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NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

ESTIMATED COSTS FOR THE U.S. FOREST PRODUCTS INDUSTRY TO MEET THE GREENHOUSE GAS REDUCTION TARGET IN THE KYOTO PROTOCOL

SPECIAL REPORT NO. 99-02

JUNE 1999

Acknowledgments

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PRESIDENT'S NOTE

In this report, NCASI has estimated the costs for reducing CO_2 emissions from the forest products industry to levels 7% below estimated 1990 emissions, a reduction called for in the Kyoto Protocol. Under a common-marginal-cost scenario (i.e., the cost for removing the next ton of carbon is the same for all facilities), the capital costs for reducing overall industry emissions from projected 2010 levels to the Kyoto Protocol target are estimated to be at least $6 billion. Estimated annualized costs have been found to be highly sensitive to assumptions about energy costs and the potential for selling excess power. Uncertainties regarding the impacts of utility deregulation contribute to the inability to narrow the range of estimated annualized costs. Plausible scenarios can be developed yielding annualized costs (i.e., annualized capital plus operating costs/savings) ranging from less than -$250 million/year to more than +$1 billion/year.

At the point where the reductions are large enough to meet the Kyoto Protocol target in 2010, the estimated marginal costs for reductions are also highly variable. At current energy prices, the range of marginal costs is approximately $25 to $177/metric ton of carbon, depending primarily on the profitability of excess power sales.

The costs for remaining under the permanent cap established by the Kyoto Protocol escalate rapidly with time. In 2020, the cumulative capital costs for reducing emissions increase to the range of $8 to $13 billion. The range in estimated annualized costs in 2020 is even greater than in 2010—from less than -$250 million/year to greater than +$2 billion/year.

An examination of the differences in projected compliance costs among different pulp and paper production categories suggests that the differences between mills within a given category are much greater than differences that might exist between categories. The variability from mill to mill is largely explained by the potential ability of some mills, but not others, to reduce emissions by generating excess power and selling it to the grid for a satisfactory profit.

A limited analysis was performed of the impacts of higher energy prices—prices that other researchers have projected could result from U.S. compliance with the Kyoto Protocol. This examination suggests that under a high-energy-cost scenario the energy cost impact of the Kyoto Protocol could be greater than the direct costs for reducing forest products industry CO_2 emissions. Even at a carbon cost of only $25/metric ton—a cost much lower than most researchers project will be needed to ensure that the U.S. complies with the Kyoto Protocol—energy costs for the industry would increase by more than $500 million/year.

Although the cost estimates in this report were based on currently available technology, a brief analysis of biomass/black liquor gasification combined cycle technology was conducted. Based on the examination of five different mill scenarios using data generated by other researchers, it appears that biomass/black liquor gasification combined cycle technology could reduce the industry's indirect emissions by 100 to 300+ kg carbon/ton pulp, an amount large enough to accomplish one-half or more of the reductions needed by 2010 if the technology were applied to all of the recovery furnace capacity expected to be at least 35 years old by that date.

There are a number of important considerations that this study did not address. First, the study did not examine credits for carbon sequestered in forests, products, and wastes. Presumably, such credits would reduce compliance costs. Second, the negative impacts of forced CO_2 reductions on the nation's economy were not addressed, even though the resulting depressed demand for forest products and increased raw material costs could be more significant to the industry than the direct costs for reducing emissions. Third, no attempt was made to examine the benefits of a nationwide or international carbon trading system. A number of studies have suggested that compliance costs would be significantly reduced under an economically efficient trading system. Fourth, the study did not attempt to quantify the additional costs that would result from a carbon tax, although it is clear that such a tax could impose substantial costs if levied on the 26.1 million tons of carbon per year remaining after the industry meets its Kyoto Protocol target. Finally, the study did not attempt to translate compliance costs into impacts on the industry's competitiveness or economic viability.

Three individuals with relevant expertise, but not working for forest products industry companies, were convened as a Peer Review Group to assist in the analysis and provide a third-party assessment of the approach used by NCASI. The findings of the Peer Review Group follow this letter.

Ronald A. Yeske

June 1999

REPORT OF THE PEER REVIEW GROUP

To assist NCASI in its efforts to estimate the costs to the forest products industry for reducing greenhouse gas emissions, and to provide a third-party assessment of the reasonableness of the approach used by NCASI, a Peer Review Group was assembled. The members of the Peer Review Group are listed at the end of the following statement prepared by that group.

PEER REVIEW GROUP REPORT

The Peer Review Group (PRG) met twice with members of the CO_2 Reduction Task Group and the NCASI staff, who did the technical analytical work that is presented in the final report. The Task Group consisted of engineering representatives from some of the major companies that constitute the forest products industry. The first such joint meeting was on September 3, 1998, and the second was on December 15. Both were all-day meetings and featured technical presentations by NCASI staff and by EKONO representatives, who were retained by NCASI to identify commercially available technologies and operating practices that might lead to reductions in energy usage. These technical presentations involved much conversation and interaction by all present. Seventeen suggestions for improvements by the Peer Review Group were duly handled. Following its final review of the work in March 1999, the PRG is pleased to submit the following report:

The Peer Review Group affirms that the estimates were made using good engineering assumptions, and potential sources of error in the assumptions were identified. In addition, all reasonable attempts were made to avoid biasing the results, and unavoidable sources of potential bias were clearly identified.

Only energy reduction technologies available today were considered (i.e., emerging ideas were omitted). The adoption of new technologies, if successful, such as impulse drying or black liquor and biomass gasification, could greatly facilitate reaching the goals proposed here. In particular, it is noteworthy that the industry seems to be coalescing about black liquor gasification as a promising emerging technology, but federal help will be necessary for adequate in-plant experiments.

We were also impressed that NCASI staff had consulted with EPRI, and others outside the industry, on relevant power-generation issues. The cost of purchased power depends on choice of fuel, which is an economic decision that depends on the region of the country. Because of the higher heat of combustion of methane, natural gas produces less CO_2 per kW or per ton of steam raised than either coal or oil. Therefore, one of the most effective steps to reduce CO_2 emissions is to convert coal- or oil-fired power boilers to natural gas or replace them with gas turbines and waste-heat boilers, as reported by NCASI.

CO_2 emissions are highly sensitive to growth in the production of paper and other forest products, and this too has been well researched and is presented in the report.

While the Peer Review Group was not asked to comment on the issue of global climate change itself, it is certainly clear that the Kyoto accords place extreme demands on the forest products industry. It is our opinion that this report is an honest and thorough study of the probable costs of implementing known technologies to reach the Kyoto goals.

Respectfully submitted, Peer Review Group

Henry A. McGee
Ralph Overend
William W. Austin - Chair, Peer Review Group

PEER REVIEW GROUP QUALIFICATIONS

Henry A. McGee, Jr.

Dr. McGee was educated in chemical engineering and theoretical chemistry at Georgia Tech and the University of Wisconsin. He is a scientist, an engineer, a teacher, an administrator, and a small businessman. He was on the faculty of Virginia Tech for 23 years, including ten years as head of the Department of Chemical Engineering, before becoming Founding Dean of the new School of Engineering at Virginia Commonwealth University. He has published dozens of technical papers in the scientific literature. His most recent book, *Molecular Engineering*, appeared in 1991. He is the recipient of numerous honors and recognitions, and in May 1994 he was selected as one of 75 founding inductees into the Academy of Distinguished Engineering Alumni at Georgia Tech.

Ralph Overend

Ralph Overend has worked in bioenergy and renewable energy since 1973. He started the biomass power program at the National Renewable Energy Lab (NREL) upon joining the laboratory in 1990. Dr. Overend's technical specialization is chemical reaction kinetics for thermochemical and biological processes of biomass. He has published five books and more than 120 journal articles, and serves as an editor for the journal, *Biomass and Bioenergy,* and the biomass section of the journal, *Solar Energy*. Dr. Overend manages the technology aspect of the Burlington, Vermont, gasifier project and recently received an R&D 100 Award for his accomplishments on this project. In addition to the Vermont gasifier project, he is currently very active in a joint project with the government of China on biomass availability. He has served around the world as lecturer and advisor for the United Nations and the UN Food & Agriculture Organization. Prior to joining NREL, he managed bioenergy programs for the National Research Council of Canada.

Bill Austin

Bill Austin was educated at North Carolina State University in electrical engineering. He graduated in 1965. His subsequent career at Procter & Gamble included increasing responsibilities in engineering and manufacturing leadership over the next 23 years, culminating in his role as Associate Director of Pulp Division Engineering. In 1987, he moved to Seattle, Washington, to found the engineering firm now known as Industra, a consulting business specializing in meeting the needs of the pulp and paper industry. Following retirement from Industra in 1998, he has recently assumed the role of President of ThermoChem, Inc., a technology development company devoted to successful gasification of biomass, including black liquor. Throughout his career, he has focused on the development and commercialization of technologies that benefit industry.

ESTIMATED COSTS FOR THE U.S. FOREST PRODUCTS INDUSTRY TO MEET THE GREENHOUSE GAS REDUCTION TARGET IN THE KYOTO PROTOCOL

SPECIAL REPORT NO. 99-02
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ABSTRACT

In this report, NCASI has estimated the costs for reducing CO_2 emissions from the forest products industry to levels 7% below estimated 1990 emissions, a reduction called for in the Kyoto Protocol. The pulp and paper sector of the industry was studied by developing quasi-mill-specific energy balances for 90 mills accounting for approximately one-third of the pulp and paper produced in the U.S. Wood products facilities were handled differently due to limited data. One model facility was prepared for each type of wood product under study. Each facility's production was assumed to grow at 1.5% per year (an important assumption, as costs have been found to be highly sensitive to growth rate). For each of the facilities, NCASI "installed" commercially available CO_2–reducing technologies in order of increasing cost per ton of carbon reduced until the target was met. As is the normal convention, biomass (e.g., black liquor, bark) was considered to have a greenhouse gas emission factor of zero in all calculations. The analysis focused on total emissions (i.e., the total of direct and indirect emissions) because (a) this best describes the impact associated with the manufacture of forest products, and (b) under a national public policy to reduce emissions, companies would pay to reduce their own emissions and would bear much of the cost for reductions required of their suppliers. The most important indirect emissions considered in this study were for purchased electricity.

Under a common-marginal-cost scenario (i.e., the cost for removing the next ton of carbon is the same for all facilities), the capital costs for reducing overall industry emissions from projected 2010 levels to the Kyoto Protocol target are estimated to be at least $6 billion. Estimated annualized costs have been found to be highly sensitive to assumptions about energy costs and the potential for selling excess power to the grid. Plausible scenarios can be developed yielding annualized costs (i.e., annualized capital plus operating costs/savings) ranging from less than -$250 million/year to more than +$1 billion/year. At the point where the reductions are large enough to meet the Kyoto Protocol target in 2010, the estimated marginal costs for reductions are also highly variable. At current energy prices, the range of marginal costs is approximately $25 to $177/metric ton of carbon, depending primarily on the profitability of excess power sales. The costs for remaining under the permanent cap established by the Kyoto Protocol escalate rapidly with time. In 2020, the cumulative capital costs for reducing emissions increase to the range of $8 to $13 billion. The range in estimated annualized costs in 2020 is even greater than in 2010—from less than -$250 million/year to greater than +$2 billion/year.

Under a system employing mill-specific targets (i.e., each mill must reduce emissions to 7% below its 1990 emissions), estimated compliance costs for the industry are significantly larger than those incurred under a system wherein each mill reduces emissions to a common marginal cost per unit of CO_2 reduced.

KEYWORDS

carbon dioxide, climate change, CO_2, emissions, global warming, greenhouse gases, Kyoto Protocol

RELATED NCASI PUBLICATIONS

Special Report No. 98-02 (December 1998). *Estimated CO_2 emissions resulting from compliance with U.S. federal environmental regulations in the forest products industry.*

Technical Bulletin No. 717 (June 1996). *Review and analysis of JABOWA and related forest models and their use in climate change studies*.

Technical Bulletin No. 690 (January 1995). *Global change and forest responses: Theoretical basis, projections, and uncertainties.*

Technical Bulletin No. 628 (March 1992). *Effects of forest management on soil carbon storage.*

CONTENTS

TABLES

FIGURES

ESTIMATED COSTS FOR THE U.S. FOREST PRODUCTS INDUSTRY TO MEET THE GREENHOUSE GAS REDUCTION TARGET IN THE KYOTO PROTOCOL

1.0 INTRODUCTION

A portion of the solar energy reaching the earth's surface is re-emitted from the surface as infrared energy. A number of atmospheric gases are known to absorb this infrared radiation, trapping it in the lower atmosphere. Without this natural "greenhouse" effect, the surface of the earth would be much colder, well below the freezing temperature of water. The primary atmospheric greenhouse gases are water, carbon dioxide, methane, and nitrous oxide, but a variety of other greenhouse gases are present in much lower concentrations (e.g., chlorofluorocarbons). Water vapor is present in the atmosphere at concentrations of approximately 1%. The average CO_2 concentration in the atmosphere is much lower, between 0.035% and 0.040%, with the remaining greenhouse gas concentrations being several orders of magnitude lower yet. The abilities of these gases to absorb infrared radiation vary greatly, as do their lifetimes in the atmosphere; also, the ability of the atmosphere to hold additional amounts of each gas varies (EIA 1997a).

