedstock for power plants and transportation. If the program were to include projects in developing countries, other commercial products could produce direct economic benefits to the local community in addition to the CO_2 sequestration benefits. These options will be elaborated in a later section of the paper.

A stronger silviculture industry will lead to trade gains

The potential trade benefits from a silviculture program should not be overlooked when estimating the net costs of global warming response actions. We can be relatively confident that international concern about global warming and sustainable natural resource use will lead to a major increase in forest regeneration commitments world-wide. This will mean a rapid increase in demand for silviculture expertise and services. While the labor component of silviculture is available wherever a program is undertaken, other components are not. High experience components of a silviculture program include expertise in diagnosing silviculture requirements, designing programs and projects, building nursery capacity, and supplying training and systems for the delivery of services. Canada excels in these areas and can become a silviculture services exporter. Native ecosystem expertise will be an important local complement to the expert services Canada can provide.

Canada's silviculture industry competitive advantage will improve as a result of the learning and experience provided by a large-scale CO_2 silviculture program supplied indirectly through the

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[23] The national burned area has already increased more than 50% since 1970. The connection between this statistic and global warming has not been made with certainty, but deserves attention (Flannigan & Van Wagner 1989).

industry. The challenge of accomplishing a part of this program in developing countries with deforestation problems will directly increase industry export experience and confidence. Increasing overall trade volume, as well as increasing the comparative advantage of silviculture exports, will be economically beneficial to Canada.

4.B.2 Other social benefits from silviculture

The social value derived from other benefits should be recognized by the federal government in its assessment of net costs of greenhouse gas limitation programs. *Figure 4* below lists some of these positive externalities.

Forest Benefits

- wildlife habitat and food
- wildlife diversity
- catch/harvest per hectare
- soil and water conservation
- flood control
- air quality
- CO_2 absorption
- recreation use and environmental amenities
  - aesthetic values
  - recreation value
  - vegetative diversity
- existence (vicarious, bequest and stewardship) values
- option values

Investment / Activity Benefits

- employment
- economic multiplier effects
- R&D and technology development
- skill development
- economic resilience (eg. strategic options)
- community stability
- distributional aspects (eg. regional equity)

Figure 4 Benefit Dimensions
Source: Adapted from (Brumelle at al 1988)

Evaluating non-timber benefits of forests

How can values be established for non-consumption benefits? Quantitative values would help to ensure these external benefits are included in cost-benefit analysis. Some can be quantified while others, such as economic resilience, distributional aspects and employment, are more difficult to pin down. Economists are beginning to agree on some methods for monetizing these values. A useful method is surveying the community's "willingness-to-pay" (WTP) for them. Non-consumption values can be grouped into use value and intrinsic, or preservation value. Studies show that WTP procedures arrive at estimates of amenity worth that are not significantly different from results using other methods for valuing non-market goods (Pearce & Turner 1990, Gunton 1991). Studies which generate base-line data unique to Canada are needed, since estimations of these values are at present largely based on U.S. studies.

The Stein Valley in British Columbia is an example of a wilderness area for which non-consumption benefits have been calculated, for the purpose of comparing logging and no-logging options for the valley. The cost-benefit analysis arrived at net present values (NPV) for the no-harvest option ranging from $1 million to $6.9 million depending on the discount rate used, lumber prices and other assumptions. The logging option produced a NPV range from -$11.5 million to $1.8 million using the same set of assumptions. The author points out that the range of values for the wilderness option is smaller than for the logging option. This suggests that uncertainties in measuring intangible values can be lower than for so-called tangible values (Gunton 1991).

Commercial plantations will also generate non-consumption benefits, and will in many cases be more accessible for recreation than will non-commercial plantations to restore park reserves and wilderness burned by wild fires.

4.B.3 The benefits will translate into political gains

In choosing its global warming response strategy, the federal government needs to consider political as well as efficiency criteria. The policies chosen will have an impact on the government's standing in the eyes of the Canadian public and industry, and will affect electability. Policies will also have an impact of Canada's standing in the international community and this affects diplomatic relations, credibility and investment attractiveness. The improved "moral status" generated by carbon sink silviculture will be a valuable gain.

Domestic political benefits

There are two main domestic political "wins" in a large scale silviculture program. Individuals will approve. The Canadian public is concerned that their forests are not being managed in an environmentally sustainable manner. *Figure 5* shows some of the responses to a survey, funded by Forestry Canada, which suggest that a significant increase in silviculture would be politically advantageous.

The environment is now threatened by the forest industry:		
	strongly agree	39%
	somewhat agree	33%
	somewhat disagree	18%
	strongly disagree	6%
What is the most important use of Canadian forests?:		
	wildlife protection	27%
	wilderness preservation	25%
	logging	12%
	tourism & recreation	6%
What is the most important consideration in land use decisions?:		
	potential environmental impact	63%
	potential economic value	11%
	potential job creation	9%

Figure 5 Public Opinion Survey
Source: Adapted from (Environics et al 1989)

Since this survey, employment and the economy have increased in importance as factors in land use decisions. Large-scale silviculture programming will reassure the public that their concerns about the forest environment are being addressed, while also enhancing opportunities for forestry-related employment. Global warming is not just a technical problem, it is a "people problem". A positive feature of a large silviculture program is its potential high profile and its visibility. Canadians will be alerted to the greenhouse gas emissions problem, the urgency to act on it and more importantly, the possibility of individually contributing to the solution. Educating the public about the issue will lead to greater support for other measures that the government will be taking, which might not in themselves be as popular.

The other domestic political benefit is that industry will also approve. Regardless of the proportion of the new silviculture program targeted to increasing the commercial forest base, increasing forest area will have the effect of decreasing the pressures on this base. This means that the initiative will be supported by the powerful industry interest group, unlike many potential GHG mitigation programs in the energy sector, which are strongly resisted by industry. The political benefit of avoiding this kind of conflict should not be under-estimated.

International political benefits

Taking an active global warming prevention strategy will, in itself, win political points for Canada. The focus on large-scale silviculture will bring further benefits. Right now our reputation for sound forest management is under siege in the international community. The Duke of Edinburgh visited B.C.in March 1992, in response to European press concerning a devastating "Chain Saw Massacre" in Canada's temperate rainforest.

Whether or not this criticism is valid, the effect on Canada's credibility is negative. European buyers of our forest product exports are being pressured to consider a boycott in protest of Canada's unsustainable forestry practices. While some might argue that this kind of action is motivated by European protectionism of its own forest product industry, the truth is probably a combination of the two. Whatever the motivation, a European boycott would be especially damaging when Canadian producers are trying to diversify from their reliance on the U.S. market, now threatened by ongoing lumber trade disputes.

The large-scale reforestation program will re-establish our reputation internationally as a forest resource leader in management practices, as well as in products. The spin-off benefits from modelling environmentally sustainable forestry will be plentiful.

SECTION 5. CARBON SINK SILVICULTURE DESIGN PROPOSAL

5.A An Outline of the Silviculture Proposal

5.A.1 The Purpose of the Proposal

The purpose of this section is to take the somewhat theoretical recommendation, that Canada undertakes carbon sink silviculture on a large-scale, and to put forward a proposal for realizing this program. While prior studies have raised or resolved some of the issues, none have developed a design blueprint. Canada's inherent opportunities and problems are its own, and Canadians will need to invent their own program. The variables involved are multiple and sometimes conflicting. They need to be organized coherently and the program designed carefully for maximum effectiveness. This proposal aims to assist in that process by providing a decision outline that could be used to build a program which will:

1. *Accomplish a clearly-defined portion of Canada's net CO_2 limitation targets* by employing benchmarks for the selection of a particular program size;
2. *Address the failure of markets to include non-product values of forests, and reduce the problems of government myopia, interest group pressures and inter-jurisdictional conflict* by clarifying some program principles;
3. *Maximize potential benefits while avoiding potential shortages in the required resources and capabilities* by identifying goals and constraints and using them as evaluation criteria;
4. *Ensure an optimal choice of program segments* by identifying the basic elements about which critical decisions are sometimes implicitly made in the evaluation of alternatives; and
5. *Increase the program's effectiveness* by outlining some implementation hurdles which could diminish the program's success if not adequately incorporated into the planning.

5.A.2 Organizing diffuse information into a coherent structure

How can the program designer draw on information that is already available? Studies of reforestation feasibility appear to fall into three categories. One category is global level analysis, based on "back-of-the envelope" estimates of land availability, growth rates and planting costs in various climate regions. Global level studies conclude that reforestation is a practical way to significantly reduce net global CO_2 emissions, and falls within the cost range of alternative global warming response options (Marland 1988).

The second kind is national level analysis, which explores the availability of various land types in a particular country, and the cost and net carbon gain of silviculture programs tailored to these areas. These studies produce conclusions about the relative feasibility and attractiveness of potential silviculture program options in a particular country (Moulton & Richards 1990, Nagle 1990). Relatively few studies have focused analysis at the national level.

The third category is project-level analysis focusing on narrower, technical issues. This kind of study compares the relative advantages of different site classes, species mixes and silvicultural treatments at the stand level (Peer et al 1991), or compares specific reforestation programs with other means of reducing net CO_2 emissions (Kraus & Koomey 1989). "Front-of-the envelope" forest carbon budget analysis is emerging (Apps & Kurtz 1991). Ideally this will be combined with forest stand management models aimed at maximizing timber growth and return on investment, and used to improve plantation carbon storage. Project-level analysis attempts to fine-tune scientific and silvicultural understanding in order to better inform national level analysis and program design. Some studies attempt to combine several levels of analysis (Dixon et al 1991).

All three levels of analysis are in their infancy since carbon management is a recent forest management concern, and large-scale reforestation for CO_2 mitigation is a recent policy issue. This proposal aims to provide a structure for organizing both national and site level analysis, within the context of some guiding principles and objectives.