Today's atmospheric levels of CO_2 are approximately 30% higher than pre-industrial levels (EIA 1997a). The Intergovernmental Panel on Climate Change reports that "this increase is primarily due to combustion of fossil fuel and cement production and to land-use change" (IPCC 1996). Attempts to relate increasing levels of greenhouse gases to changes in global climate are performed using enormously complex mathematical simulation models. Although there is a great deal of variability among models and large uncertainties surrounding their output, these models generally predict an increase in global surface temperature with increasing atmospheric concentrations of greenhouse gases (EIA 1997a; IPCC 1996). These findings have given rise to international concern about the potential for increasing atmospheric concentrations of greenhouse gases to cause changes in global climate. In recent years, this concern led to an effort by the United Nations to forge an international agreement to limit or reduce greenhouse gas emissions, an effort that reached fruition in Kyoto, Japan, in 1997.

In December 1997, the Clinton Administration endorsed the Kyoto Protocol to the United Nations Framework Convention on Climate Change, and subsequently signed the Protocol in November 1998. As of the beginning of 1999, the Protocol, an excerpt of which is included in this report as Appendix A, had been signed by a number of heads of state, but few countries had obtained the needed endorsement from their respective legislative bodies. The Kyoto Protocol, if ratified by the U.S. Senate and implemented by the Administration, would require the U.S. to reduce its greenhouse gas emissions dramatically (down to 7% below 1990 levels) by sometime between 2008 and 2012.

The U.S. forest products industry, represented by the American Forest and Paper Association (AF&PA), has adopted a position statement on global climate change that emphasizes, among other things, the need to base public policy on good science, the importance of a level international playing field, the assignment of a CO_2 emission factor of zero to biomass burned for energy, and the need to use carbon accounting rules that include sequestration in forests, products, and wastes. The AF&PA Position Statement is attached as Appendix B.

Public policy discussions at the state, national, and international level have generated a number of questions that the industry must address in order to understand the potential impacts of efforts to reduce greenhouse gas emissions. The industry has launched a number of studies intended to address these questions. Among the issues being studied are (a) the role of forests and forest management practices in carbon sequestration and cycling, (b) the cycling and storage of carbon in forest products and wastes, (c) projected business-as-usual emissions of greenhouse gases, (d) options available for reducing manufacturing-related emissions of carbon dioxide, and (e) the CO_2 emissions associated with efforts to comply with regulatory requirements targeted at other environmental concerns.

This report contains the results of NCASI studies dealing with current and projected manufacturing-related emissions, the cost of currently available measures for reducing these emissions, and the potential impact of several emerging technologies.

2.0 BACKGROUND

Six classes of greenhouse gases are targeted for reduction by the Kyoto Protocol to the United Nations Framework Convention on Climate Change – carbon dioxide, methane, nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Of these, carbon dioxide is the most important, accounting for over 80% of the total global warming potential associated with U.S. emissions of greenhouse gases (EIA 1998a).

These gases are often reported in quantities of metric tons of carbon equivalents (MTCEs), a reporting unit which reflects the weight of the carbon in the equivalent amount of CO_2 from a "global warming potential" standpoint. A metric ton of carbon dioxide, therefore, is equivalent to 0.27 metric tons of carbon equivalents (12/44 = 0.27). A metric ton of methane is often considered to have the global warming potential of 21 tons of carbon dioxide (EIA 1997a). Because 21 tons of carbon dioxide contain approximately 6 tons of carbon, a ton of methane can be reported as 6 metric tons of carbon equivalents. Carbon dioxide is the greenhouse gas of primary interest in this report. In most cases, it is reported as metric tons of carbon, meaning metric tons of carbon equivalents.

Using U.S. Department of Energy (DOE) emission factors, NCASI has estimated forest products industry-related CO_2 emissions from industry fuel consumption and purchased power statistics. An emission factor of zero has been used for biomass fuels, including spent pulping liquor. The U.S. forest and paper industry's direct CO_2 emissions from primary manufacturing facilities are estimated to have been approximately 20 million metric tons C in 1995. Adding indirect emissions associated with purchased power increases the 1995 industry total by about 10 million metric tons. Accordingly, mid-1990s total (direct plus indirect) CO_2 emissions were approximately 30 million metric tons carbon per year. (The calculations used to derive these estimates are discussed in detail later in this report.)

Total U.S. annual emissions of CO_2 are estimated to be approximately 1.5 billion metric tons carbon, while total industrial emissions approach 500 million metric tons per year (EIA 1997a). Thus, forest product industry-related emissions are 2% of total U.S. emissions and 6% of CO_2 emissions from all U.S. industries.

There are a variety of methods for developing the Kyoto Protocol target for the industry. In this study, NCASI examined targets encompassing total emissions (the total of direct and indirect emissions) because (a) they represent the overall impact of the industry's manufacturing activities, and (b) the industry would be likely to bear the cost of forced reductions in both direct and indirect emissions. In some cases, the pulp and paper industry target has been developed separately from that for the wood products sector of the industry. The various Kyoto Protocol targets are listed in Table 1.

The Kyoto Protocol contains a target to be met in the 2008 to 2012 time frame. Accordingly, estimating the costs to comply with this target requires an estimate of the industry's future business-as-usual (BAU) emissions. In Section 3, the forest products industry's emissions of carbon dioxide are estimated for the years 2010 and 2020. The estimates are developed by extrapolating trends from the recent past. These BAU extrapolations are then compared to the target contained in the Kyoto Protocol for the United States. The year 2010 is examined because if the Kyoto Protocol is adopted in the U.S. the target will have to be met in the 2008 to 2012 time frame. The year 2020 is also considered, because the Kyoto Protocol target is permanent and the industry must continue to expend capital to remain below the target beyond 2010.

Table 1. Kyoto Protocol Targets for the Forest Products Industry (7% below 1990 emissions)

	Kyoto Protocol Target (10^6 metric tons C/yr)		Mid-1990s Emissions (10^6 metric tons C/yr)	
	Direct Emissions	Total Emissions	Direct Emissions	Total Emissions
Pulp and paper	16.7	22.8	19.0	26.3
Wood products	1.0	3.3	1.2	3.7
All forest products	17.7	26.1	20.2	30.0

In the following analysis of the costs to meet the target, a variety of assumptions have been required that have the potential to impact the results. Those suspected of being most significant are listed below.

1. As is the normal convention, a greenhouse gas emissions factor of zero is used for biomass burned for energy. The rationale for this widely used convention is explained elsewhere (Lucier 1999). Without this assumption, estimated costs would be expected to be higher.
2. Although there are compelling technical and policy justifications for allowing credits for carbon stored in forests, products, and wastes, such sequestration credits are not considered in this study due to the current uncertainty regarding how such credits would be calculated and assigned. Estimated compliance costs would be lower if some of the needed reductions could be accomplished through sequestration credits.
3. It is assumed that as the industry reduces its consumption of purchased electricity or sells additional electricity to the grid it will receive credit for avoided greenhouse gas emissions at the local utility. In this study, it is assumed that the credits will be equal to the avoided emissions from the generation of marginal power supplied to the regional grid. This assumption maximizes the credit for avoided emissions at the utility. Credits based on other assumptions would result in higher estimated compliance costs.
4. The industry is assumed to grow by 1.5% annually through 2020. This appears to be a reasonable mid-range projection, but the cost estimates are highly sensitive to changes in this assumption.
5. The industry is assumed to meet its Kyoto Protocol target by reducing mill emissions to a constant marginal cost across the industry, an optimal, least-cost approach requiring the equivalent of a perfectly efficient intra-industry carbon trading system. To the extent that such a system is less than perfectly efficient or alternative approaches are used, the costs would be higher.
6. The study assumes that all needed reductions will be accomplished by reducing forest product manufacturing-related emissions; i.e., there is no opportunity to participate in a carbon trading program outside of the industry. The availability of a national or international carbon trading program would reduce compliance costs.
7. Only currently available technologies are considered in the analysis.

8. Capital costs are annualized by repaying them over ten years at a 10% annual interest rate.

These and other sources of uncertainty and potential bias are discussed in greater detail later in this report.

3.0 ESTIMATED 2010 AND 2020 CARBON DIOXIDE EMISSIONS ATTRIBUTABLE TO THE U.S. FOREST PRODUCTS INDUSTRY

3.1 Projected Pulp and Paper Mill Emissions of Carbon Dioxide

3.1.1 *Energy Use and Production Data*

The American Forest and Paper Association (AF&PA) surveys the industry annually to document, among other things, the industry's pulp, paper, and paperboard production and energy use. Data for fossil fuel use, electricity purchases, and total industry production (essentially equal to the sum of paper, paperboard, and dried pulp production) are shown in Figure 1 and listed in Appendices C and D (AF&PA 1997a, 1998a).

The data document that until the early 1980s the industry's total fossil fuel use declined, and that it has been increasing since the mid-1980s. Purchased electricity consumption has increased steadily over the period of record, as has, in general, the industry's total production. The fossil fuel use and purchased electricity consumption per unit of production are plotted in Figure 2. These data document a general reduction in the amounts of fossil fuel used per unit of production and, since approximately 1980, a similar but less pronounced trend in purchased energy consumption. Not shown in the figure, and not considered in this analysis, are past or current energy sales. Since the mid-1980s, pulp and paper industry energy sales per unit of production (assumed to be primarily excess power sales) have remained essentially constant at less than 3% of total purchased energy (fossil fuel and power) per unit of production. Excluding them, therefore, would not be expected to introduce significant error. Later in this report, however, it becomes clear that future excess power sales could become an important element of the industry's efforts to reduce manufacturing-related emissions.

NCASI has independent fossil fuel data sets for 1990 and 1995. The 1990 data agree well with AF&PA's, but NCASI's 1995 data set suggests somewhat higher fossil fuel use. Because NCASI's 1995 database contains fuel use data by boiler (information needed for portions of this exercise), the NCASI data were used in developing the 1995 mill energy models discussed later in this report. AF&PA's energy data, however, are more complete over time and more widely cited than NCASI's. In this study, therefore, the AF&PA data were used to estimate future emissions from the industry.

3.1.2 *Emission Factors*

Emissions from fossil fuel burning were estimated from fuel use data using DOE emission factors (EIA 1997a). As is the common convention, biomass fuels were assigned a CO_2 emission factor of zero. For purposes of projecting future emissions, the emission factor for purchased electricity was developed by using DOE state-specific emission factors for purchased electricity and industry production statistics, by state, to derive an industry production-weighted emission factor for purchased electricity. The emission factors used in this study to project business-as-usual (BAU) emissions are shown in Table 2.

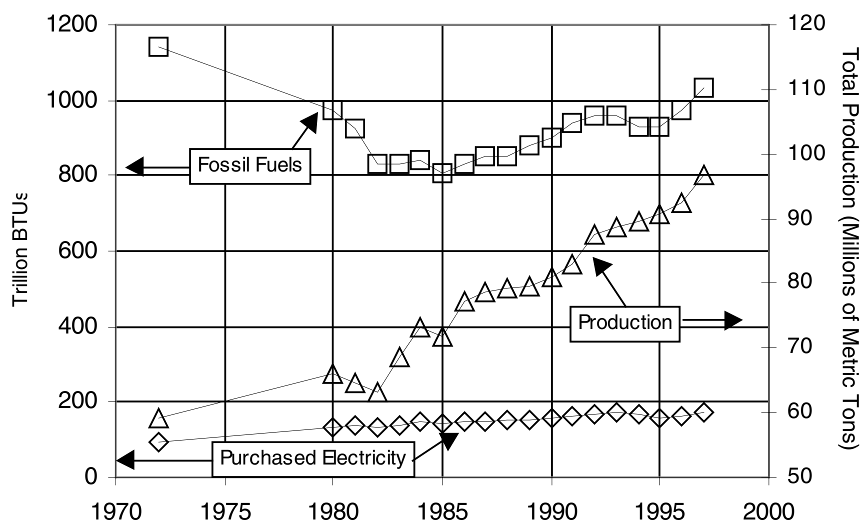

Figure 1. AF&PA Data on Fossil Fuel Use, Purchased Electricity, and Industry Production

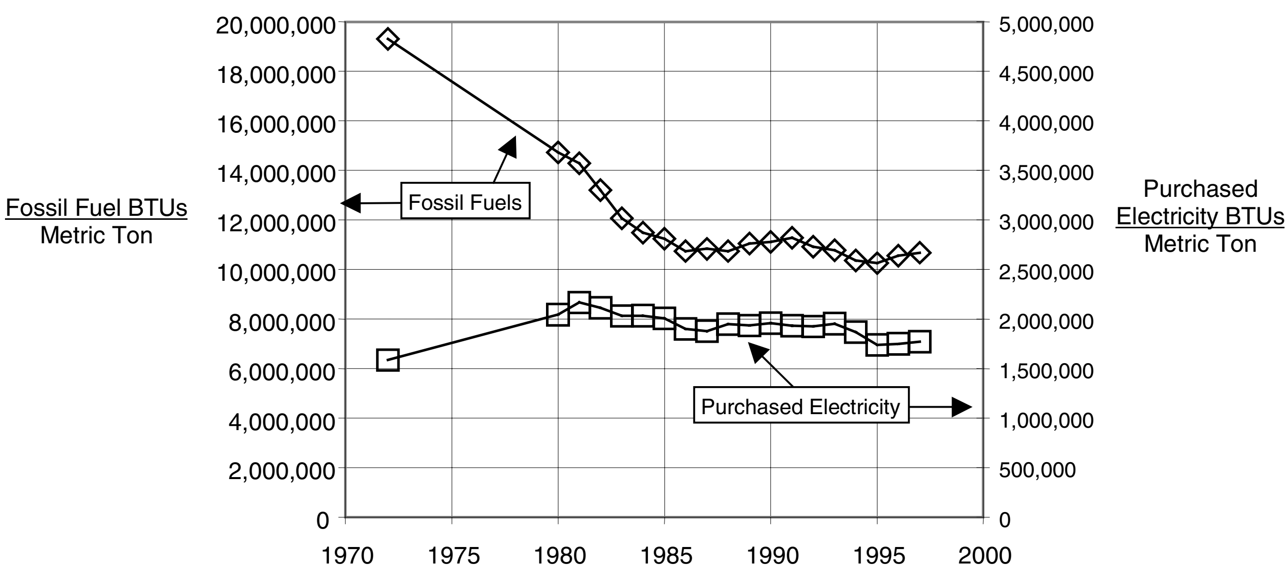

Figure 2. Fossil Fuel and Purchased Electricity Use per Unit of Production

Table 2. CO_2 Emission Factors

Energy Form	CO_2 as equivalent metric tons carbon	Units
Purchased electricity	140.5	per 10^9 Watt-hours
Natural gas	14.47	per 10^9 BTU in fuel
Diesel	19.95	per 10^9 BTU in fuel
Coal	25.63	per 10^9 BTU in fuel
Residual oil	21.49	per 10^9 BTU in fuel
Biomass	0	per 10^9 BTU in fuel

3.1.3 *Projected Pulp and Paper Mill Emissions*

Emissions from the industry are a function of two parameters, the amount of carbon emitted per unit of production (e.g., per ton of paper) and the industry's production. If both of these parameters continue to change in the same direction and rate as occurred in the past, a direct extrapolation of emissions data would be reasonable. The rate of improvement in fossil fuel use per unit of production (shown in Figure 2) is slowing, however, suggesting that further business-as-usual improvements in per unit emissions will not occur at the same rate as previously observed. At the same time, there is reason to believe that the industry will grow more slowly over the next decade. These factors complicate the interpretation of directly extrapolated emissions data.