Weaknesses in current analysis

Incomplete data

Incomplete data for inputs at each of the levels of analysis is a shortcoming, making comparisons very difficult (Andrasko et al 1991). Forest inventory data especially is inadequate in quantity, quality and accessibility. The attractiveness of large-scale silviculture programming as a global warming response will increase the momentum for more sophisticated and more complete analysis at the national and site levels.

Exclusion of direct economic benefits from program cost calculations

Analysis has centered on cost projections compared with carbon sink benefits. The value of marketable benefits and other external benefits have not been quantitatively included to arrive at net costs. This mirrors the failure of markets which under-value investments with long pay-offs, and neglect to internalize non-consumption benefits of forests. These benefits need to be accounted so that the segments chosen to be part of a large silviculture program achieve maximum overall efficiency from a social perspective.

Oversimplification

The problem of decision-making about global warming was described previously as "wicked", with many uncertainties in the problem, the states of nature and the potential outcomes. Decisions governing a silviculture program can also be categorized as "wicked". This is due to the combination of potential human interventions, and the mix of biotic organisms and incompletely understood complex ecosystems. The result will always be some unpredictability in plantation responses. The multiple levels of uncertainty means that decision-makers will tend to limit the factors considered to those that they are familiar with or which are most expedient. Over-simplification in national level analysis can lead to arbitrary choice of program segments, based on just a few criteria.

Silviculture vs. reforestation

Other studies of this issue discuss large-scale *reforestation*, reflecting the over-simplification pitfall. The term reforestation suggests a one-shot activity of planting a tree. Increases in terrestrial carbon absorption can be achieved using silviculture treatments other than simply planting trees. *Silviculture* suggests a dynamic process that includes other inputs to maintain and improve the plantation. Certain treatments can dramatically increase the rate of soil carbon storage or the rate of biomass carbon storage over the life of the plantation. For example managing the competing vegetation so that the forest seedlings, rather than the annual and perennial brush, dominate the plantation will result in significantly higher total biomass. Allocating a portion of the program budget to stand enhancement activities will also improve the commercial returns from timber and bio-fuel stands, and reduce net cost. Trees planted in developing countries especially will need the follow-up maintenance and protection implied by the term silviculture.

The proposal structure

The approach taken in this proposal is to disentangle the issues and variables that need to be addressed, by organizing them into five steps.

1. Select an appropriate program size, backed by accompanying rationales;
2. Identify guiding principles that will constitute the background against which other design decisions will be made;

3. Define criteria for success, based on national objectives and constraints, which can be used to evaluate program design parameters;

4. Analyze some alternative program design elements; and

5. Discuss the selection and implementation of program components.

The group of potential program components that will emerge from the decision process described in the proposal is not the main focus of the exercise. The purpose is not to design a silviculture program. Rather, the object is to examine the thinking and the explicit and implicit expert decision-making that might go into designing a large-scale carbon sink silviculture program. An illustration is then provided of how to estimate the net cost of such a program, using some of the basic assumptions revealed in the decision process. The proposal framework could apply to the overall Canadian program or could be tailored for a provincial or sectoral portion, since many of the critical elements are common. *Figure 6* on the following page illustrates the framework of this silviculture program proposal.

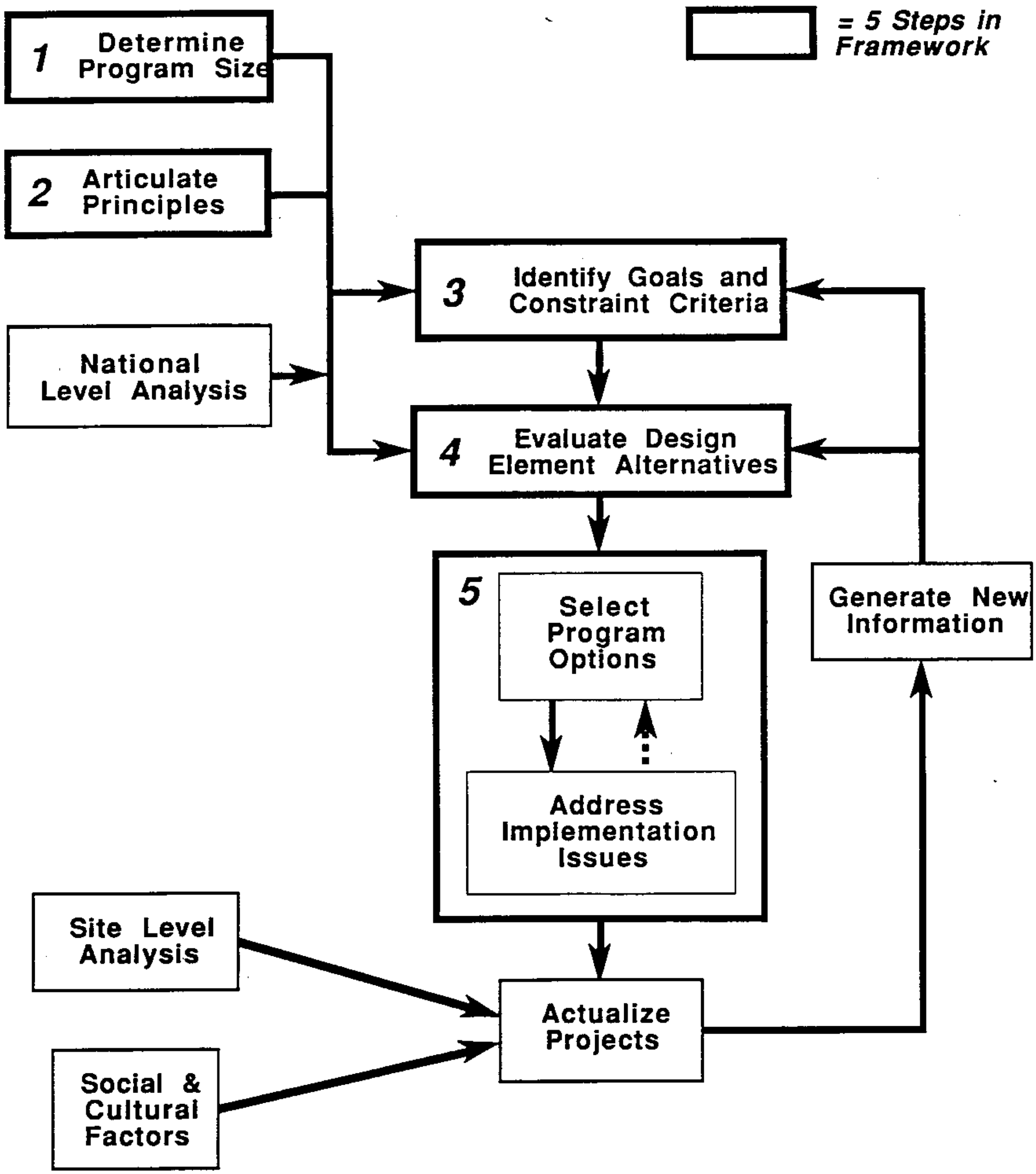

Figure 6 Proposed Decision Framework for Carbon Sink Silviculture Program

5.B Defining a Program Size and Carbon Impacts

5.B.1 Four benchmarks suggest program size

The first task in the decision framework is to determine the scale of the proposed silviculture program. The Green Plan's Community Tree-planting Program program calls for planting 325 million trees. The program will, for seven years, plant the equivalent of merely one-quarter of the forest we are losing each year by not ensuring regeneration of areas currently harvested. The proposed new silviculture program needs to be much larger to make a serious dent in Canada's current or future CO_2 reduction commitments.

Four different benchmarks have been used to select the national program size. Figures have been translated into estimates of forest area to be treated. There are necessarily some simplifications made in these calculations in order to arrive at common units of comparison.

The Noordwijk Declaration of International Environment Ministers

In 1989, international representatives to the Dutch Ministerial Conference in Noordwijk, the Netherlands, formulated a recommendation to the IPPC panel. They proposed that the world goal be to achieve a net increase in forest area of 12 million hectares each year by the year 2000, and to sustain this effort for 40 years (Noordwijk Conference Report 1989, in Dixon et al 1991). Given the current and projected levels of tropical deforestation, ranging from 17 to 30 million hectares a year, the net gain of 12 million hectares requires forest improvement on an estimated total of 35 million hectares per year.

A U.S. Environmental Protection Agency (EPA) report analyzing the potential for implementing this global goal, considers it to be feasible, although a major undertaking with numerous obstacles. The EPA report points out that fewer obstacles exist where the increased effort can be levered upon existing active forest management programs. For that reason the authors recommend that forested nations contribute to the global program in proportion to the size of their respective forest land bases (Dixon et al 1991).

In the report Canada is listed as having 12 % of the world total closed forest area, or 436 million hectares out of 3,654 million hectares. This implies Canada's share of the total program should be 4.2 million hectares a year of incremental forest management, for 168 million hectares total over 40 years (=12% x 40 years x 35 million hectares gross area to be reforested worldwide). If Canada's share was elected to be equivalent instead to our relative share of greenhouse gas emissions, our allotment would be 2% of the total program, or 700,000 hectares a year. Over 40 years this means 28 million hectares in total.

Precedent created by U.S. reforestation program

"America the Beautiful" is the U.S. administration's program to plant or improve one billion trees a year for twenty years, primarily on marginal and environmentally sensitive agricultural cropland and pasture land (USDA 1990). The program reflects the U.S government's confidence that reforestation's numerous benefits outweigh the costs. Forests are comparatively more important to Canada than to the U.S.[24] and an abundance of marginal agriculture land and other areas in Canada also are suitable for reforestation (Nagle 1990). With an estimated 600,000 hectares annually to be placed into forest, at an average density of 2000 seedlings per hectare (Dixon et al 1991), the "America the Beautiful" program will increase forests by 12 million hectares in total.

Doubling current silviculture program

A third benchmark for the silviculture program is the extent of current Canadian silviculture activities. Federal statistics report the area of forest management activities undertaken by provincial, federal and industry organizations in 1988 (Forestry Canada 1991):

Site preparation	451 thousand hectares
Planting	413 thousand hectares
Direct seeding	377 thousand hectares
Stand tending	269 thousand hectares.