Accordingly, an attempt was made to examine trends in per unit emissions and production growth separately so that the impacts of varying growth rates could be examined. The industry's total (direct plus indirect) emissions of carbon per unit of production are plotted in Figure 3. The data were analyzed to develop a best-fit curve to project future emission factors. Pre-1982 data were not included because a visual examination of the industry's energy use patterns suggests that the directional trend in energy use changed between 1981 and 1982 (Figures 1 and 2). The trend line used to extrapolate the unit emission factors is the best fit line of the data transformed to fit an equation of the form:

$$\ln(Y - a) = m X + b$$

where Y = emissions in tons carbon/ton production
X = year
a = the asymptote that Y approaches, and
m, b = terms selected based on the best fit of the transformed data.

This mathematical relationship was selected based on the observation that progress in reducing business-as-usual emissions per ton is being made at a diminishing rate toward a limiting minimum emission factor. The data were analyzed to obtain the best fit for a, m, and b. The data and the best fit equation are plotted in Figure 3. The coefficient of determination (R-squared) of the curve-fit was 0.94.

The extrapolated unit emission factors for 2010 and 2020 shown in Figure 3 are essentially the same, 0.2796 and 0.2794 metric tons carbon per metric ton of production, respectively, before accounting for new environmental regulations. These emission factors were applied to future industry production assuming three scenarios. The mid-range case assumed that industry production would increase by 1.5% per year from the mid-1990s through 2020. AF&PA has projected that capacity will increase at 0.9% annually for the 1999 through 2001 period (AF&PA 1998b). This is lower than the 1.2% growth in capacity in 1998 and significantly lower than the 2.6% annual growth observed in the 1986 to 1996 period. For several reasons, however, it was determined that a mid-range production growth projection as low as 1% was inappropriate for the period through 2020. First, the low capacity growth projected through 2001 reflects a global economic slowdown. This situation is not expected to continue through the 2010 to 2020 time period. Second, production is expected to grow more rapidly than capacity as companies move to higher operating rates in an attempt to improve profitability. Third, paper consumption has generally expanded at the same rate as gross domestic product, which is projected by the Congressional Budget Office to increase by 2.3% annually between 2000 and 2008 (CBO 1998). Finally, the USDA Forest Service has projected a 1.5% annual growth rate for U.S. pulp and paper production for the period 1991 through 2010 (Haynes, Adams, and Mills 1995). For these reasons, a 1.5% annual growth rate in pulp and paper production was chosen as the mid-range case.

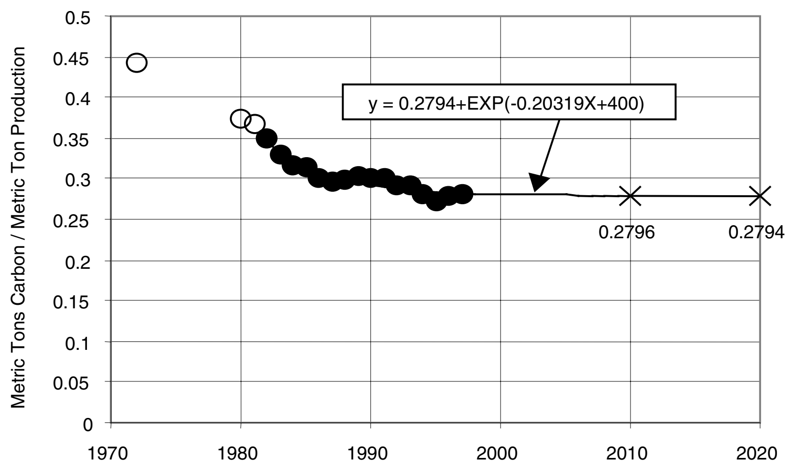

Figure 3. Pulp and Paper Industry Carbon Emissions per Unit of Production
- Extrapolated from 1982-1997 Data -
(without the impact of expected new environmental regulations)

Annual increases of 1.0% and 2.5% were also examined, the 2.5% case being near the growth rate of the last decade. Table 3 shows the expected production in 2010 and 2020 at these various growth rates, while the projected emissions without new regulations are shown in Table 4.

NCASI has examined the expected impact of a variety of regulatory initiatives on the industry's future emissions of carbon (NCASI 1998). In specific, the analysis has included examination of the impacts of recently revised effluent limitations guidelines, two rounds of maximum achievable control technology (MACT) regulations (i.e., MACT I and II), the industrial combustion coordinated rulemaking (ICCR), and requirements related to non-attainment of national ambient air quality standards (NAAQS) for ozone in eastern states. The analysis of these regulations addressed emissions related to on-site use of fossil fuel, generation of purchased electricity, and the off-site use of electricity to produce chlorate needed to comply with the revised effluent limitations guidelines. NCASI's analysis suggests that these new regulations will add approximately 2.8% to the total (i.e., direct plus indirect) emissions of carbon related to pulp, paper, and paperboard manufacture.

Accordingly, the projections without new regulations were multiplied by 1.028 to account for new environmental regulations. The results shown in Table 4 are the final projected carbon emissions adjusted to account for new environmental regulations. At a 1.5% annual production growth rate, pulp and paper manufacturing emissions in 2010 are projected to be 32.7 million metric tons of carbon. This compares to the Kyoto target for pulp and paper manufacturing of 22.8 million tons of carbon, which is 7% below 1990 emissions.

Table 3. Projected Pulp and Paper Industry Production (million metric tons)

Annual Growth from 1996*	Year 2010	Year 2020
1.0% Growth	106	117
1.5% Growth	114	132
2.5% Growth	131	167

* 1996 production = 92.4 million metric tons

Table 4. Projected Total (direct plus indirect) Carbon Dioxide Emissions Attributable to Pulp and Paper Manufacture (million metric tons carbon)

Extrapolated Based on Annual Growth Rates of	Without New Environmental Regulations		With New Environmental Regulations	
	2010	2020	2010	2020
1.0%	29.7	32.8	30.5	33.7
1.5%	31.8	36.9	32.7	37.9
2.5%	36.5	46.7	37.5	48.0

3.2 Projected Wood Products Manufacturing-Related Emissions of Carbon Dioxide

Historical data on energy use at wood products manufacturing facilities are limited. Data from DOE reports on "Manufacturing Consumption of Energy" for 1988, 1991, and 1994 were used in this analysis. The data were those reported for SIC code 24, "lumber and wood products" (EIA 1991, 1994a, and 1997b). The data are listed in Appendix E.

The energy data were converted to carbon emission estimates using the DOE emission factors in Table 2. The estimated historical emissions are listed in Appendix F. Because there were only three data points available, it was not felt to be appropriate to estimate future emissions by extrapolating the data. Instead, the three data points were used to calculate an average emission factor per billion cubic meters of wood products production for the three years with data. The production data were derived from several sources listed in Appendix G. The emission factors in 1988, 1991, and 1994 were 28.4, 32.7, and 36.8, respectively, averaging 32.6 metric tons of carbon per billion cubic meters of wood products production. It should be noted that although the data were too sparse to allow projections based on trends in emissions per unit of production, these three data points suggest that the unit emission rates were increasing over the period of record. If, indeed, this is the case, the estimates below understate future emissions, perhaps by a considerable amount.

The average emission factor was combined with annual growth rates of 1.0%, 1.5%, and 2.5% to estimate emissions in 2010 and 2020. Again, a mid-range estimate of 1.5% annual growth was used. This is close to the 1.25% annual growth projected by the United Nations Food and Agriculture Organization (FAO) for the period between 1994 and 2010 (FAO 1998). The USDA Forest Service projects lumber production to increase at only 0.35% annually from 1990 through 2010, structural panel production to increase by 1.54% annually from 1991 through 2010, and nonstructural panel production to increase by 0.85% annually from 1990 to 2010 (Haynes, Adams, and Mills 1995).

The projected production figures at an annual growth rate of 1.5% annually are shown in Table 5, while the emission projections are shown in Table 6.

Table 5. Projected Total Wood Products Production (million cubic meters)

Annual Growth from 1994*	Year 2010	Year 2020
1.0% Growth	132	146
1.5% Growth	143	166
2.5% Growth	167	214

* 1994 production = 112.4 million cubic meters

Table 6. Projected Total (direct plus indirect) Carbon Dioxide Emissions Attributable to Wood Products Manufacture (million metric tons carbon)

Extrapolated Based on Annual Growth Rates of	Without New Environmental Regulations		With New Environmental Regulations	
	2010	2020	2010	2020
1.0%	4.3	4.8	4.6	5.1
1.5%	4.7	5.4	5.0	5.8
2.5%	5.4	7.0	5.9	7.5

NCASI's analysis of the impacts of new environmental regulations on CO_2 emissions from wood products manufacturing indicates that the wood products MACT regulation is likely to increase total wood products-related CO_2 emissions by approximately 7.9% (NCASI 1998). Assuming that this increment remains at 7.9%, emissions in 2010 and 2020 which include the impacts of the expected wood products MACT rule can be estimated. The results are shown in Table 6.

The numbers in Table 6 can be compared to the 1991 carbon emissions from wood products plants of 3.6 million metric tons of carbon (there are no data for 1990). Assuming that the 1990 levels were approximately the same as 1991 levels, the Kyoto Protocol target would be approximately 3.3 million metric tons of carbon.

3.3 Projected Overall Forest Products Industry Emissions

The estimates from Tables 4 and 6 can be added to obtain the overall industry's total emissions of carbon dioxide. The results are shown in Table 7 and Figure 4. The Kyoto Protocol goal for total industry emissions (26.1 million metric tons carbon per year) is also shown.

Table 7. Projected Annual Emissions of CO_2 from Pulp, Paper, and Wood Products Manufacture (million metric tons carbon)

Extrapolated Based Annual Growth Rates of	2010	2020	Kyoto Protocol Target - Permanent
1.0%	35.2	38.8	26.1
1.5%	37.8	43.8	26.1
2.5%	43.4	55.5	26.1

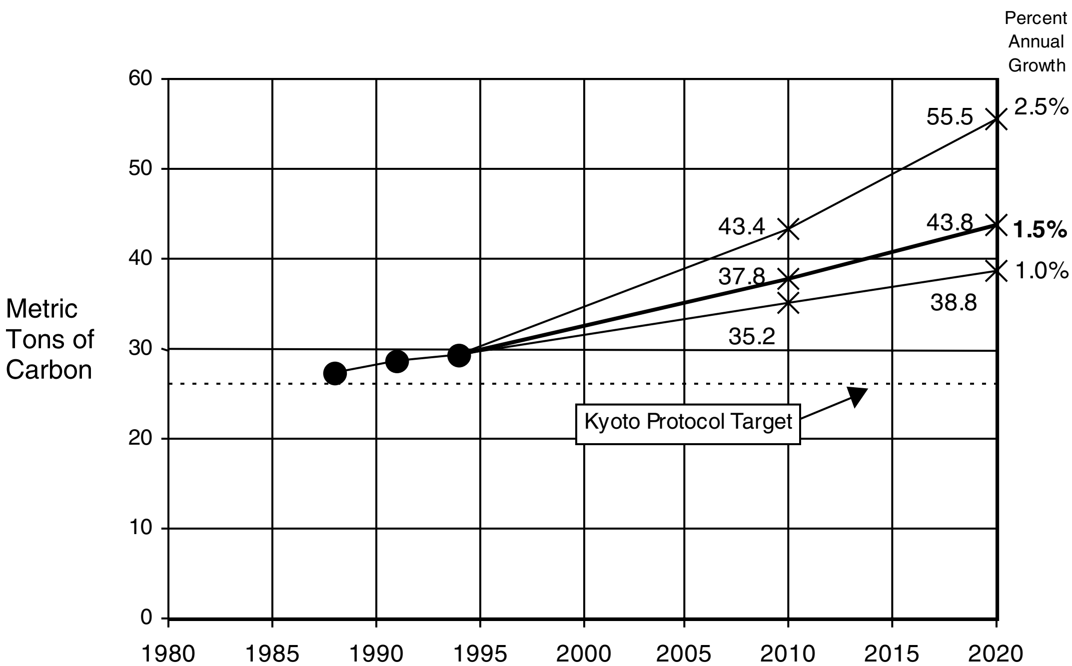

Figure 4. Projected Forest Products Industry Total Annual Emissions

3.4 Reductions Required from 2010 and 2020 Levels to Meet the Kyoto Protocol

The projected emissions in Table 7 have been compared to the corresponding Kyoto Protocol target to calculate the required reductions to meet the target for total carbon dioxide emissions. In Table 8, the reductions are shown as both tons of carbon and percent reductions from BAU emission levels in 2010 and 2020.

Table 8. Required Forest Products Industry CO_2 Reductions to Meet Kyoto Protocol Target

	Annual Industry Growth	Million Metric Tons Carbon		Percent Reduction	
		2010	2020	2010	2020
Pulp and paper	1.0%	7.8	10.9	25	32
	1.5%	10.0	15.2	31	40
	2.5%	14.8	25.2	39	53
Wood products	1.0%	1.3	1.8	28	35
	1.5%	1.7	2.5	34	43
	2.5%	2.5	4.2	43	56
Overall industry	1.0%	9.1	12.7	26	33
	1.5%	11.7	17.7	31	40
	2.5%	17.3	29.4	40	53

The estimates in Table 8 highlight several important considerations in assessing the impacts of the Kyoto Protocol on the forest products industry. First, the required reductions are highly dependent on the growth rate of the industry. Increasing the industry's growth in production from 1% to 2.5% per year approximately doubles the number of tons of carbon that must be reduced from BAU emissions to meet the target. The required reductions also increase rapidly with time. Meeting the target at projected industry production levels in 2020 requires approximately 50% more tons of reductions than required to meet the target in 2010. Under the highest growth scenario examined (2.5% annual growth), BAU emissions in 2020 would have to be reduced by approximately 50% to stay within the Kyoto Protocol target.

Second, if the wood products sector were required to meet the target independently, it would need to make larger reductions than would be required of the pulp and paper sector. This is due mainly to the major impact of expected MACT regulations on CO_2 emissions from the wood products sector.

4.0 DESCRIPTION OF APPROACH FOR ESTIMATING COSTS FOR MILLS TO REDUCE CO_2 EMISSIONS VIA CURRENTLY AVAILABLE TECHNOLOGY OPTIONS

4.1 Energy Data Sources

Energy use data for the pulp and paper and solid wood products industry were gathered from two sources. Data on fuels used in power boilers, recovery furnaces, and lime kilns are periodically collected by NCASI and used to track industry emissions (NCASI 1997). These data from the years 1990 and 1995 were obtained for pulp and paper mills and used to characterize fossil fuel use by each mill in the industry for which the data were available. AF&PA tracks industry energy use on an annual basis (AF&PA 1997a). These data were obtained for the years 1991 (data for 1990 were not available) and 1995 and used to characterize the quantities of purchased electrical power and the production rates of pulp and paper industry mills. As neither of these data sources presented complete coverage of the industry, the data sets were combined in a database and the mills for which complete coverage existed in both data sets for both years were selected for inclusion in the present analysis. This exercise resulted in the inclusion of 90 pulp and paper mills in the analysis. The mills used in the analysis are listed in Appendix H.

The full AF&PA 1995 data set, which contained 235 pulp and paper mills (representing about 75% of the industry's production) and NCASI's subset of 90 mills are compared in Figures 5 and 6. The comparison in Figure 5 suggests that in NCASI's database mills over 500,000 metric tons per year in size are slightly under-represented, while mills of smaller size are slightly over-represented. The median mill size in the AF&PA database is approximately 250,000 metric tons per year, while in NCASI's sample of 90 mills it is approximately 300,000 tons per year. The significance of these differences to the cost estimates is unknown.

When the data are plotted as cumulative production, one finds that the one-third of the industry's tonnage produced by the largest mills contributes about 28% of the CO_2 while the one-third of production from the smallest mills contributes about 37% of the CO_2. This suggests that emissions per ton are somewhat lower at larger mills. When the data are plotted as cumulative number of mills rather than cumulative production, one finds, not unexpectedly, that the largest one-third of mills contributes approximately two-thirds of the emissions, while the smallest one-third contributes less than 10%.

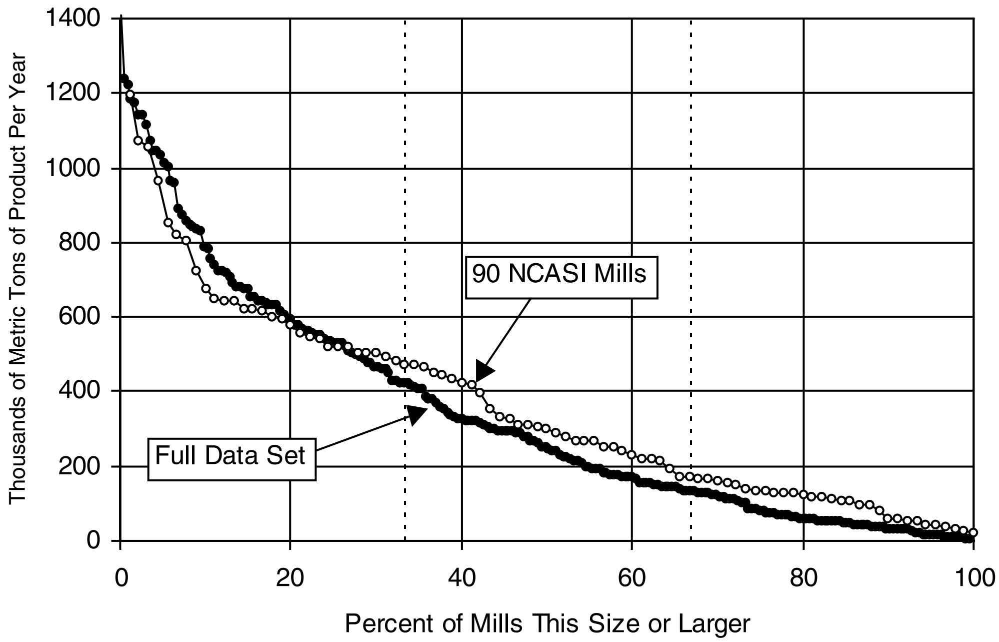

Figure 5. Comparison of the 90 Sample Mills and the 235 Mills in AF&PA's 1995 Database

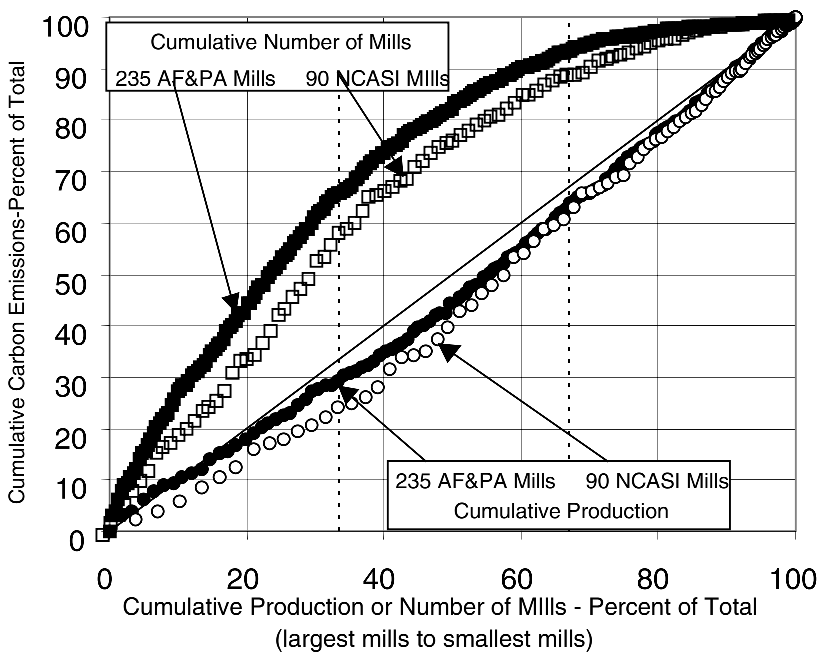

Figure 6. Distribution of Emissions Across the Pulp and Paper Industry

The mills were classified into industry sectors based on the production at the mill sites. Several mills produced multiple grades, and the total production of these mills was distributed among the appropriate industry sectors. The level of industry representation was thus determined in each of sixteen production categories, as shown in Table 9.

Table 9. Level of Industry Representation in Analysis

Production Category	Totals for 90 mills (metric tons/yr.)	Estimated ind. tot. (metric tons/yr.)	Estimated ind. total after comb. (metric mons/yr.)	Percent of total represented in sample	Percent of total (adjusted)	Percent of category in ind. tot.
Bleached kraft container & boxboard (or plus market pulp)	2,628,041	6,640,491	6,640,491	39.6	49.59	6.67%
Deinked tissue	138,193	3,606,841	3,606,841	3.8	4.80	3.62%
Dissolving pulp, sulfite or bleached kraft	316,814	1,359,173	1,359,173	23.3	29.21	1.37%
Market pulp, bleached kraft or sulfite	2,566,251	7,352,302	7,352,302	34.9	43.73	7.39%
Recycled containerboard	430,437	3,845,196	3,845,196	11.2	14.03	3.86%
Recycled paperboard	1,799,405	10,197,868	15,040,592	12.0	14.99	15.11%
Recycled tissue	107,755	497,176	497,176	21.7	27.16	0.50%
Newsprint: mechanical (or plus deinked newsprint)	2,258,273	5,456,904	5,456,904	41.4	51.85	5.48%
Deinked newsprint	914,022	1,357,597	1,357,597	67.3	84.36	1.36%
Packaging and industrial, purchased	140,700	1,942,243	1,942,243	7.2	9.08	1.95%
Printing and writing, bleached kraft	5,508,718	16,584,850	16,584,850	33.2	41.62	16.67%
Printing and writing, mechanical	2,737,041	3,734,997	3,734,997	73.3	91.82	3.75%
Printing and writing, purchased	952,564	5,870,541	5,962,541	16.0	20.02	5.99%
Printing and writing, sulfite	342,868	1,726,406	1,726,406	19.9	24.88	1.73%
Semi-chem corrugating medium	1,872,111	4,187,923	4,187,923	44.7	56.01	4.21%
Unbleached kraft	8,558,585	25,155,333	25,155,333	34.0	42.63	25.28%
Construction	0	4,842,724	0	Combine with recy. ppbd.		0.00%
Other (cotton linter pulp)	0	92,000	0	Combine with P&W purchased		0.00%
TOTAL	31,271,777	99,515,842	99,515,842	31.4	39.37	100.00%

At the conclusion of the analysis it was determined that the projected total industry emissions based on the 90 included mills were higher than those independently approximated based on total industry fuel use. To bring the two overall emissions figures into agreement, the 90 mills, as modeled in the cost estimating work, were increased in size (production tonnage) without increasing estimated mill emissions. Because after this adjustment the 90 mills represented a larger fraction of industry tonnage, a smaller scale-up factor was needed to estimate overall industry emissions from the 90-mill sample. Consequently, the emissions estimate extrapolated from the 90-mill sample agreed with the overall industry estimate from overall fossil fuel use statistics.

Data for the solid wood products sectors of the industry were not as complete as those available for the pulp and paper sectors. Energy use in 1995 by facilities in the solid wood products sectors was characterized by a total energy use figure computed from responses to an AF&PA survey which included energy in the form of fossil fuels, biomass fuels, and purchased and self-generated electrical power.

4.2 Modeling Baseline Energy Use at Pulp and Paper Mills

Approximate steam and electrical power demands were estimated for the various process units involved in the pulp and paper mills selected for inclusion in the study. These estimates were performed by EKONO, Inc. (Bellevue, Washington). The energy demand estimates for the process units were based on EKONO's experience working with North American and European mills, and their process modeling capabilities. Process units included those associated with producing pulp from a variety of furnish and process combinations, and those associated with converting pulp to products such as paper or board. For most process units, multiple steam and power demand estimates were developed to represent new, medium, or old equipment types and technologies.

Energy demand estimates were developed for the following process units:

Pulping/fiber-making process units:

- Bleached softwood (SW) kraft (new, medium, and old)
- Bleached hardwood (HW) kraft (new, medium, and old)
- Unbleached kraft (new, medium, and old)
- Bleached sulfite (new, medium, and old)
- Semichemical (new, medium, and old)
- Dissolving kraft (new, medium, and old)
- Dissolving sulfite (new, medium, and old)
- Thermomechanical pulp (TMP) (new, medium, and old)
- Refiner mechanical pulp (RMP) (new, medium, and old)
- Chemithermomechanical pulp (CTMP) (new, medium, and old)
- Stone groundwood (SGW) (new, medium, and old)
- Pressurized groundwood (PGW) (new, medium, and old)
- Deinked pulp (DIP) (new, medium, and old)
- Old corrugated containers (OCC)/news (new, medium, and old)
- Purchased pulp

Converting/papermaking process units:

- Market pulp (new, medium, and old)
- Fine paper - uncoated free sheet (new, medium, and old)

- Fine paper - coated free sheet (new, medium, and old)
- Solid bleached sulfate (SBS) board - coated (new, medium, and old)
- SBS board - uncoated (new, medium, and old)
- Linerboard (new, medium, and old)
- Recycled board - uncoated (new, medium, and old)
- Recycled board - coated (new, medium, and old)
- Newsprint (new, medium, and old)
- Lightweight coated (LWC) (new, medium, and old)
- Uncoated groundwood (GW) paper (new, medium, and old)
- Corrugating medium (new, medium, and old)
- Tissue (new, medium, and old)
- Kraft paper (new, medium, and old)

In the analysis, it was assumed that currently, all on-site electricity production was via back pressure steam turbines. This assumption precludes consideration of any gas turbine combined cycle systems or condensing steam turbines which may be in use at some of the mills. Additionally, although estimates of current industry emissions and emission reduction targets included emissions from fuel used in direct-fired paper machine dryers and in pollution control combustion units (e.g., emissions incinerators), these sources were not included in the energy balances prepared by EKONO and were not targeted for reductions.