For the most part, site preparation and planting or seeding are consecutive activities on the same site. The total hectares treated with some form of silviculture activity was therefore not the cumulative figure, but encompassed roughly 1 million hectares. The total number of seedlings established through planting, seeding and natural regeneration on prepared sites in 1988 is

[24] Canada is the highest volume producer of forest products trade globally (Canada. Forestry Canada 1991a), so forests are comparatively more important to the Canadian economy than the U.S. economy. They are also a proportionally greater feature of Canadian landscape. Land base comparisons show that, of the total US land area of 919 million hectares, 297 million hectares is covered by closed forest and other woodland. Of 961 million hectares total in Canada, a larger ratio, or 325 million hectares, is closed forest and woodland (Mitchell, in Hummel et al 1988). The 325 million figure is a lower total than the one reported by Dixon et al 1991, cited on the previous page. This may be due to definitional differences.

estimated to be about 1 billion trees. If the carbon sink silviculture program were to match our current industrial harvest silviculture program in size it would cover 1 million hectares annually. Sustained over a 40 year period, the result would be to increase the extent of Canada's carbon sink by 40 million hectares in total.

Achieving a portion of Canada's CO_2 net emission reduction targets

What proportion of Canada's CO_2 limitation targets could be accomplished through incremental silviculture? Background preparation for the Green Plan Community Tree Planting Program included analysis of the CO_2 benefits of planting 555,000 hectares a year over fifteen years in Canada, for a 8,325,000 hectare total (Nagle 1990). The analysis combined a mix of eight to ten species in each province, on eight different types of sites. CO_2 absorption potential mid-way through the program was estimated for the year 2000, and for the total program for the year 2005, summarized in Appendix 5. These carbon absorption estimates can be compared with estimated CO_2 reductions needed to meet Canada's commitment to limit emissions to 1990 levels. They can also be compared with reductions needed to limit emissions to 80% of 1988 levels, the Toronto Conference target recommended by the House of Commons Standing Committee on the Environment. These reductions are shown in Appendix 5. *Table 9* below shows the percentage of limitation targets that would be achieved by the scale of program considered in the Nagle study. The bottom row shows a larger program which will accomplish more of the targeted reductions.

Table 9 **Percentage of Reduction Targets Achieved by Two Program Sizes**

Program area (million hectares)	Share of CO_2 reduction from projected year 2000 emissions level to achieve 1990 level (percentage)	Share of CO_2 reduction from projected year 2005 emissions level to achieve 1990 level (percentage)	Share of CO_2 reduction from projected year 2005 emissions level to achieve Toronto target [b] (percentage)
8.325	44	35	19
12.500	67	54	28

[b] The Toronto target is to reduce emissions to 80% of the 1988 emissions level, by the year 2005.

By the year 2000, the smaller program would account for almost 44% of the CO_2 emission reduction required to meet Canada's current CO_2 targets. By 2005 the plantations would account for a lower portion of required reductions since expected emissions will be higher.[25]

A fifteen-year program designed to realize close to two-thirds of the reduction to 1990 levels in the year 2000, and over one-quarter of the reductions needed for the Toronto target in 2005 would encompass 840,000 hectares annually, or 12.5 million hectares in total. At an average stand density of 1220 trees per hectare (aggregate density over all stand types and regions, from Nagle 1990), this means the equivalent of 15.25 billion trees over the term of the program.

While achieving two-thirds of Canada's CO_2 reduction targets is an impressive achievement, CO_2 emissions are only half the greenhouse gas problem. Other gases must be reduced as well to meet limitation commitments. In effect, the larger of the two programs would account for approximately one-third of Canada's total greenhouse gas reduction requirement in the year 2000, and close to 14 % of the total requirement in 2005.

5.B.2 Canada's program: 15 billion trees on 12.5 million hectares

Selecting a program size is to some degree an arbitrary exercise. The benchmarks discussed suggest a range from 550,000 to 1 million hectares a year. This supports the selection of a program of 833,300 hectares a year. Accordingly, an initial program is proposed which will reforest, or otherwise manage for carbon, a total of 12.5 million hectares over fifteen years. At the average density of twelve hundred trees per hectare, this implies a one billion tree per year effort, for a total of fifteen billion trees. Realistically the program should ramp up over several years before reaching a steady level for the balance of the program duration.

In accord with the National Action Strategy principle of program flexibility, the size of the program can be easily changed later in response to changes in scientific uncertainties about global warming, changes in the relative feasibility of other mitigation options, or changes in the status of international agreements. The Canadian government could consider extending the program

[25] The carbon absorption calculations upon which these estimates are based assume a program commencing in 1990 and completed by 2005. Since this timetable will obviously not be met and the silviculture program CO_2 reductions will be moved forward, and the percentage of targeted reductions in the years 2000 and 2005 will be correspondingly lower.

duration by selling CO_2 emission reduction capacity to other nations without adequate forest land base.[26] A portion of the program should take place in developing countries to fully capture the potential political benefits.

5.C Program Principles Correct Market and Government Failures

5.C.1 Three program principles

Program principles must seek to ensure that the product, the plantations, reflect the concerns of the Canadian public about the historic shortcomings in forest management practices which undervalue the external benefits of forests. They must enable the program process to side-step the common failures of markets and governments which emphasize short-term returns. The principles must also facilitate a program structure that is proof against undue interest group pressures and jurisdictional political conflict. To achieve these ends, three principles are suggested.

Principle 1. Environmental Sustainability

The foremost principle should be a commitment to environmental sustainability. This principle is critical to enrolling public support in the program, and also to ensuring that the program results are congruent with the emerging direction for forest management at both the provincial and national levels.[27] The term, environmental sustainability, can be interpreted in many ways. A working definition and criteria will need to be developed. A starting point could be the output from meetings of the cross-sectoral Forest Roundtable on Sustainable Development, which has the important goal of clarifying this concept (Brinkman 1992). Three controversial issues that are central to sustaining critical ecosystem processes are: the use of native species, the preservation of species bio-diversity, and the elimination of chemical vegetation and pest control. A fuller discussion of these issues can be found in Appendix 6.

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[26] Future international negotiations could well determine set levels of greenhouse gas reductions required by each country. These requirements may be tradeable, in order to encourage overall mitigation at the lowest marginal cost. Canada has ample suitable land for silviculture, beyond the proposed carbon sink program. If Canada were to charge other nations the net cost, after direct economic returns and non-consumption benefits, for silviculture programs to offset CO_2 emissions, the product could be beneficial both to Canada and its "clients".

[27] The Canadian Council of Forest Ministers (Forestry Canada 1990) and the federal Green Plan have both endorsed the principle of sustainable development with respect to Canada's forests.

Principle 2. Long time-frame

The requirement for a long time-frame for a program involving trees may seem self-evident. This needs to be an explicit principle, however, to address the pervasive failure of both market forces and government policies to adopt a long-term view. Myopia leads to the preference for deferring costs to future generations and results in the current roller-coaster of government funding for backlog and incremental silviculture. In order to accomplish the objectives of the large-scale carbon sink silviculture program, a long view is necessary. Planning horizons, funding mechanisms, and plantation maintenance commitments, for example, will need to reflect this principle.

Principle 3. Political autonomy

Domestic support for the program is an important rationale for its existence. In order to balance support from different interest groups, and to ensure that the principles of environmental sustainability and the long time frame realistically can be implemented, an autonomous administration of the program is needed.

Forestry Canada is, on the surface, the obvious choice to lead the project team. However the federal government has historically not given this ministry much power since forests largely fall under provincial jurisdiction. Forestry Canada is not strong, and has demonstrated little vision with respect to the potential of Canada's forest base to contribute to global warming solutions.[28] The program should have the committed support of other ministries such as Environment, Finance, Energy and Agriculture .

The overall driving decision authority needs to have an infrastructure that overcomes inter-jurisdictional conflicts and joins federal and provincial forces. The program must be endowed also with a funding mechanism that will endure through changes of government. A further discussion of these issues can be found in Appendix 6.

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[28] A recent strategy paper (Canada. Forestry Canada 1990b) is reactive rather than proactive with respect to the role of forests and climate change. Maintaining sources of fibre supply in the face of increased challenges from climate stress on forests is the main focus of the strategy.

5.D The Program Must Achieve Diverse Social Goals

5.D.1 The goals can be used to test decision alternatives

What is this program hoping to accomplish, and what could get in the way? The answers are the way a knowledgeable person would intuitively weigh program options. Making the program goals and constraints transparent means they can be used to explicitly evaluate the program design alternatives.

Lack of data at the country level and the site level will make it difficult to measure objectively the impact of an alternative on the goals and constraints, at least at first. As data become available through the course of implementing the program, evaluation can become more quantitative. The feedback can then be used to adjust the program design.

The four goals selected will contribute to maximizing the various benefits available from large-scale silviculture: 1. Least-cost carbon absorption; 2. Direct economic benefits; 3. Other external benefits; and 4. Political benefits. The total economic cost of a program is the direct cost per tonne carbon stored <u>less</u> the direct economic benefits <u>less</u> the quantified other external benefits. These components of the total net cost are expressed as separate goals in order to more easily evaluate alternatives which may rate high on one component, but low on others.

Each goal can be further segmented into specific determinants or categories, which reflect some distinctions that are critical to the design of the silviculture program. These important distinctions, for all four goals, are elaborated in Appendix 7.

Goal 1. Least-cost carbon absorption

Least-cost carbon absorption is the goal of sequestering CO_2 at the lowest cost per tonne of carbon. The three determinants that will collectively determine whether a particular option achieves the goal of least-cost carbon absorption are: maximum carbon absorption per unit (whether the unit is hectare treated or tree planted), minimum cost per unit, and maximum indirect reduction in GHG emissions.

Goal 2. Direct economic benefits

Direct economic benefits reduce the net cost of a program. They are produced by harvesting and selling plantation products. Static factors such as the inherent productivity of the soil or the bio-regions climate underpin economic returns. Dynamic factors are also important. Advancements in seed genetics, improvements in nursery and seedling transport processes, and post-planting investments in the plantation can increase returns. The three general categories of direct economic benefits considered are: timber supply, bio-fuel supply, and supply of other commercial forest products.

Goal 3. External benefits

External benefits are the many non-consumption benefits received from trees and forests that are not accounted for in commercial transactions. The value that societies place on these benefits is one of the bases for the wide spread support for reforestation as a global warming response. External benefits can be grouped into two categories: social, and indirect economic benefits. These benefits will generally accrue to communities in the vicinity of the project.

Goal 4. Political benefits

The political benefits from silviculture have been included as a separate goal to underline the fact that support, at the outset, is critical to get the program off the ground. The diffuse and long-term nature of silviculture benefits, and the competing pressures for immediate other uses of government investment and resources, mean a balance of potential political benefits needs to be achieved for this support to be sustained. Public approval, industry interest group support, and international reputation are the three categories considered.

5.D.2 Constraints must be considered

Silviculture on some scale is practised wherever people co-exist with forests. Large-scale silviculture programming encounters constraints to success that are inherent in the increases in scale. If the constraints are considered when formulating design decisions, they can be viewed as precautions or matters to resolve rather than as obstacles (Dixon et al 1991). Constraints will be particularly important to consider when designing programs for developing countries. International stature from large-scale silviculture will depend on the success of the individual projects, which will have diverse social and cultural hurdles in addition to technical constraints. For the purpose of this framework three constraints are considered: land, knowledge, and infrastructure. Each constraint can be divided further into several categories, discussed in Appendix 8.

Constraint 1. Land

Land constraints are one of the basic determinants of program design for large scale silviculture. Since up-to-date inventories of land type and use at the national level are inadequate, even in countries like Canada with strong incentive to maintain this information base, best estimates will often have to be used. Land constraints can be divided into technically available land and socially suitable land. This is especially an important distinction for silviculture in developing countries.

Constraint 2. Knowledge

Knowledge is a key requirement for an effective silviculture program design which maximizes benefits and minimizes costs. Knowledge can be divided into scientific research and information administration categories. There are inevitably some gaps in knowledge, but uncertainty should not be a reason for postponing action. Instead it can be used to select among program design options. The importance of good knowledge levels has implications for program implementation, discussed further in the paper.

Constraint 3. Infrastructure

Infrastructure is the existing investment in capital upon which the operational requirements of the silviculture program can be levered. Infrastructure can be divided into three categories: administrative capability, tree seedling nursery capacity and silviculture delivery capacity. All categories will tend to be constraints to programs components that are both large and experimental or unfamiliar in the region they are being implemented. Infrastructure is well-developed for many potential program options in Canada as mentioned in the silviculture industry "diamond" discussion. It will tend to constrain projects elsewhere.

This summary of goals and constraints is illustrative as opposed to exhaustive. Program designers can add others they feel may be relevant to predicting program success. The specific distinctions made within each goal and constraint, discussed in Appendices 7 and 8, should also be customized. The point is to identify the criteria which are most useful to evaluate the alternatives for basic program design elements, such as the ones described in the next section.

5.E Program Design Elements

5.E.1 Each element offers several alternate choices

The next step in this proposal is to identify and discuss the common design elements which implicitly underlie large-scale silviculture program design. Five basic elements are common in various CO_2 silviculture reports. For the purpose of this analysis they are labelled *location*, *focus*, *geography*, *land ownership* and *plantation type*. Each element requires that a decision be made among several alternatives, shown in *Figure 7* on the next page. The order of these decision points is important since each one sequentially serves to narrow down the parameters of the final program options.

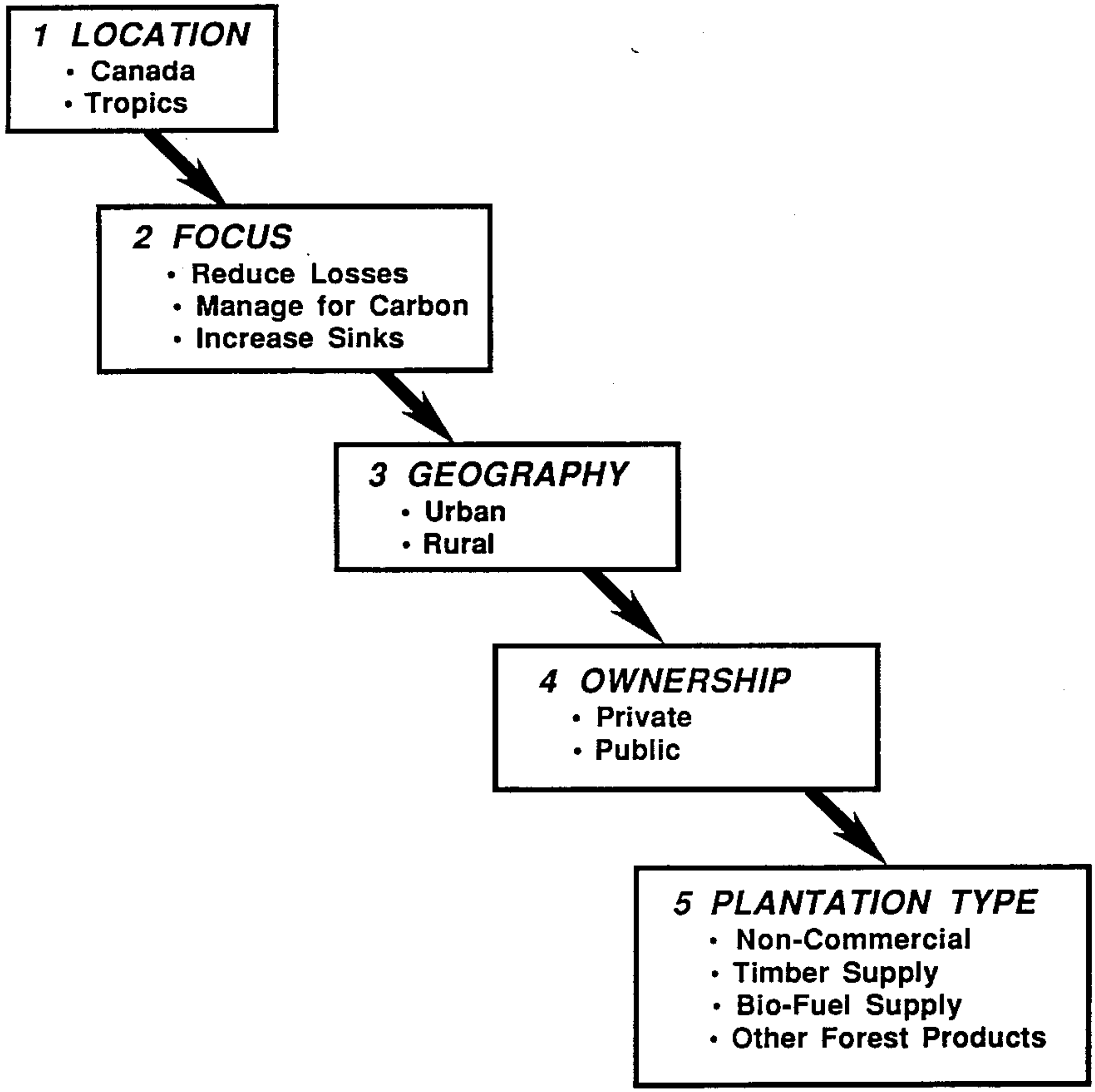

Figure 7 Decision Sequence

The following discussion about the design decisions is intended to illustrate the use of goals and constraints to evaluate elements of a silviculture program. For each design element, first the alternative choices are described, then the contributions of the alternatives to the first goal of least-cost carbon storage are compared, and finally the impacts of the alternatives on other goals and constraints are assessed.

The alternatives in each case are not mutually exclusive - one or more could be selected. The ones chosen will collectively define the composition of the overall silviculture program.

Decision 1. Location

The alternatives

Canada and ***Tropical forest nations*** are the two potential program locations considered. Programs can take place exclusively in Canada, or some portion of the program can be targeted to silviculture programming in tropical countries where deforestation is a recognized problem. The CO_2-reduction benefits of silviculture are a global public good, and international negotiators acknowledge that a country can fulfill its own mitigation commitments by reducing greenhouse gases outside its boundaries. Obviously there is a vast array of different potential sites within the Canada and Tropical forest nations so the discussion at this level can only be very broad.

Least-cost carbon storage impacts

Tropical plantations best meet the least-cost carbon goal compared with plantations in Canada. Tree growth rates are far higher on average in tropical forests than temperate forests as shown in *Table 10* below.

Table 10 **Tree Growth Rate Comparisons**

Country		Net annual growth (M^3 per ha. per year)
U.S.	average	3.15
	potential	5.18
Canada	average	1.7
	potential	3-5
Tropical moist forest		6-15

Source: Adapted from (Marland 1988)

Costs of establishing plantations are also lower in developing countries with costs ranging from $100 -$200 for dry area tropical plantations and $1000 per hectare for moist tropical sites

(Andrasko et al 1991).[29] Estimates for the cost per hectare of establishment of timber plantations in the U.S. include $514 to $2350 (Moulton & Richards 1990),[30] $1500 (Owston et al, in Winjum et al 1991)[31] and $2000 (Myers & Goreau 1991).[32]

The cost of sequestering carbon in three social forestry programs in Central America ranges from $0.82 to $1.37 per short ton carbon sequestered (Andrasko et al 1991). Projects in the U.S. incur costs ranging from $5.26 to $43.33 per ton carbon (Moulton & Richards 1990). Canadian rates will be slightly higher than in the U.S. due to slower bole growth on average.