4.3 Modeling Baseline Energy Use at Wood Products Facilities

Facility-specific energy data were not adequate to support detailed process modeling in the wood products sector of the industry. Therefore, a single model facility was modeled for each major wood products segment. These models were calibrated using representative energy values, determined from data collected by AF&PA for 1995.

4.4 Technology Options to Reduce Carbon Dioxide Emissions

4.4.1 *Steam and Electricity Conservation Measures*

A list was prepared of currently available technologies and management practices that pulp, paper, and paperboard mills, panel plants, and lumber mills could implement to increase energy efficiency and thus reduce emissions of carbon dioxide from combustion of fossil fuels (either on the mill site or off the mill site, in the production of electrical power by utility companies, for example). Working with an NCASI task group of pulp and paper company energy experts, EKONO selected and examined in detail the seventy-one technologies listed in Table 10 to characterize their costs and effectiveness in reducing carbon dioxide emissions.

Criteria, or decision rules, for the application of each technology option listed in Table 10 were developed based on the option's applicability to different process units of varying technology ages. The costs of implementation, both capital and operating, and the carbon dioxide emission impacts were estimated for each technology option as applied to each process unit type and age. The capital costs for each technology option were estimated using information EKONO had developed in projects performed for mills in North America and Europe. Indirect costs were estimated based on ratio factors. A contingency cost of 15% was included. EKONO has indicated that the resulting estimates, if properly applied, should be within 40% of actual installed costs. The capital cost estimates were computed for a production base of 1000 short tons (909 metric tons) of product per day, and were therefore directly scaleable to a mill's production rate using capacity factors.

Table 10. Energy and Carbon Dioxide Reducing Technologies Examined

1.	STEAM AND POWER SUPPLY
1.1	Replace low pressure level boilers and install turbogenerator capacity in order to utilize full back-pressure power generation potential
1.2	Install new bark boiler or rebuild existing one in order to maximize utilization of biofuels
1.3	Preheat demineralized water with secondary heat before steam heating
1.4	Rebuild or replace low efficiency boilers
1.5	Install steam accumulator to facilitate efficient control of steam header pressures without using fossil fuels
1.6	Install ash re-injection system in bark boiler
1.7	Install bark press or bark dryer to increase utilization of bio fuels
1.8	Install additional heat recovery systems to boilers to lower losses with flue gases
1.9	Implement energy management program to provide current and reliable information on energy use and cost in different areas of the facility
2.	WOOD SUPPLY, DEBARKING, CHIPPING, ETC.
2.1	Replace pneumatic chip conveyors with belt conveyors
2.2	Use secondary heat instead of steam in debarking and/or thawing
3.	KRAFT PULPING
3.1	Rebuild mill hot water system to provide for separate production and distribution of warm (120°F) water and hot (160+°F) water
3.2	Install blow heat (batch digesters) or flash heat (continuous digester) evaporators
3.3	Convert batch cooking to cold blow techniques or continuous process
3.4	Use flash heat in continuous digester to pre-heat chips
3.5	Use evaporator condensates on decker showers
3.6	Use two pressure level steaming of batch digesters to maximize back-pressure power generation
3.7	Optimize dilution factor control
4.	KRAFT BLEACHING
4.1	Optimize filtrate recycling concept for optimum chemicals and energy use
4.2	Preheat ClO_2 before it enters mixer
4.3	Use oxygen based chemicals to reduce use of ClO_2 (O_2 delignification, E_p, E_{op}, etc.)
5.	PULP DRYER AND PAPER MACHINE
5.1	Eliminate steam use in wire pit by providing hot water from heat recovery and/or from pulp mill and by reducing water use on machine
5.2	Upgrade press section to minimize required water removal in dryer section
5.3	Enclose machine hood (if applicable) and install air-to-air and air-to-water heat recovery on machine hood exhaust
5.4	Install properly sized white water and broke systems in order to minimize white water losses during upset conditions
5.5	Implement hood exhaust moisture controls in order to minimize air heating and to maximize heat recovery
5.6	Implement efficient control systems for machine steam and condensate systems to eliminate excessive blow through and steam venting during breaks

(Continued on next page.)

Table 10. Continued

6.	KRAFT RECOVERY
6.1	Convert recovery boiler to low odor concept and implement high solids firing of black liquor
6.2	Perform evaporator boilout with weak black liquor as much as possible
6.3	Convert evaporation to seven-effect operation
6.4	Install high solids concentrator in order to maximize steam generation with black liquor
6.5	Implement an energy efficient lime kiln (lime mud dryer, mud filter, product coolers, etc.)
6.6	Replace lime kiln scrubber with electrostatic precipitator
6.7	Integrate condensate stripping to evaporation
6.8	Install methanol rectification and liquefaction system
6.9	Install bio fuel gasifier, use low Btu gas for lime reburning
7.	MECHANICAL PULPING
7.1	Heat recovery from TMP process to steam and water
7.2	Add a third refining stage to the TMP plant
7.3	Replace the groundwood mill with pressurized groundwood (PGW) operation
7.4	Countercurrent coupling of machine white water system with the white water system of mechanical pulping
8.	DEINKING PLANT
8.1	Supply waste heat from other process areas to deinking plant
8.2	Install drum/dry pulpers
8.3	Implement closed heat and chemical loop
9.	MILL GENERAL
9.1	Optimize integration and utilization of mill secondary heat recovery systems
9.2	Implement preventive maintenance procedures in order to increase equipment utilization efficiency
9.3	Implement optimum spill management procedures
9.4	Maximize recovery and return of steam condensates
9.5	Recover wood waste that is presently going to landfill and use as fuel
9.6	Install energy measurement, monitoring, reporting, and follow-up systems
9.7	Convert pump and fan drives to variable speed drives
9.8	Install advanced process controls
9.9	Replace over-sized electric motors
9.10	Use high-efficiency lighting
10.	SAW MILLS (SEE ALSO 1. STEAM AND POWER SUPPLY AND 9. MILL GENERAL)
10.1	Use advanced controls to control drying process
10.2	Install heat recovery systems to dryer exhaust
10.3	Insulate kiln and eliminate heat leaks
10.4	Use heat pump for lumber drying
10.5	Convert batch kiln to progressive kiln
10.6	Implement steam load management systems to level out steam demand variations
11.	PLYWOOD PLANTS (SEE ALSO 1. STEAM AND POWER SUPPLY AND 9. MILL GENERAL)
11.1	Use advanced controls to control drying process
11.2	Insulate dryer and eliminate air and heat leaks from/to dryer
11.3	Install heat recovery systems to dryer exhaust
11.4	Use boiler blow down for block conditioning

(Continued on next page.)

Table 10. Continued

12.	PARTICLE BOARD MILLS (SEE ALSO 1. STEAM AND POWER SUPPLY AND 9. MILL GENERAL)
12.1	Measure and control dryer exhaust moisture content in order to minimize air heating
12.2	Recover heat from dryer exhaust
12.3	Use wood waste as fuel for drying (suspension burning)
13.	FIBERBOARD MILLS (SEE ALSO 1. STEAM AND POWER SUPPLY AND 9. MILL GENERAL)
13.1	Install heat recovery
13.2	Preheat drying air with steam
14.	OSB PLANT (SEE ALSO 1. STEAM AND POWER SUPPLY AND 9. MILL GENERAL)
14.1	Screen flakes before drying and dry fines separately from other material
14.2	Use advanced control systems in drying process
14.3	Use dry powdered resins to reduce drying before formers

The operating cost impacts were predominately based on each technology's effect on fuel and energy use. Fuel and energy use were expressed on a per-ton-of-product basis, and were therefore directly scaleable to a mill's production rate via that process unit. As most of the technology options are related to increased efficiency of steam production or utilization, the steam savings associated with technology implementation can be directly related to decreased fuel demand at the mill. An important premise of the current analysis was the net zero contribution of biomass fuels to greenhouse gas emissions. Therefore, the lower fuel demand was assumed to result in decreased fossil fuel use at the mill rather than decreased use of biomass. In order to compute the operating cost impact of lowered fuel demand, a marginal fuel for the mill was identified based on the mill's 1995 fuel use data. For pulp and paper mills, the marginal fuel was defined as the highest priced fossil fuel (on a regionally dependent $/MBtu basis (EIA 1998b)) used by the mill in sufficient quantities to absorb offsets represented by the total fuel demand savings resulting from the implementation of the technology options to the mill process units. For wood products facilities, natural gas was assumed to be the only marginal fuel. EIA reports that in 1994 only two fossil fuels were used in any quantity at lumber/wood products facilities, distillate oil and natural gas, with natural gas representing more than two-thirds of fossil fuel use on a Btu basis (EIA 1997b). The price of the marginal fuel combined with the heat demand reductions was used to determine the operating cost savings associated with technology option implementation. Some technology options involved savings in electrical power demand at the mill. In these cases, operating cost savings were determined from reduced electricity use at the prevailing 1998 regional electrical power prices (EIA 1998b).

The carbon dioxide emission implications of each technology option were determined by the estimated impact of the technology on marginal fuel and electricity use at the mill. Decreases in fossil fuel combustion at the mill imparted reductions to direct emissions of carbon dioxide. The carbon dioxide emissions resulting from combustion of various fossil fuels are listed in Table 11 (EIA 1994b). Similarly, reductions in electrical power demand at the mill resulted in decreased levels of purchased electricity. Some of the technologies impacted the amounts of chlorine dioxide or caustic used in bleaching, in which case the off-site impacts on power consumption for chemical manufacturing were also considered. Regionally dependent carbon dioxide emission factors associated with the production of electrical power by utility companies were generated based on information from the EIA, presented in Table 11, and used to estimate the impact of off-site (or indirect) emissions of carbon dioxide associated with the implementation of each technology option. The baseline emissions of each mill (before installing CO_2–reducing technologies) were estimated using the average regional emission factors for purchased power. Reductions in purchased power or exports of excess power resulting from implementing CO_2-reducing technologies were credited by assuming that utility emissions were reduced by amounts associated with the generation of marginal power.

Table 11. CO_2 Emission Factors for Fuel Combustion and Purchased Power

Fuel Combustion:	kg carbon/MBtu
Liquor	0
Bark	0
Coal	25.7
Oil	21.5
Natural Gas	14.5

Purchased power Census Region	Average kg carbon/MWh	Marginal Kg carbon/MWh
New England	115.8	223.8
Middle Atlantic	130.5	249.1
East North Central	202.0	263.0
West North Central	200.9	262.3
South Atlantic	175.9	252.2
East South Central	190.5	260.7
West South Central	183.3	220.2
Mountain	190.3	258.8
Pacific Contiguous	28.6	181.2
Pacific Noncontiguous	191.1	215.3
US Average	167.3	249.0

SOURCE: EIA 1994b

The analysis of total emissions, including both direct and indirect sources, was complicated by the fact that many mills generate electrical power on site from boiler steam as the steam pressure is reduced to process steam levels. Therefore, as an energy efficiency technology option has the potential to reduce direct emissions due to decreased steam demand, indirect emissions can actually increase due to the increased purchases of electrical power needed to compensate for lower levels of electricity generated on site as boiler steam production decreases. The emission impact computations for technology options were designed to estimate the quantity of electricity required for mill operations (dependent upon process types and production rates), and compare that estimation to the quantity of purchased electrical power (an input variable). The difference was assumed to be generated on site. The on-site power was generated from the mill's steam energy, the supply of which was computed based on the quantity of fossil and biomass fuels used. The amount of steam energy required to produce the on-site generated power was estimated (based on back pressure turbine generation requirements), then expressed as a percentage of the total energy of the mill's steam supply. The result is a fraction of the mill's steam energy which is used to generate power. (A cap was placed at 20% of the mill's steam energy available for electricity generation. This is the practical maximum for back-pressure power.) Therefore, when application of technologies reduces the steam demand of the process, the associated reduction in on-site generated power is estimated based on the percentage of this reduced total steam energy used for power generation.

In addition to the technologies listed in Table 10, power boiler fuel switching to natural gas, fuel switching to biomass (waste wood), installing combined cycle gas turbine systems for process steam and electricity production, and landfill gas capture were examined by NCASI. These four emission reduction measures are discussed below in more detail.