The differences in the estimates for carbon sequestration rates in tropical versus North American reforestation may be exaggerated by the use of different sets of assumptions and variables. A study which directly compares conserving carbon through rural treeplanting in the U.S., with achieving the same carbon outcome in developing countries, concludes that in developing countries the cost range is just half that of the U.S. Higher expected tree survival rates partially compensate for the higher establishment costs in the U.S. (Kraus & Koomey 1989). While significantly more costly than in tropical countries, silviculture in temperate zones does still compare favorably with other CO_2 mitigation options. Assessments up to $161 per ton of carbon possibly face U.S. utilities under proposed regulations to internalize the social cost of CO_2 emissions (Sundt 1992d).[33]

29 This large difference could be explained by the fact that dry tropical sites are typically degraded and abandoned lands with few land use opportunity costs, whereas moist tropical sites are more productive and will require incentive payments to encourage the substitution of plantations for other potential uses of the sites.

30 These figures represent an analysis based on annualized costs of plantations on various site categories throughout the U.S. The costs include investment in infrastructure capitalized over 40 years, plantation establishment cost, site preparations and other silviculture treatment, and land rental costs. The upper bound is for plantations on cropland in the U.S. corn belt, where high rental payments reflect the high opportunity cost for the land.

31 1989 average cost per hectare reforested, including conifer release and animal protection costs, in a National Forest in western Washington.

32 Estimated average cost of commercial timber plantations in the U.S.

33 The Oregon Public Utilities Commission (PUC) is recommending that utilities be required to include external costs of CO_2 emissions in their planning. The PUC proposed a tax ranging from $11 to $44 per ton CO_2. Using a 3.667 multiplier to convert CO_2 to carbon (Jaques 1989), this tax could be $40 to $161 per ton carbon. The federal Department of Energy (DOE) proposed the higher ($161) value in its 1991 energy plan (Sundt 1992d).

Impacts on other criteria

Canadian projects will generate substantial direct economic and other external benefits for Canadians which will mitigate the higher plantation establishment costs. For this reason the majority of the silviculture program should be located in Canada. Political benefits will be greater with a domestic program, although international reputation will be enhanced with successful tropical projects.

Projects undertaken in developing countries will generate few other benefits for Canadians, except where the project is tied to export of Canadian services and goods. Constraints are far higher for tropical forestry programming. Social pressures constrain the area of suitable land. Knowledge and infrastructure to handle large-scale projects, which is largely in place in Canada, is unavailable in many tropical areas needing reforestation. To address these constraints, programs will need to be divided into many small projects at the farm and community level, and to be designed to include grass-roots participation. The extra administration and program design costs have not been not factored into the cost comparisons. Despite these drawbacks, a part of the program should be located in tropical forest countries to capture the political benefits.

Decision 2. Focus

The alternatives

Reducing forest losses, Managing existing forests for carbon, and ***Increasing forests*** are the three alternative program foci considered. Reducing forest losses in tropical countries means restoring forest areas recently degraded by unsustainable agricultural encroachment . In Canada it means replanting forest areas recently cleared by wildfires, pests and timber harvest or other commercial activities such as urban expansion and transportation, power line and pipeline corridors. Managing existing forests for carbon means replacing some current forest management techniques with others that achieve similar economic objectives while increasing soil and biomass carbon storage.[34] Increasing forests, or afforestation, means

34 Examples of this are: use other site preparation methods instead of slash burning which depletes soil carbon; re-design or replace heavy harvesting and site prep equipment, which compact soils and reduce carbon storage capability (and soil productivity) through erosion and oxidation; replace the indiscriminate chemical destruction of competing non-commercial vegetation with the manual elimination of vegetation in the area directly surrounding the crop tree; maintain and improve soil fertility using municipal, animal and industrial wastes as cheap fertilizers; reduce erosion caused by

establishing trees on non-forest sites such as marginal agriculture lands, and replacing forests that have long been without adequate tree cover for a variety of reasons.

Least-cost carbon storage impacts

Data with which these alternatives can be quantitatively compared are not readily available. *Table 11* below summarizes some biotic policy options in the U.S. that correspond roughly to the above alternatives. The cost ranges suggest that Managing for carbon may be least-cost, with Increasing forests next, and Reducing forest losses the highest cost carbon storage alternative.

Table 11 **Cost Ranges for Silviculture Program Focus**

Option	Practical benefit (millions of tons C/yr)	Cost ($/ton C)
Soil carbon build-up (Managing for carbon)	10-25	$0-10
Private land conversion (Increasing forests)	50-150	$0-50
Forestry management (Reducing forest losses)	35-75	$0-100

Source: Adapted from (Andrasko et al 1991)

Managing for carbon can be accomplished at relatively low cost by utilizing different harvest and silviculture equipment and treatments. Building soil carbon sequesters CO_2 that otherwise is released into the atmosphere, and the improved soil health boosts tree growth and thus increases biomass carbon storage.

Projects aimed at Increasing forest area will primarily use marginal agriculture land. Land that is fallow or under cultivation stores far less carbon than do forest soils which accumulate organic litter and store sizeable quantities of carbon in tree root masses. As a result, converting agriculture lands to forests will achieve an estimated 122% of the increase in soil carbon content compared with plantations on logged or burned forest sites (Nagle 1990).

road-building and harvest activity; and mulch trees with mulch pads or plant residues to maintain moisture, slow decomposition and conserve carbon.

Projects for Reducing forest losses will largely be rehabilitation projects where there will already be successionalry vegetation on the site. This means the incremental carbon storage will be lower per hectare. The sites may also be more expensive to re-plant due to isolated access and difficult terrain.

Impacts on other criteria

Projects designed for Reducing forest losses will include a proportion of urban green zone forests to compensate for forest losses to urban development, and will be highly valued by the public for their use opportunities. Projects aimed at rehabilitating burned timber areas will add to the working forest base and thus be appreciated by industry.

Managing for carbon will eventually generate economic benefits over several crop rotations. The problem of soil depletion from multiple crop rotations will be reduced, and productive soil means faster-growing timber. Any areas that are currently being managed as a part of the working forest are suitable for this alternative. Managing for carbon will generate public support since forest management techniques designed to maximize carbon storage are more "environmentally friendly." Industry might not be supportive since greater regulatory control of current harvest and forest management practices will be imposed. Managing for carbon is a very new thrust of forest management, so knowledge levels are low. This alternative is certainly worth including on an experimental basis. Carbon benefits can in the future be levered off all Canadian forest management activities once the experimental results are analyzed.

Greater direct economic benefits will accrue to Increasing forest area since these projects will largely be commercial plantations, and will tend to take place on accessible, easy-to-harvest marginal agriculture lands. The private sector stands to gain the largest share of benefits from these projects, which means they will generate less public support, but greater support from industry interest groups. Since this alternative involves placing forests on lands that were not recently forested, the increase in forest amenity benefits will be greater, on the margin, than for other alternatives. The economic advantages of this alternative support a major emphasis in the overall program composition.

Plants act as carbon sinks because they normally use more carbon dioxide in the photosynthetic process than they release when they respire. Respiration is also said to occur when plants and animals die and decay, releasing carbon dioxide. Respiration annually releases about 100 billion tonnes of carbon. Releases of carbon dioxide that are wholly or partially attributed to human activity include fire, mostly from tropical woodlands and savannas (2 to 5 billion tonnes of carbon annually), and burning fossil fuels (about 5 billion tonnes of carbon annually).

The amount of carbon dioxide tied up in other blocks of the carbon cycle - sedimentary rocks, fossil fuels, and water - far exceeds that in vegetation. But more is probably known about carbon dioxide exchange and storage in land-based ecosystems than other large components of the carbon cycle. For this reason, discussions about increased carbon dioxide in the atmosphere tend to focus on land-based ecosystems. Human modifications of the earth's land-based ecosystems, such as deforestation, have reduced the ability of these components of the carbon cycle to act as carbon sinks. To the amount by which their carbon uptake is reduced, these ecosystems can be thought of as carbon sources. One estimate placed the net annual release of carbon dioxide to the atmosphere due to recent changes in the earth's ecosystems at 1.6 billion tonnes. That figure represents about a third of the carbon dioxide released by fossil fuel burning.

Methane

Methane concentrations in the atmosphere have doubled over the past 200 to 300 years to present levels of 1.7 ppmv. Concentrations are rising at a rate of one percent annually, about two and a half times the rate of carbon dioxide. This is a relatively rapid rate of increase, and methane is from 20 to 25 times more effective than carbon dioxide as a greenhouse gas. The combination of these factors indicates that methane will be an important greenhouse gas. Part of the reason why methane and other trace gases are so effective at trapping infrared radiation is that carbon dioxide concentrations are close to a saturation point. The large mass of carbon dioxide in the atmosphere means each incremental increase in carbon dioxide is less effective as an energy absorber. Larger quantities of this gas are needed to absorb similar amounts of infrared energy.

Gases in lower concentrations, for example, methane, are still very effective. They also tend to absorb radiation in the atmospheric window region, where less long-wave radiation is currently absorbed than elsewhere in the electromagnetic spectrum. Some of the gases are more efficient at absorbing long-wave radiation than carbon dioxide; they have stronger absorption band strengths. While increases in sources of methane as a result of global expansion of agriculture may be responsible for rapid increases in atmospheric methane, changes to methane sinks may be more important. The annual burning of grasslands, a common feature of farming in Australia and parts of Africa, offers one example of a methane sink that is being altered. The dryland soils in these areas are normally an important sink for methane. Changes in the activity of soil microbes as a result of burning grasslands could be responsible for extra amounts of methane in the air. Nitrogen fertilizers and the nitrogen that enters the soil as a result of acid rain are also thought to have reduced the ability of soils to act as methane sinks.

Changes on the atmosphere are also important in accounting for the rise in atmospheric concentrations of methane, because most methane destruction probably occurs in the atmosphere. There has, however, been a large reduction (about 25 percent) in the amount of hydroxyl radicals in the atmosphere over the past 40 years. Apparently, the hydroxyl cleansing system is too overloaded with carbon monoxide, from sources like vehicle exhaust, to remove methane.

Presently, 50 million tonnes more methane enters the atmosphere annually than leaves it; and the injected methane remains about ten years in the atmosphere.

Nitrous Oxide

Nitrous oxide is present in the atmosphere at concentrations of about 300 parts per billion by volume. Concentrations are increasing about 0.2 percent annually. Nitrous oxide is formed by soil and water-based microbes in those parts of the nitrogen cycle that result in the conversion of inorganic nitrogen into gaseous nitrogen. The production of nitrous oxide from nitrates (the nitrate form of nitrogen) is most rapid in anaerobic soils (soils that lack oxygen) and in anaerobic pockets within aerobic soils.

The production and subsequent soil application of nitrogen fertilizers, which are applied as nitrates or converted to nitrates, supplement naturally produced nitrates. They may thus be a source of increasing amounts of nitrous oxide in the atmosphere. Most of the increase in nitrous oxide concentrations, however is from combustion of biomass (vegetation) and fossil fuels. The reaction between nitrous oxide and activated oxygen in the stratosphere is the major known sink for nitrous oxide. This reaction may also contribute to ozone depletion.

CFCs

CFCs are present on the atmosphere in small concentrations. The two most important greenhouse CFCs, CFC-11 (used as foam blowers) and CFC-12 (refrigerants), are present in concentrations of about 0.2 and 0.3 ppbv. The small concentrations belie their importance as greenhouse gases. CFCs are up to 10,000 times more effective on a molecule-to-molecule basis than carbon dioxide

Forestry-related recommendation from the National Action Strategy on Global Warming

Source: (CCME 1990:30)

Recommendation 7.6 Forestry

It is recommended that governments take steps to increase the storage of carbon in forest sinks. While not a permanent solution to the problem of greenhouse gas concentrations, the fixing of carbon in trees leads to a temporary reduction in net CO_2 emissions, and therefore buys time for the development of a longer term response.

Appendix 4.

Silviculture Segmentation

Table 4.1 **Silvicultural Activities and Treatment Types**

Silvicultural Activity	Treatment Type (method)
Site Preparation	none
	prescribed burning
	root raking
	stump pulling
	lop and scattering (manual, mechanical)
	scarification (manual, mechanical)
	crushing (manual, mechanical)
	chemical (herbicide)
	windrowing (manual, mechanical)
	pre-harvest stem girdling
Regeneration	natural regeneration
	planting alternate species for pest management
	broadcast seeding (manual, mechanical)
	partial seeding (manual, mechanical)
	planting bare root (manual, mechanical)
	planting container (manual, mechanical)
Weeding	none
	chemical
	mechanical
	manual
	mulching
Stand tending	none
	fertilization
	juvenile/pre-commercial thinning
	pruning

Source: Adapted from (Brumelle at al 1988)

Table 4.2 Impacts of Silvicultural Activities on Stand and Forest Ecosystems

Silvicultural Activity	Impacts on: Age Structure	Productivity	Timber Quality
Site Preparation	• permits establishment of regeneration	• encourages nutrient availability • changes bulk density • controls pests, pathogens and coppicing	
Regeneration:			
<u>Natural Seeding</u>	• tends to create uneven age structure	• may create irregular stocking due to clumping or deciduous stand components	
<u>Planting</u>	• tends to create even age structure	• accelerates regeneration • improves stem distribution • initial density affects subsequent growth patterns	• selects species, genetic improvements
Weeding	• reduces vegetative competition	• increases growth • alternative species for pest management	
Stand Tending	• reduces age at which stand reaches harvestable age (except pruning)	• fertilization increases yield • thinning improves stem distribution and redistributes growth • increased proportion of total stand volume which is merchantable	• fertilization increases the diameter growth rate for a time • thinning increases the diameter growth rates • pruning yields knot-free lengths • increases merchantable portion of log

Source: Adapted from (Brumelle et al 1988)

Appendix 5

Data Used to Estimate the Percentage of Canada's emission Reductions that Could be Accomplished By a Large-Scale Silviculture Program

Table 5.1. Canada's Required Emission Reductions

Year	Canada's actual and predicted annual CO_2 emissions (000 tonnes CO_2)	Reduction to meet 1990 level target (000 tonnes CO_2)	Reduction to meet Toronto target of 80% of 1988 level (000 tonnes CO_2)
1988	493,000 (80% =394,400)		
1990	544,000		
2000	630,000[a]	86,000	
2005	705,000[a]	161,000	311,000

Source: Adapted from (Nagle 1990).

[a] Forecasts assume no change in past patterns of population growth and energy consumption.

Table 5.2. CO_2 Sequestered at year 2000 and year 2005

Segment	Area (000 ha)	No. trees (million)	Annual CO_2 at year 2000 (000 tonnes)	Annual CO_2 at year 2005 (000 tonnes)
Crown NSR	312	566	1,027	1,555
Crown other	238	179	1,063	1,610
Recent burns	498	882	1,595	2,413
Woodlot	2,892	4,085	11,836	17,934
Pasture	3,734	3,734	19,489	29,528
Shelterbelts	329	247	1,822	2,765
Indian lands	193	259	895	1,338
Federal lands	130	191	458	693
National Total	8,325	10,142	38,185	57,836
Proposed program[a]	12,500	15,000	57,277	86,754

Source: Adapted from (Nagle 1990)

[a] The various benchmarks discussed in the text suggest a larger program than the national total recommended by Nagle.

Appendix 6

Program Principles

1. Environmental Sustainability

Forests management must have a wider scope than simply maintaining the sustainable yield of timber supply. The scope must include the long-term viability and resilience of forest ecology systems for future generations. Ecological resilience can be defined as "the ability of the ecosystem to maintain its structure and patterns of behaviors in the face of disturbance, i.e. the ability to adapt to change"(Pearce & Turner 1990), a particularly important concept in view of impending ecosystem stress from climate warming. Adopting the principle of environmental sustainability means the program designers will have to explore and resolve some controversial issues:

<u>The use of native species in plantations.</u>

Environmental critics claim that widespread introduction of exotic species can degrade ecosystems (Williams 1991). Foresters claim that the use of fast-growing exotic species can help to achieve carbon and fibre production goals, and that non-native species may be better adapted than native species to warming-induced changes in ecosystems (Winjum et al 1990). The principle of environmental sustainability suggests that program designers should err on the side of caution when weighing the potential suitability of non-native species.

<u>Species diversity</u>

Maintaining a diversity of vegetation, wild-life and micro-organism species in the new plantations is important to protecting ecosystem integrity and resilience. This could be an impediment to productivity goals in short-rotation crops. In plantations for bio-fuel, for example, fast-growing species such as hybrid poplar are the preferred species. Commercial plantations for timber harvest already incorporate a diversified mix of species in many parts of Canada. The Society of American Foresters position statement on biological diversity recognizes that diversity is essential in healthy productive forests (Baird 1992).

<u>Non-chemical vegetation and pest control</u>

Evidence is mounting that forestry chemicals present a threat to species diversity and to environmental sustainability. Chemical forest management methods have been banned or limited in a number of North American jurisdictions, including several Canadian provinces. The use of chemicals, particularly herbicides, is increasing in other areas of Canada (such as B.C.), despite public concern and opposition. A recent policy analysis of chemical use in forestry concluded that cost effective manual methods are available for most treatment requirements. Phasing out the use of these products in Canada is a practical solution (George et al 1991).

Principle 3. Political Autonomy

The two main dimensions of this principle are the conflicting demands of the environmental and the industry interest groups; and the allocation of program responsibility to ensure overall effectiveness.

Interest group pressure

The program as a whole conceptually enjoys the support of the forest industry. However, without neutral administration, industry interest group pressures will skew the program design toward one which generates commercial benefits at the expense of other potential social benefits. At worst the program could become a tax-payer-financed fund used to fill outstanding gaps in current reforestation of the industrial harvest, allowing the forest industry to systematically abrogate its responsibility to replant areas harvested. This would mean a major new subsidy for the forest industry's fibre supply, and add fuel to the U.S. countervailing duty lobby.

The environmental interest group will tend to lobby against silviculture intended for eventual commercial exploitation, preferring wilderness restoration and urban planting. These competing pressures can be reconciled.

Inter-ministerial leadership

The leadership and coordination of the program should be shared by a number of Ministries. Participation by Forestry as well as Environment, Finance, and Energy will be critical. The overall responsibility should not be fragmented to the provincial level, despite the vast proportion of forests that are under provincial jurisdiction. Under provincial jurisdiction there is too much risk that the silviculture program funding will be threatened by provincial budget deficits and other short-term priorities. The program must also avoid becoming a pawn or trade-off in federal-provincial negotiations on other short term issues. Allocating high-level responsibility for the program to an inter-ministerial agency at the federal level may be the best way to achieve this political neutrality.

Appendix 7

Goals

Goal 1. Least-cost carbon absorption

Determinants:

Maximum carbon absorption

Maximum carbon absorption is a function of the rate of soil carbon storage and tree biomass accumulation. Globally, 1.5 to 3 times as much carbon is stored in soils as in terrestrial vegetation. This makes program effects on soil carbon an important factor in this goal (Dixon et al 1991). With proper management, reforestation of degraded lands can sequester large amounts of carbon in the soil. Soil carbon storage will be subject to variables such as site preparation method, plantation type, and the prior land use of the area.

Biomass carbon accumulation will be subject to a number of silvicultural variables which affect plantation health and bole growth, such as tree species, plantation density, site productivity, and climate region. Premature tree harvesting and other unanticipated losses, such as wild fire burns and pest infestations, will also affect biomass carbon storage. Different potential program options will have varying susceptibility to the risk of losses.

Minimum cost per unit

Minimum cost per unit is a function of the cost of program design and administration, and the cost of program delivery. Programs utilizing existing formats and channels will be cheaper to design, administer and deliver. Programs that break new ground in silvicultural or organization domains, such as bio-fuel plantations for example, may be more expensive to design and administer, at least until an information and experience base has been developed. Projects that require ongoing protection of the plantation from competing pressures for the land or trees could be more expensive to deliver. Tree size, site accessibility, availability of existing infrastructure, and land rents are some other factors that will impact the cost.