4.4.2 *Power Boiler Fuel Switching to Natural Gas*

Fuel switching to natural gas was intensively studied as part of an earlier NCASI investigation. The results of that analysis were incorporated into the present study on a mill-by-mill basis for those mills where fuel switching to natural gas was an option (those mills not currently using natural gas as the sole fuel source for power boilers, and which currently have access to natural gas or are within 35 miles of an existing pipeline). The scope of the natural gas fuel switching analysis was limited to existing pulp and paper mill power boilers. (Fossil fuel switching was not considered at wood products facilities because it was assumed that natural gas was the only marginal fuel in use, an assumption discussed earlier in this report.) Baseline carbon dioxide emissions were estimated based on reported annual fuel consumption and carbon dioxide emissions resulting from combustion of various fossil fuels, as listed in Table 11 (EIA 1994b). Projected emissions were based on substitution of oil and coal fuels with natural gas. Changes in boiler efficiency resulting from the altered fuel mix and boiler modification were considered. Wood or other supplemental fuels (tire-derived fuels, wastewater treatment residuals, etc.) were assumed to remain at current consumption levels. Capital costs included the cost of boiler modifications (burners, pipe racks, control systems, and superheater) and lateral pipeline installation from the trunk line to those mills which currently do not have natural gas available on site.

Representative costs to modify various types of boilers to natural gas-fired operation were prepared by R.W. Beck under contract to NCASI. Operational costs included the incremental fuel cost resulting from the replacement of coal and oil with natural gas. Other operating cost considerations potentially significant for boilers converted from coal to natural gas included savings resulting from reduced fuel and ash handling, discontinued use of particulate control devices and continuous emission monitoring, and ash disposal requirements. Although it is not trivial to quantify these savings, estimates were made based on information provided by R.W. Beck, available in EPA documents, and on landfill cost data drawn from a recent NCASI solid waste survey.

4.4.3 *Power Boiler Fuel Switching to Biomass (Waste Wood) Fuel*

This emission reduction measure was similar in scope to the natural gas fuel switching option. The costs and carbon dioxide emission impacts of converting existing fossil fuel-fired and combination fuel-fired power boilers at pulp producing mills (e.g., does not include non-integrated or secondary fiber mills) to a fuel mix in which 90% of the boilers' fuel heat is provided by wood fuel were estimated. Boilers were not considered for fuel conversion if the boiler capacity was less than 100,000 lb/hr of steam or if the boiler was utilized at less than 20% of its rated capacity in 1995. Fuel switching to wood waste was not considered at wood products facilities. Even if all fossil fuel use at wood products facilities was eliminated, it would reduce industry emissions by less than 5%, suggesting that this is not an important source of error in the study. This error would be larger if a significant fraction of wood products facilities began to use biomass to produce electricity in the future, a practice that is relatively uncommon at present.

Baseline carbon dioxide emissions were estimated based on reported annual fuel consumption and carbon dioxide emissions resulting from combustion of various fossil fuels, as determined by the EIA and listed in Table 11. Projected emissions were based on substitution of oil, coal, and natural gas fuels with wood-derived fuels, assuming zero emissions of carbon dioxide from combustion of wood. Operating costs were determined based on the incremental fuel cost resulting from the replacement of coal, oil, and natural gas fuels with wood, so that 90% of the boiler's heat input originated from wood fuel.

One of the difficulties associated with estimating the operating costs of this measure is the uncertainty regarding the impact of increased demand on waste wood fuel costs. It was assumed that the current price of waste wood fuel was $1.3/MBtu, and that the increased demand resulting from widespread industry boiler conversions and outside competition for biomass fuels would cause the wood fuel price to increase to current natural gas prices on an equivalent steam heat basis. Accordingly, additional biomass imported to support expanded reliance on biomass fuel was priced at $2.36/MBtu. (This pricing assumption was subjected to sensitivity analysis, discussed later.) Other operating cost considerations potentially significant for boilers converted from natural gas or oil include costs associated with increased fuel and ash handling, the need for particulate control devices and continuous emission monitoring, and ash disposal requirements. To account for these factors, an additional $0.18/MBtu was added to the fuel costs for wood fuel replacing either oil or natural gas. These additional costs were assumed to not apply when substituting wood for coal.

Depending on the current fuel mix of the boiler, capital costs associated with conversion to wood fuel include those associated with either boiler replacement (basis of $33 million for 200,000 lb/hr steam), boiler modification (basis of $23 million for 200,000 lb/hr steam), or no significant changes. The fuel mix criteria are as outlined below.

- If more than 75% of the fuel heat originated from wood fuel, no modifications are required.
- If 10% to 75% of the fuel heat originated from wood fuel, the boiler will require a rebuild.
- If greater than 90% of the fuel heat originated from coal, the boiler will require a rebuild.
- If greater than 90% of the fuel heat originated from oil or gas or a combination of these fluid fuels, the boiler will have to be replaced.
- For combination boilers burning less than 10% wood, and the remainder a combination of fluid (oil and/or gas) and coal fossil fuels, if the amount of coal in the fuel mix is greater than the amount of fluid fuel, a rebuild will be required. If the amount of coal in the mix is less than the amount of fluid fuel, a new boiler will be required.

4.4.4 *Installing Gas Turbine Combined Cycle (GTCC) Systems*

For a variety of reasons, combustion turbine combined cycle systems are becoming attractive alternatives for producing electricity. EIA projects that even without the added incentive of the Kyoto Protocol, "[f]or new capacity additions, the low capital costs and high operating efficiencies of natural-gas-fired combined-cycle plants make them the most economical choice for most uses" (EIA 1998c). Indeed, EIA suggests that "[o]ver time, new gas fired combustion turbine and combined-cycle plants are expected to dominate new power plant additions in all regions" (EIA 1998c). This trend becomes even more pronounced under scenarios where greenhouse gas emission reductions are necessary (EIA 1998d). Gas turbine combined cycle (GTCC) systems also have potential applications in industries like the forest products industry where they can be used to co-generate process steam.

For these reasons, it was important to address the potential role of GTCC systems in NCASI's analysis. These systems were not analyzed in the same manner as the technologies shown in Table 10, however, for several reasons. First, because of the high ratio of electrical output to process steam possible with these systems, it is conceivable that a mill might size a combined cycle gas turbine system to generate electricity for export to the grid. This is much less likely to occur (although certainly not impossible) with the other technologies being considered. Second, a GTCC system will often alter the energy balance of a mill so fundamentally that all other changes that are made to save energy must be reexamined to determine their impact on greenhouse gas emissions. Of special significance is the fact that technologies that reduce steam use may also cause reductions in the amounts of power that can be exported to the grid, undoing some of the credit that had been given to the mill to reflect the avoided emissions at the local utility. Finally, if a mill commits to the expensive option of installing a gas turbine, it will probably alter the need for, and feasibility of, other changes that might be made to reduce greenhouse gas emissions. For these reasons, the methods used to analyze GTCC impacts and costs were different than those used on the other technologies.

Gas turbine combined cycle systems were addressed in the following way. Two scenarios were examined. The first involved sizing the GTCC system to provide all of the facility's process steam requirements that had formerly been satisfied by burning fossil fuels. This put most facilities in the position of exporting significant amounts of power to the grid; therefore this scenario is termed the large turbine scenario. In the second case, the small turbine scenario, the GTCC system was sized only to generate enough electricity to eliminate the need to purchase power from the grid (with the added constraint that steam not be generated in excess of process steam requirements previously met by combustion of fossil fuels).

Several sources were consulted for GTCC system prices. The annual *Gas Turbine World Handbook* includes a survey of, among other things, turnkey combined cycle budget price levels for GTCC systems. NCASI used the data from the 1997 and 1998 editions (GTW 1997, 1998). Material was also obtained from a DOE study of options for reducing greenhouse gas emissions (DOE 1997). Both sources of information were used to prepare a plot (Figure 7) of installed cost as a function of GTCC output. Regression analysis was used to develop an equation describing each set of data. The resulting equations are shown in the figure.

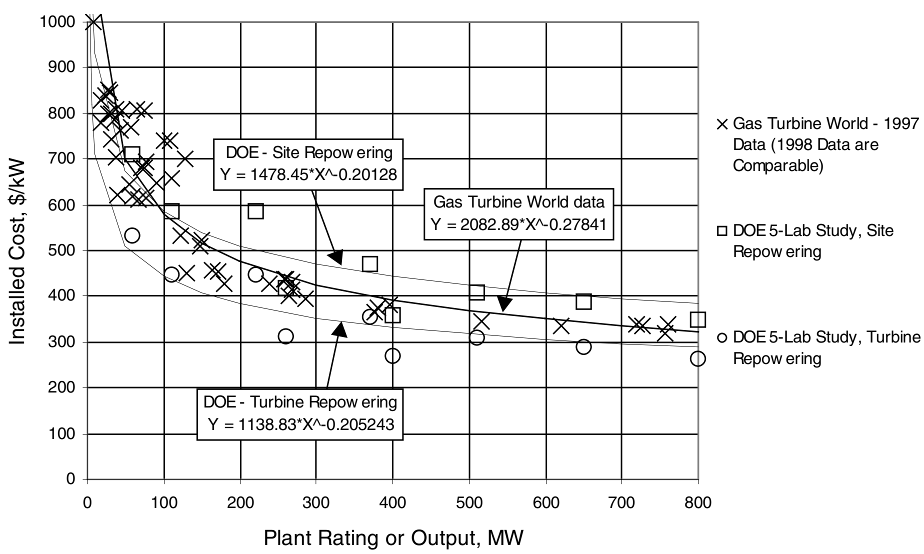

Figure 7. Installed Gas Turbine Combined Cycle System Prices

After reviewing the two sources of information, it was decided to use the DOE cost data in NCASI's analysis. Several factors were responsible for this decision. First, the DOE capital cost data were accompanied by operating cost data, while the Gas Turbine World data were not. NCASI required both capital and operating cost data for the analysis. Second, the DOE data were specifically developed for the case where an existing power plant was to be repowered, a situation perhaps more relevant to a mill than a greenfield GTCC plant. An important deficiency in both databases was the lack of GTCC cogeneration systems. Gas Turbine World had data for only two such systems, only one of which was equipped with a steam turbine. These two systems had power outputs of 2.65 and 5.72 MW with installed costs of $825 and $725 per kW, respectively. These costs are in the same range as those plotted in Figure 7 for non-cogeneration systems.

NCASI decided to use the DOE cost data for site repowering (requiring the installation of a new steam turbine) rather than turbine repowering (making use of the existing turbine). Although this decision may often result in overestimating the costs for the steam turbine component of the system, this is compensated for by the fact that DOE's site repowering costs do not include, for instance, (a) demolition costs, (b) costs for upgrading the power transmission system, (c) cogeneration steam or utility tie-ins, and (d) a variety of indirect costs. For these reasons, NCASI decided that the site repowering costs were probably better estimates of what a mill would encounter.

The DOE data for site repowering were fitted to the following equation (see Figure 7):

$$\text{Installed cost (\$/kW)} = 1478.45 * (\text{Output in MW})^{(-0.20128)}$$

For the average case in NCASI's analysis, this indicates installed costs of $600 to $700/kW. Over the range of sizes encountered in the analysis, the costs range from about $500 to $1000+/kW. The costs include low NOx burners and selective catalytic reduction (SCR) systems so that NOx emissions are less than 9 ppm (DOE 1997). In the analysis of converting coal- and oil-fired boilers to coal (discussed above), costs for installing gas laterals had been estimated. These same estimates were used for the GTCC analysis.

For operation and maintenance (O&M) costs, the DOE five-lab study factors were used (DOE 1997). For the case of converting a coal-fired boiler to a GTCC system, DOE factors indicated that compared to the coal-fired case, fixed O&M costs should be reduced by $30/kW and variable O&M costs reduced by $1/MWh. In the case of a conversion to GTCC from an oil-fired boiler, fixed O&M costs were about the same but variable O&M costs were $1/MWh lower than the oil-fired boiler. For conversion from a gas-fired boiler, fixed O&M costs were $5.5/kW higher for the GTCC system while variable O&M costs were about the same.

For each of the 90 mills, a "large" gas turbine and a "small" gas turbine (described above) were sized. The costs were determined as described above, and their impacts on direct and indirect emissions were estimated. Regional power grid emission factors were used to estimate the indirect impacts on emissions due to reduced generation by the electric utility company. One of the important factors impacting the economic viability of power-exporting GTCC systems is the price at which power can be sold to the grid. For this reason, the annualized costs for gas turbines were estimated across a range of power sale price-to-purchase price ratios.

An estimate of the capital and annualized costs for "large" and "small" turbine systems was developed for each mill, and these costs were integrated into the overall analysis as follows. At each marginal cost of reducing carbon, the total annualized costs for the GTCC systems were compared to the annualized costs for the combination of "conventional" technologies determined to be most cost effective. The most cost effective of the options (large GTCC system, small GTCC system, and combination of conventional technologies) having a marginal cost less than the cutoff was chosen for each mill. This is the same approach as was used for all other technologies in the core analysis, except that it did not consider combinations of GTCC and other technologies at a given marginal cost, only one or the other.

4.4.5 *Capture of Landfill Gas Emissions*

Anaerobic biodegradation of organic carbon in landfills can generate significant quantities of methane and carbon dioxide. The carbon dioxide generated might be considered as having come from biomass, and therefore not be counted as a net addition to greenhouse gas in the atmosphere. The methane, however, because of its higher global warming potential, could be counted as a net addition of greenhouse gas to the atmosphere (although it has not been included in the estimates of industry emissions). NCASI surveys of solid waste management practices in 1988 and 1995 were used to characterize landfilling practices in the last decade. Methane generation in industry landfills was assumed to occur in accordance with the EMCON Methane Generation Model:

$$Q_{CH_4} = \sum kL_0R_i\left(e^{-kt_i}\right)$$

where Q_{CH4} is the methane generation rate for year t since landfilling started, m^3/year; L_0 is the potential methane generation capacity of the material, m^3/Mg; R_i is the wet organic mass of the layer added in the i^{th} year of landfilling, Mg; k is first order decay or methane generation rate coefficient, 1/year; and t_i is the number of years the i^{th} layer has been in place.