Maximum indirect reduction in GHG emissions

Replacing activities which produce greater GHG emissions indirectly reduces emissions. This determinant is a function of the other potential uses of the sites selected. Plantations on marginal agricultural and grazing lands replace agricultural activities that are major producers of greenhouse gases such as methane and nitrous oxide. Bio-fuel plantations close to electrical utilities will replace the emissions produced by the transport, to the utility, of coal or petroleum fuels. Trees planted in urban areas to shade buildings can reduce energy consumption for air conditioning by 10 to 50% (Steinhart 1990).

Goal 2. Direct economic benefits

Timber Supply

Timber supply benefits from program plantations will be a function of the site productivity and accessibility, the cost of silviculture treatments, and future timber product prices among other factors. The expected rate of return for silviculture is controversial, as mentioned previously in the text. The choice of expected rate will be used to discount the future direct benefits of the silviculture project, and will thus be a major determinant of the relative level of return from timber supply plantations.

Sites that are owned by corporations or are a part of the public "working forest" will tend to be utilized for timber supply. Since the forest industry faces future reductions in annual allowable cut due to the diminishing commercial forest base, the allocation of a significant portion of the silviculture program to this use should be considered. Increasing future timber supply will diminish the pressure on the forest industry stemming from the removal of forest areas for parks and old-growth forest preservation.[1]

Bio-fuel supply

Bio-fuel power plants are considered to be a good alternative power source compared with coal or oil-fired plants from the perspective of greenhouse gas emissions. The growing wood absorbs carbon, and the combustion of the wood releases it, for a net zero incremental emission (as long as the plantation management practices selected minimize greenhouse gas emissions). The potential for generating direct benefits with bio- fuel plantations is a function of site productivity,

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[1] Preserving heritage forests increases net forest carbon storage. A recent study concludes that old-growth forests store a much larger proportion of carbon in soils and root masses than younger forests. When soils are disrupted by harvest and slash burning, carbon is released into the atmosphere. In the overall carbon budget, this factor more than compensates for the faster rate of carbon uptake in the above-ground biomass of a young plantation than a mature one (Harmon et al 1990).

plantation costs, plantation distance from an energy utility that can utilize wood-based fuels, the price of alternative utility fuel sources, and the discount rate chosen.

Extensive trials conducted in Europe over the past decade suggest that bio-fuel plantations can generate stand-alone returns. A collection of bio-fuel plantations studies, published by the Commission of European Communities concludes that short rotation forest biomass plantations will constitute the best use of up to 5 million hectares of land in Europe that is expected to be released from agricultural production as subsidies are reduced. In the longer term, the energy market may have even greater potential than the pulp market as buyers of biomass plantation product (Hummel et al 1988). These claims are based solely on cost and price factors, ignoring carbon storage and other external benefits of forests and the external costs of fossil fuel burning. Since bio-fuel plantations have shorter rotation, use a smaller species mix, and need more intensive management, the potential for recreation benefits is low compared with other commercial plantations.

Bio-fuel production is at an earlier experimental stage in North America. A study of bio-fuel economic viability in the the U.S. estimates that bio-fuel grown in the Pacific-Northwest-west region can be supplied to electrical utilities at about half of the break-even feedstock price. Including both fuel and non-fuel costs, utilities producing electricity from wood-burning co-generation power plant can save up to $12.50 per MWH compared with producing electricity from a coal power plant with a flue gas de-sulphurization unit (Peer et al 1991). In other regions bio-fuel feedstock costs were above break-even. With some needed technological advancements, wood will be an economic fuel source in Canada as well.

The chief uncertainty about large-scale bio-fuel production is whether high productivity can be maintained over a broad area, without damaging the environment through soil depletion and reduction of biological diversity. The principle of environmental sustainability requires that project managers design poly-cultural strategies as well as maintain a portion of the land in natural condition, recycle nutrients, and include in the species mix some that fix nitrogen in the soil (Hall et al 1991).

<u>Other commercial forest products</u>

Tropical forests can produce numerous other commercial products such as latex, resins, fruits and nuts. The value of these products will be a function of the factors such as climatic region, species mix, commodity prices for the product and success in protecting the plantations from other pressures for the land and timber. Mixed-use forestry, as opposed to timber supply is a more socially suitable use of forest areas in developing countries since the immediate needs of the local communities can better be met (Trexler, in Winjum et al 1991).

Goal 3. Other external benefits

Social benefits

Social benefits include non-consumption use values such as recreation opportunities from forests and parks, the aesthetic and cooling effects of urban shade trees and green zones.[2] Included also is the non-use satisfaction received by individuals from healthy forest environments. This satisfaction is a form of consumer surplus known as preservation value. Preservation value can be further divided into existence value and option value, the value of preserving the option of alternative uses in the future (Gunton 1991). Non-consumption benefits are recognized by economists and translated into dollar values in order to reflect these values in cost-benefit analysis. They will tend to be greater for projects replicating a natural forest ecosystem, and which minimize follow-up silviculture interventions designed to manipulate plantation density, rotation age and timber quality. Use values will be greater for forests in closer proximity to urban centers.

Skills development, work experience, and education about the global warming problem are some other social benefits.

Indirect Economic benefits

Indirect economic benefits include non-product values such as employment "rents". This benefit equals the difference between wages for the well-paid jobs in silviculture, harvesting, processing, sales, distribution, etc. generated by the silviculture program, and wages the workers would otherwise be earning. The rent-in-wages also produces economic multiplier effects which contribute to community stability, regional equity and government tax revenues. Employment benefits will clearly be greater for projects generating commercial forest products. Forest habitat

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[2] An Environment Canada survey of the economic significance of wildlife to Canadians concluded that the total willingness-to-pay for the enjoyment of wildlife related activities in 1987 was over $6 billion. The survey also calculated that wildlife enhancement currently costs federal and provincial treasuries only $1 for every $4.50 returned in tax revenues. Further investments to protect declining wildlife habitats and populations are rational (Filion 1991).

improvements will create other indirect economic benefits such as increased supply of animal fodder and fuel, food (fish, wildlife and fruits) and shelter materials for local populations.

Goal 4. Political Benefits

Public approval

The Canadian public is concerned about the current state of land use allocation and forest management practices. Public approval will in general be stronger for projects which can not be construed as primarily benefitting forest corporations. It is important that the program seek to uncouple silviculture from unpopular industrial harvest practices in the public's mind. This connection, fostered by public opinion leaders from the environmental movement, is resulting in a softening of public support for silviculture. This has enabled governments to make recent cuts in silviculture programs unopposed.[3] The confusion surrounding this issue means that education and promotion of the variety of benefits of this large-scale silviculture program may be critical to effective program implementation.

Industry interest group support

Industry support will obviously be greater for projects that protect or increase industry access to forest products raw materials supply. Remote or reserved forest plantations will be viewed less favorably, although in the long run increasing the total Canadian forest base reduces the pressures on the working forest. Projects which increase harvesting costs in order to improve soil carbon storage will impact industry profitability in the short-term and will be less popular.

International reputation

International reputation benefits will be greater for programs in developing countries, assuming the projects are successful. Development projects of this kind have a reputation for being top-

[3]Environmental organization leaders are claiming that eliminating clear-cuts will reduce the need for silviculture, since smaller areas cut will tend to regenerate naturally. This simplistic view ignores the role of silviculture in increasing forest productivity, whatever the harvest method. The effect of this claim is that the Canadian public is becoming confused as to whether to press governments and industry to maintain silviculture programs, even though harvest practices have not changed. The incentive of public pressure is the essential ingredient for efficient levels of silviculture funding, and counteracts the failures of market and governments to adequately internalize the external benefits and long time horizons of silviculture.

down in design and delivery, and thus being insensitive to cultural factors and to the needs and well-being of the local population. A prime example is the Tropical Forestry Action Program (TFAP). TFAP is an international program administered by the Forestry division of the U.N. Food and Agricultural Organization (FAO). TFAP allocates significant international funding to forest management in over eighty developing countries. This program has been severely criticized for flawed administration and process, leading to poor results, and certainly few diplomatic reputation gains for its sponsors. Discussion in the international community centers on whether the program can be salvaged by a major overhaul based on recommendations from a recent comprehensive study of the programs results, or whether it needs to be removed from FAO jurisdiction altogether in order to increase success (Sattaur 1991).

Some international forestry projects are successful. One example is a U.S. agro-forestry project in Guatamala, which is widely referred to in global warming literature, and undeniably generates political benefits for the U.S. This project is financed by a Tennessee power generation company, Applied Energy Services (AES), to offset emissions from a newly constructed coal power plant. The AES objective was to implement a forestry project that would sequester the same amount of carbon, 15.5 million tons, as would be produced over the life of the new plant (Trexler, in Winjum et al 1991). Responsibility to design and administer the program was delegated to an international relief organization, CARE International. CARE has been involved in agriculture and forestry projects in Guatamala since 1974, and had established contacts and relationships with a network of local NGOs and communities. This local presence is considered to be a key factor in the program's success.

Appendix 8

Constraints

Constraint 1.

Technically available land

Technically available land is land for which silviculture would be an efficient use in that conversion to silvicultural use would not lead to opportunity costs greater than the aggregate benefits generated by silviculture. A report by a forestry consulting firm concludes that there are over 84 million hectares of land technically available for incremental silviculture programming in Canada (Nagle 1990). The greatest proportion of available land is classified as marginal agriculture land. Other available land is found in areas in which forest losses have historically not been re-stocked. Some of the largest wild fire burns occur in parks and forest reserves, many of which are difficult to access for fast response to fires. These burns are usually not re-planted.