Appropriate values for k and L_0 are not well known, since studies of methane generation have not been carried out on pulp and paper mill landfills as they have been on MSW landfills. However, recent work on landfill emissions indicates a probable range of values. Table 12 summarizes the values used in the estimating exercise.

Table 12. Parameters Used in the EMCON Model

	k, yr^{-1}	L_o, m^3/Mg
Low Range	0.01	50
High Range Estimates*	0.04	100

* High range parameters are equal to the EPA AP-42 default values for MSW

The control option considered as a reduction measure in the current analysis is collecting and combusting methane generated in the landfills. Information from municipal solid waste facilities, pulp and paper landfills, and two NCASI solid waste management surveys was used to estimate the costs of this operation. Methane emission reductions were expressed as carbon dioxide equivalents. This reduction measure was applied to those mills included in the analysis for which landfill data were available to NCASI.

4.5 Modeling Emissions Reductions at Pulp and Paper Mills

The mills selected for inclusion in the analysis were “modeled” by combining the appropriate steam and power demands associated with the various process units in place at the mill. Direct and indirect carbon dioxide emissions of the mill were then calculated in two ways: (1) based on fuel composition data and steam and power demand estimates corresponding to the process units in place at the mill, and (2) based on 1995 fossil fuel use data from NCASI and 1995 purchased electricity data from AF&PA. Based on the process units in place at the mill, the appropriate carbon dioxide reduction measures (technology options) were identified and ranked according to their overall cost effectiveness (considering both capital investment requirements, paid for over 10 years at 10% interest, and operating cost changes) when applied to the mill's processes. A cost of capital of 10% was recommended by AF&PA based on the results of a recent study of the pulp and paper industry (AF&PA 1999). The emission reduction measures were then sequentially "implemented" to reduce the mill's baseline carbon dioxide emissions calculated from fuel composition data and process unit steam and power demand estimates.

As the reduction measures were implemented, the associated costs were accumulated and the mill's emission levels were lowered. When the modeled mill's carbon dioxide emissions approximately equaled the emissions based on the 1995 fuel and energy use data for the mill, the "modeled" mill was assumed to be sufficiently representative of the current mill situation. The remaining emission reduction technologies identified as applicable to the mill's process units and not yet "implemented" during this phase of modeling were considered appropriate for application to achieve emission reductions towards meeting the emission target.

In Figure 8, the baseline direct emissions from the tuned model mills are compared to the actual 1995 emissions for the 90 mills. Most of the examples of poor agreement between modeled and actual emissions are at mills with unusual conditions which are not reflected in the model mills and which cause emissions to be larger than would be expected under normal circumstances. An example might be a mill having a fossil fuel-fired boiler dedicated to producing electrical power for export. NCASI's baseline model mills did not include components to model such conditions.

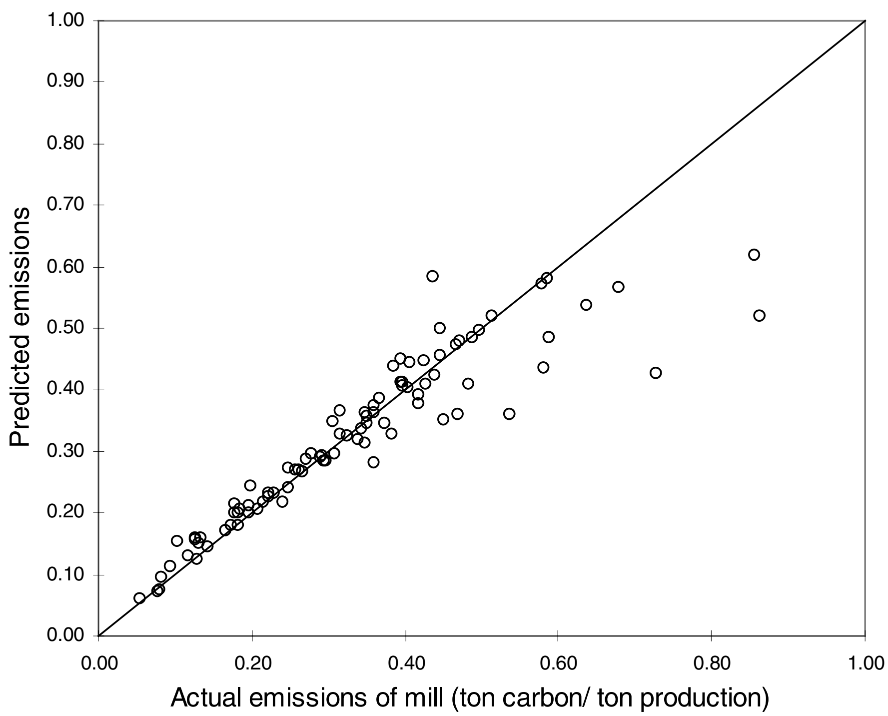

Figure 8. Comparison of Predicted and Actual Baseline Emissions

Production data from 1995 for the included mills were used to develop the mill models. However, production is anticipated to increase between 1995 and the implementation dates for any carbon dioxide emission target. For reasons outlined elsewhere in this report, a 1.5% annual growth rate in pulp and paper production was chosen as the mid-range case. The estimated production increases were used to predict the energy use and associated carbon dioxide emissions of the mill at implementation dates of 2010 and 2020. The emission and cost impacts of the remaining emission reduction measures (those not already applied to tune the model to reflect the current mill situation) were adjusted to account for the estimated production increases.

The approach used to model pulp and paper mills can perhaps best be described as pseudo-mill-specific in that it utilizes mill-specific furnish and product profile information and mill-specific furnish and fuel and purchased power data to construct and calibrate mill energy balances. The approach did not attempt to define the unit processes actually in place at each mill. The approach, therefore, requires an assumption that although the technologies actually in place at a mill are not identical to those used to develop the corresponding hypothetical mill energy balance, on average the cost/emission reduction relationships for the hypothetical mill balances will be similar to those of the corresponding mills.

4.6 Modeling Emissions Reductions at Wood Products Facilities

In the case of wood products facilities, generic energy balances were developed by EKONO for panel plants and lumber mills representative of the U.S. solid wood products manufacturing industry. The approach used to develop the energy balances was similar to that for pulp and paper mills. The five mill types investigated included lumber mills, plywood plants, particleboard plants, oriented strand board (OSB) plants, and hardboard mills. For each mill type, the appropriate technologies were examined in terms of their ability to cost effectively reduce carbon dioxide emissions and were ranked according to their overall cost effectiveness. Natural gas was selected as the marginal fuel at all wood products facilities; therefore, the option of switching to natural gas was not considered. In addition, due to the lack of fuel use data for wood products mills, increased use of biomass was not included as an option.

For each of the five mill types, a single hypothetical mill energy balance was created based on EKONO's energy demand estimates. Each of these energy balance estimates was used to represent all mills in the appropriate wood products industry sector by modeling a hypothetical facility having the average MBtu/ton energy consumption value and average production capacity of industry mills within the relevant production category (based on AF&PA and NCASI data). The 1995 carbon dioxide emissions for each wood products sector representative mill were first estimated using that sector's average 1995 energy consumption value and relationships developed by EKONO which correlated hypothetical mill energy use to carbon dioxide emissions. Based on the cost-effectiveness rankings, the technologies were then "implemented" into each hypothetical wood products mill energy balance, as appropriate, to reduce the baseline carbon dioxide emissions to a level consistent with the average emission of the representative industry mill in that sector (determined from average energy use data as described above). When the carbon dioxide emissions related to the hypothetical energy balance equaled the emissions of the representative mill based on the sector's 1995 total energy use data, the energy balance was assumed to sufficiently model the current representative industry sector mill. The remaining emission reduction measures were then sequentially "implemented" to the representative mill's energy balance. As the remaining reduction measures were implemented, the associated costs were accumulated as the mill's emission levels were lowered. The costs were then totaled across all types of wood products facilities. Because most wood products facilities do not generate electricity on site, gas turbine combined cycle technology was not included as an option for these facilities.

5.0 COSTS FOR MEETING THE EMISSIONS TARGET

5.1 Reducing to a Common Marginal Cost at Current Fossil Fuel and Power Costs

If the emissions target is allowed to be met on an industry-wide basis, a rational way to allocate the reductions would be to have all mills reduce emissions to the same marginal cost for additional reductions until the target is met. In this manner, mills which can achieve emission reductions at lower costs would make more significant reductions than mills where reductions are more costly. An analysis of costs for the industry to achieve the emissions reduction target according to this approach was undertaken by examining the reductions accomplished across all mills at a series of common marginal costs for reducing emissions; i.e., the cost per ton of carbon for reducing the next ton of carbon was approximately equal at all mills. This represents an optimal allocation and minimum cost approach for making the needed reductions.

Estimated carbon dioxide emission reductions achievable at discrete intervals of marginal cost per ton of carbon were compiled, along with associated capital and annual costs for these reductions, for each of the pulp and paper and representative solid wood product mills included in the analysis. These quantities of potential emission reductions and associated costs were scaled up to represent the U.S. industry in a similar fashion to that described earlier (based on the level of industry representation contained within the data set).

In the process of conducting the analysis, it became clear that the industry's estimated annual compliance costs were greatly influenced by the conditions under which excess power could be sold to the grid. For this reason, the results are presented as a function of the difference between the price for purchasing power and the price at which excess power can be sold. The results are shown in Table 13 and plotted in Figures 9 and 10. Also shown in the table is the fraction of mills which found the most economical choice to be small gas turbines, large gas turbines, or a combination of conventional technologies. All wood products facilities were assumed to use a combination of conventional technologies for reasons discussed earlier. The figures also show linear regression models which describe the annualized costs and marginal costs as a function of selling prices of electricity, expressed as a percent of purchase price. The table illustrates how large gas turbines, which export power to the grid, become a more attractive option as the ratio of sale price to purchase price increases. While the impact of power exports on annual costs is evident, it is interesting that there is relatively little impact on capital costs, with the total for the industry remaining at about $6 billion across the range of power sales scenarios examined.

Table 13. Calculated Costs for the Forest Products Industry to Meet the Kyoto Protocol Target in 2010 Assuming Various Power Sales Scenarios and Current Fossil Fuel/Power Prices

Selling Price of Power as Percent of Purchase Price	Capital Costs ($ billion)	Annual Costs ($ million)	Marginal Cost ($ / metric ton C)	Percent of Pulp and Paper Mills Using*: Conventional Technologies	Small GTCC	Large GTCC
30%	5.74	135	63	62	29	9
40%	6.15	-50	43	58	27	15
50%	6.17	-259	25	58	18	24
60%	5.91	-512	1	59	17	24

* All wood products facilities assumed to be using a combination of conventional technologies

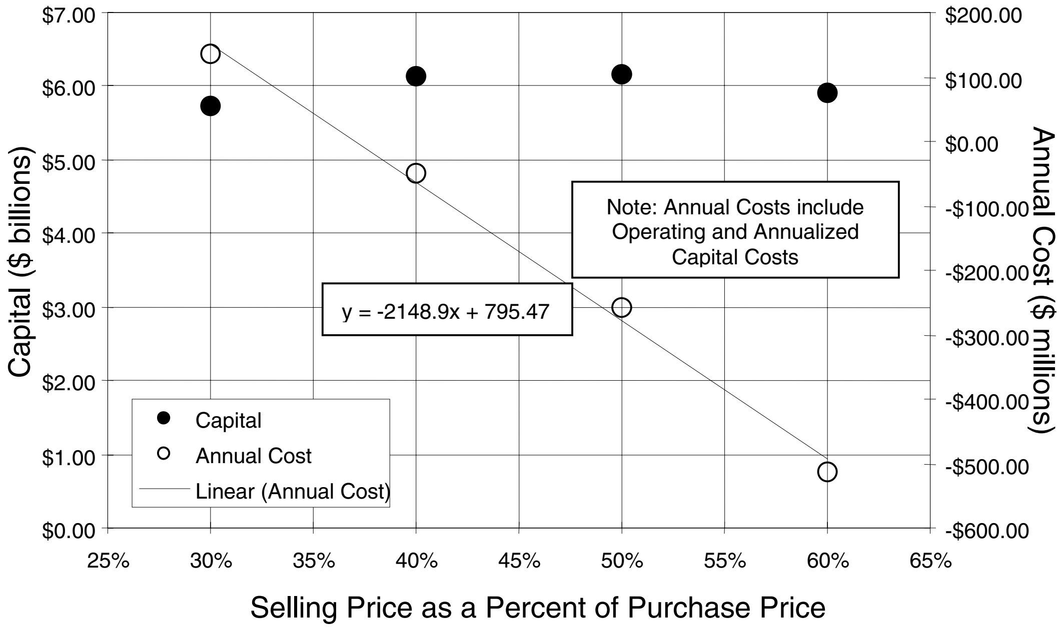

Figure 9. Impact of Excess Power Sales Price on Capital and Annualized Costs for the Forest Products Industry to Meet the Kyoto Protocol Target
- Assumes current fossil fuel/power prices and widespread use of GTCC to generate excess power -