Vast unstocked areas from old and new harvests are also available. The area not sufficiently re-stocked (NSR) in productive non-reserved forest lands increased 4.7 million hectares in the decade from 1977 to 1986 and is continuing to increase. Canada's NSR totaled 15 million hectares in 1986 according to the federal government's conservative calculations (Canada. Forestry Canada 1990a). According to industry spokespersons, the current NSR actually totals a staggering 27 million hectares. They assert that the lower NSR figures claimed by governments result from a sleight-of-hand in which lower stocking densities are characterized as "sufficient", and less productive areas are removed from NSR classification. The official NSR totals thus decline progressively, without any further stocking taking place (Brinkman 1992).

In tropical countries available land includes abandoned lands that are eroded and degraded from swidden agriculture, deforested areas, and marginal agriculture and pasture lands. An estimated 758 million hectares of degraded lands, much of which has little alternative use, are available for forest replenishment in developing countries. Of this total, 203 million hectares falls in the potentially very productive category of previously forested land in the humid tropics (Sedjo 1989).

Socially suitable land

Socially suitable land area is a sub-set of the area technically available. Available land may not be socially suitable for silviculture for a number of reasons. Difficult access, owner objectives and preferences with respect to private land use, land-use customs and cultural taboos, unauthorized exploitation of land stemming from population increases and poverty are some of the social factors that can mean available land is not suitable. This constraint tends to be greater in more densely populated regions targeted for potential silviculture projects. "Socially suitable" is an especially important distinction when planning silviculture projects in developing countries.

Constraint 2. Knowledge

Research

Scientific understanding of the carbon cycles of soils, biotic species and industrial activity (fertilizing, harvest and transportation for example) is needed for least-cost CO_2 mitigation. Forestry and forest economics research provides an understanding of plantation management systems which will maximize tree survival and growth goals. Ecology research advances understanding of ecosystem diversity and resilience. Research will be more complete for silviculture activities and objectives that are already operational on a large scale. It will tend to constrain the size of experimental program options.

Information administration

Reliable information improves the effectiveness of a silviculture program. Good data collection and analysis is needed to create the necessary feedback loops. Sophisticated information administration is more likely to be found in corporations, where accountability to stakeholders for budgets and results is a greater priority than it may be in government departments. Information from government-administered forest lands tends to be collected and held at the district level, and systems for coordinating this into aggregate information need improvement. This is not a critical criteria since information administration capability is easily bought or transferred.

Constraint 3. Infrastructure

Administrative capability

Administrative capability has both people and systems elements. Expertise in diagnosing silviculture requirements, and designing and directing programs is one aspect. Another is administrative systems such as well designed contracts,[4] worker health and safety standards and other regulatory requirements which ensure the smooth functioning of large projects. In developing countries, Canadian funded forestry projects will be dependent on the administrative capabilities of local organizations that are knowledgeable in forestry.

Seedling nursery capacity

Seedling production is the most capital-intensive phase in silviculture. Productive and innovative nursery facilities are a key to achieving least-cost, quality plantations. Canada's seedling production industry could, in aggregate, immediately double its seedling production without significant increases in investment, since recent cuts in silviculture funding have left nurseries operating well below capacity. Projects in Canadian regions without existing nursery facilities could utilize seedlings transported from other regions until local facilities are constructed. For the most part, large projects in developing countries will require construction of new greenhouse facilities.

Silviculture delivery capacity

Delivery capacity for rural projects consists of the people, organizations and equipment in the silviculture industry as well as its related and supporting suppliers. Landscaping firms, tree maintenance firms and property owners are capable of delivering program components for urban trees. Delivery capacity in tropical countries is more likely to depend on local community groups and non-governmental organizations, and equipment and supplies may need to be imported.

[4] What defines quality in silviculture services? Since the answer has many variables, monitoring of silviculture suppliers requires subjective judgement. The design clarity, completeness and fairness of a silviculture legal contract has a major role in ensuring the cost-effective and quality supply of silviculture services.

Appendix 9

Silviculture Program Cost and Benefit Analysis

1. Gross Cost Assumptions

Nursery cost

- Tropical segment relatively high cost due to absence of existing infrastructure.
- Domestic segments cost (Brinkman 1992).

Planting cost

- Includes all contractor cost including overhead and profit.
- Domestic rural segment cost (Brinkman 1992).
- Urban trees cost (Nagle 1990).

Site preparation and maintenance

- Tropical segment includes protection and replacement of plantation losses.
- Domestic segment includes vegetation management and other treatments necessary to ensure plantation health and productivity. Per hectare cost (George et al 1991).

Program Administration

- Cost incurred by government to administer and monitor program.
- 20% of total other costs (not including rent).

Per hectare cost

- Assumes a density of 1200 trees per hectare (Nagle 1990).

Land rent

- Tropical and urban segments assume public land with low opportunity cost. Therefore rent = $0
- Rural segments assume Timber supply is 75% private land, 25% public NSR land; Bio-fuel supply is 100% private land. $127 per hectare rent paid on private land as incentive to landowner (Andrasko et al 1991).

2. Economic Benefits Assumptions

Rates of return

- Tropical segment assumes no return to Canada, although returns are probably available to the host country.
- Timber supply assumes 20% of timber supply plantations are situated on "good" sites and 80% on "medium sites", averaging a 5% real rate of return (Tolnai 1991).

- Bio-fuel supply assumes 3% return, lower than the 5% returns reported in (Hummel et al 1988) since this program is experimental in Canada..

Expected return

- 5% low risk discount rate and 8% social discount rate used to discount economic returns.
- Plantation harvest rotation is 75 years (Nagle 1990).

3. Non-consumption Benefits Assumptions

Tropical segment

- Assumes no benefit to Canadians.

Domestic segments

- Benefits are applied only to areas within 200 km of urban centers.
- Urban non-consumption benefits are $433 per hectare per year based on per activity day values established for Seymour Mountain recreation use, in North Vancouver, B.C. (Heaps 1985). Using a 5% discount rate NPV = $8653 per hectare. Using an 8% discount rate NPV = $5408 per hectare. 1979 dollar values are adjusted to 1991 values.
- Non-commercial plantations benefits are $5.75 per hectare per year based on the range of values established for the Stein Valley, B.C. (Gunton 1991). The value selected is at the one-quarter point of the range. Using a 5% discount rate NPV = $115 per hectare. Using an 8% discount rate NPV = $72 per hectare. 1985 dollar values are adjusted to 1991 values. Calculations assume 10% of project areas are within the 200 km limit.
- Timber harvest plantations provide recreation and other non-consumption benefits on the 75% which is on marginal agriculture land, and thus will be within the 200 km limit. No benefits assumed for the 25% on NSR land.
- Bio-fuel supply assumes no non-consumption benefits due to shorter rotation period for these plantations.

4. Carbon Sequestration Assumptions

Rate of carbon uptake

- Tropical forest rate estimated to average 3 times temperate rural forest rate (Marland 1988).
- Urban trees rate estimated to be 2 times rural forest rate due to fuel carbon avoidance from temperature moderation effects.
- Non-commercial and Timber supply forests rate based on (Nagle 1990).
- Bio-fuel plantations use species such as hybrid poplar with 2-3 times growth rate of other species (Nagle 1990); 2 times rural forest rate assumed in the calculations.

Table 9.1 **Establishment Costs**

Program Segment	Nursery & Transport ($/tree)	Planting contract ($/tree)	Site prep & Maintainance ($/tree)	Program Admin ($/tree)	Plantation Cost ($/tree)	Plantation Cost ($/hectare)	Land rent ($/hectare)	Total ($/hectare)
Tropical	0.15	0.05	0.15	0.07	0.42	504	0	504
Urban trees	3.00	5.00	2.00	2.00	12.00	14400	0	14400
Non commercial	0.17	0.22	0.33	0.14	0.86	1037	0	1037
Timber supply	0.17	0.22	0.33	0.14	0.86	1037	95	1132
Bio-fuel supply	0.17	0.22	0.33	0.14	0.86	1037	127	1164

Table 9.2 **Direct Benefits**

Program Segment	Area (000 ha)	Gross Cost ($million)	Real Return (percentage)	(k=5%) NPV (million$)	(k=8%) NPV (million$)
Timber supply	6250	7075	5	7075	855
Bio-fuel supply	1250	1455	3	1455	42

Table 9.3 **Non-consumption Benefits**

Program Segment	Area (000 ha)	Portion near urban center (%)	(k=5) NPV (per hectare)	(k=8) NPV (per hectare)	(k=5) Total value ($million)	(k=8) Total value ($million)
Urban	1250	100	8653	5408	10816	6760
Non-commercial	2500	10	115	72	29	18
Timber supply	6250	75	115	72	539	338

Table 9.4 **Net Cost Summary**

Program Segment	Program Portion (%)	# units (000 ha)	Cost/ha ($)	Gross cost ($million)	(k=5) Economic Benefit ($million)	(k=8) Economic Benefit ($million)	(k=5) Non-consump. Benefit ($million)	(k=8) Non-consump. Benefit ($million)
1. Tropical	10	1250	504	630	0	0	0	0
2. Urban	10	1250	14400	18000	0	0	10816	6760
3. Non-commercial	20	2500	1037	2593	0	0	29	18
4. Timber supply	50	6250	1132	7075	7075	855	539	338
5. Bio-fuel supply	10	1250	1164	1455	1455	42	0	0
Total	**100**	**12500**		**29753**	**8530**	**897**	**11384**	**7116**

	(k=5) Net cost ($million)	(k=8) Net cost ($million)	Carbon sink per hectare (metric Tonne)	Total Carbon Storage (000 Tonne)	(k=5) Net Cost ($/T Carbon)	(k=8) Net Cost ($/T Carbon)
1. Tropical	630	630	370	462225	1.36	1.36
2. Urban	7184	11240	247	308150	23.31	36.48
3. Non-commercial	2564	2575	123	308150	8.32	8.35
4. Timber supply	-539	5883	123	770375	-0.70	7.64
5. Bio-fuel supply	0	1413	247	308150	0.00	4.59
Total	**9838**	**21740**			**3.78**	**9.73**

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