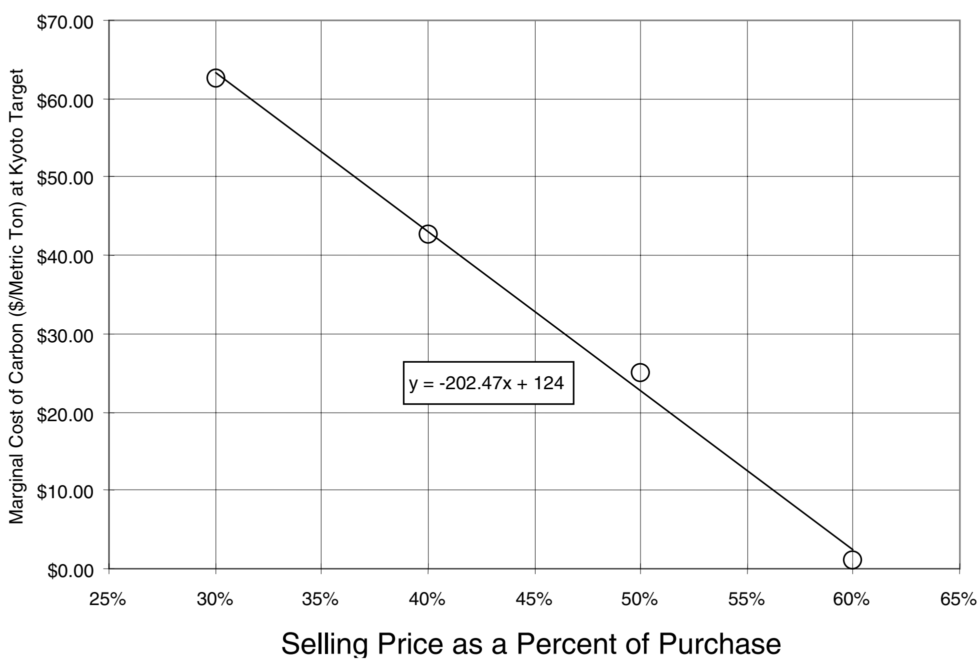

Figure 10. Impact of Excess Power Sales Price on the Marginal Cost of Carbon Reductions at a Point Where the Forest Products Industry Meets the Kyoto Protocol
- Assumes current fossil fuel/power prices and widespread use of GTCC to generate excess power -

Given the sensitivity of estimated annual compliance costs to power prices, the development of an estimate of industry-wide compliance costs must be attached to a selected ratio of power sale price-to-purchase price. For purposes of reporting a mid-range compliance cost estimate, NCASI selected a sale price for electricity that was 50% of the purchase price. This value was selected for a number of reasons. In part, it was based on analysis of data on national average prices for sale-for-resale power and power sold to industries. In 1996, the average sale-for-resale price for power was 3.3 cents per kWh, while the average price paid by industrial customers was 4.69 cents per kWh (EIA 1997c). Using these values, it is estimated that utilities sold power for resale at a price that was approximately 70% of the average price paid by industrial customers.

NCASI also surveyed a number of its large member companies to solicit their experience with selling excess power. Although limited, the results of that survey, summarized in Table 14, documented a very large range in power sale prices, with sale prices ranging from less than 30% to over 70% of the mills' purchase prices (median of approximately 40 %). In a number of instances, the companies reported that the current sale price was fixed in a long-standing contract and that it was very unlikely that current conditions would support as high a sale price. Indeed, one mill not included in the analysis reported that it was selling power at twice the current purchase price as the result of a long-term contract that was certain not to be renewed.

Table 14. Power Selling Prices for Eight U.S. Pulp and Paper Mills

Region of US	Selling Price as a Percent of Purchase Price
South-Central	19%
South-Central	19%
Northeast	30%
South-Central	36%
South-Central	40%
Northeast	56%
Northwest	70%
North-Central	76%
Median	38%

In addition, NCASI discussed this issue with the DOE Energy Information Administration. These discussions suggest that under current conditions, buy-back prices (unless fixed in long-term contracts) will sometimes be reduced because (a) with few exceptions, truly competitive markets have not yet developed, (b) utilities have adequate base load capacity in many areas of the country (demand may exist for power to meet peak loads, but industrial co-generation systems are best operated continuously), and (c) where additional capacity is needed, utilities can often add it themselves at a very competitive cost using gas turbine combined cycle technology. Over the longer term, as utilities retire their more expensive generation capacity and electricity markets become more competitive, electricity prices are expected to come down (unless impacted by other forces such as forced reductions in CO_2 emissions, a scenario discussed later) and the spread between the prices at which power can be purchased from versus sold to the grid should narrow. There is great uncertainty regarding the pace at which these changes will occur.

It is likely, however, that in a competitive power market the prices for power will be lower, making investments in power exporting technology less attractive, especially if natural gas prices increase in response to increased demand. In addition it must be observed that as utilities increasingly rely on the same GTCC technology that industrial facilities might employ for generating power for export, the only advantage for the industrial generator using a fossil fuel GTCC system is the opportunity to operate the GTCC technology in a co-generation mode. The utility using GTCC technology is likely to maintain advantages in the areas of financing costs, fossil fuel costs, and a variety of economies of scale. In addition, disincentives remain for mills interested in installing GTCC systems, including possible requirements that "acid rain" credits be purchased to offset GTCC emissions (and perhaps other emissions from the mill) (Bailey and Wilson 1999). For these reasons, caution is warranted in projecting potential profits from industrial sales of excess power, especially when such sales require substantial capital investments, as in the case of GTCC installations.

Given all of the factors discussed above, NCASI decided to use an excess power sale price equal to 50% of a mill's current purchase price where a single value was needed to analyze scenarios involving the sale of excess power. Under these conditions, approximately one-quarter of the mills in NCASI's core analysis are predicted to use large gas turbines in 2010, with almost all of these mills exporting excess electricity. It is very clear, however, that NCASI's estimates of annual compliance costs are highly sensitive to assumptions about power costs, fuel costs, and the impacts of deregulation, distributed power generation, and "green" marketing on energy markets – factors that are outside the scope of NCASI's analysis. Great caution, therefore, is warranted in using these point estimates of annualized costs. Estimated capital costs, however, do not appear as sensitive to these factors. Table 15 contains the results of NCASI's analysis under current fossil fuel and power prices, assuming widespread use of GTCC systems to generate excess power for export at a sale price of 50% of the regional purchase price.

Table 15. Estimated Costs for Reducing Emissions Using Current Fossil Fuel/Power Prices and Assuming that Excess Power from GTCC Systems can be Sold at 50% of Purchase Prices

	Units	2010	2020
Business-as-usual emissions	million metric tons C/year	37.8	43.8
Kyoto target	million metric tons C/year	26.1	26.1
Marginal reduction cost at Kyoto target	$/metric ton carbon	25	35
Capital costs for reductions to target	$ billion	6.2	8.3
Fraction of pulp and paper mills exporting power from GTCC systems	percent	22	29
Annualized costs for reductions (including operating and annualized capital costs)	$ million per year	-259	-241

Because of the substantial impact that GTCC systems have on the analysis and the great uncertainty surrounding the future profitability of such systems in mill settings, the analysis was rerun without GTCC systems as an option. This approach can be viewed as providing an upper bound estimate of the costs. It is also likely to be significantly less uncertain than the analysis incorporating GTCC systems since the estimates are less sensitive to assumptions about power sales by mills. The results are shown in Table 16.

The analysis clearly indicates the extent to which the estimated annualized and marginal costs are dependent on the assumption that the industry will be able to install GTCC systems and profit from power sales to the grid. Without GTCC systems in the analysis, annualized costs are $1 to 2 billion annually compared to -$250 million annually with GTCC systems included. Likewise, without GTCC systems marginal costs are $177 to $205/metric ton carbon, compared to $25 to $35/metric ton carbon with GTCC systems included (at a sale price for power of 50% of purchase price). This finding further reinforces the need for great caution when projecting annualized or marginal costs for meeting the Kyoto Protocol.

Table 16. Estimated Costs for Reducing Emissions Using Current Fossil Fuel/Power Prices, With and Without GTCC Technology as an Option – Excess Power Sold for 50% of Current Purchase Price

		Without GTCC		Including GTCC*	
	Units	2010	2020	2010	2020
Business-as-usual emissions	million metric tons C/year	37.8	43.8	37.8	43.8
Kyoto target	million metric tons C/year	26.1	26.1	26.1	26.1
Marginal reduction cost at Kyoto	$/metric ton carbon	177	205	25	35
Capital costs for reductions to target	$ billion	7.6	12.6	6.2	8.3
Fraction of pulp and paper mill exporting power from GTCC systems	percent	0	0	22	29
Annualized costs for reductions (operating + annualized capital costs)	$ million per year	1078	2059	-259	-241

* From Table 15

Capital cost estimates are far less sensitive to assumptions about the availability and profitability of GTCC systems in mill settings. Without GTCC systems, the estimated capital costs in 2010 are only 22% higher than they are when GTCC systems are included as an option. In 2020, the difference is somewhat greater, with capital costs being approximately 50% greater for the no-GTCC scenario compared to the scenario wherein GTCC technologies are available.

5.2 Sensitivity of Cost Estimates to Energy Costs

Because NCASI's analysis is limited to the forest products industry, it does not address the potential impacts of forced CO_2 reductions on energy costs. A number of other studies, however, have examined the impact of the Kyoto Protocol on the U.S. economy and have determined that much of the economic impact is expected to be due to higher energy costs (costs reflecting the carbon price found necessary to allow the U.S. to reduce CO_2 emissions to 7% below 1990 levels). These studies are discussed in more detail later in this report.

With energy prices being critical to the findings of numerous other studies, it was important that NCASI examine the impacts of energy prices on the costs for the forest products industry to meet the Kyoto Protocol target. This was done by comparing the results of the current-energy-price analysis for a subset of mills to the results of several similar analyses performed using different energy prices.

To examine the situation where fossil fuel prices are driven to high levels by public policies and market conditions intended to force reductions in U.S. greenhouse gas emissions, NCASI used price projections developed by EIA in its analysis of the impact of the Kyoto Protocol (EIA 1998a). EIA addressed a number of scenarios based on varying assumptions about, for instance, the geographical bounds of a carbon credit trading system and the availability of sinks. EIA's "1990-7%" scenario was most consistent with the assumptions in NCASI's analysis because in this EIA scenario the U.S. meets the Kyoto Protocol target "without the benefit of sinks, offsets, international carbon permit trading, or the Clean Development Mechanism." (The Clean Development Mechanism, or CDM, allows developed countries to claim credits for reductions they accomplish via projects in developing countries.) Carbon trading within the US, however, was allowed under this EIA scenario, while NCASI allowed carbon trading only within the U.S. forest products industry.

In the analysis of the impacts of higher energy prices, it was necessary to assign a price to additional amounts of wood waste or other biomass fuels that might be burned for energy in the forest products industry. One option was to assign a cost to wood waste equivalent to natural gas on a BTU-in-steam basis, using the higher EIA prices for natural gas. (Because EIA's projected prices include a carbon cost, the projected cost for natural gas is lower than that for oil or coal; see Table 17.) This approach yielded a biomass fuel energy cost of $7.35/MBtu. At 17 MBtu/dry ton, this is equivalent to approximately $130/dry ton of wood, a price that appears to make the fuel value of wood highly competitive with its value as a raw material for the forest products industry. This price estimate is driven by demand for wood as a greenhouse gas emissions-free energy source. It ignores the relative costs for generating additional supplies of biomass and public policies that might be put in place to make biomass less expensive than fossil fuels.

An alternative method to derive an estimate for biomass costs in a Kyoto Protocol-driven economy is to rely on studies that attempt to define the impact of higher prices on biomass availability. Oak Ridge National Laboratory (ORNL) is examining the supply curves for various sources of biomass, and has projected that several non-wood sources of biomass, switchgrass in particular, can be supplied at a lower cost and a higher return to landowners than wood (Walsh 1999). The ORNL analysis indicates that at a cost of $50/dry ton, the highest price examined by ORNL, approximately 350 million dry tons of biomass becomes available. Adding transportation costs, this is equivalent to approximately $3.50/MBtu.

There is no way of knowing whether market pressures in a high fossil fuel price environment would force biomass energy prices up toward the demand-driven estimate of $7.35/MBtu, or if expanded supplies and public policy would moderate biomass prices to keep them closer to the lower estimate of $3.50/MBtu. To address this uncertainty, the high cost scenario was run twice using the two projected wood waste prices. In both cases it was assumed that exported power could be sold for 50% of the purchase price at each mill.

In addition, it was of interest to examine the sensitivity of the core analysis cost estimates to the assumption that even at current fossil fuel and power prices national efforts to reduce greenhouse gases would cause biomass costs to increase due to increased competition for the resource and longer haul distances. Because of these factors, the price for additional wood waste in the core analysis was assumed to be $2.36/MBtu, even at current fossil fuel and power prices. To test the sensitivity of the results to this assumption, a scenario was examined wherein fossil fuel and power costs remained at current levels and additional wood waste was available at $1.30/MBtu, a cost generally reflective of current costs for wood waste. Table 17 lists the fuel prices used in the various sensitivity analyses.

Ideally, the analysis of the impact of higher energy prices would have been performed on all 90 mills in NCASI's database. Because of the time involved in recalculating the energy balances for all 90 mills, however, NCASI chose to examine the sensitivity of the results to energy costs using a subset of the 90 mills. The mills were selected with the goal of including production from a wide variety of the predominate categories within the industry and a range of marginal fuels. Three mills were selected from each of the following production categories:

- Unbleached kraft board/sack grades
- Integrated bleached kraft fine paper
- Non-integrated fine paper
- Mechanical pulp production and paper making

Table 17. Prices Used to Examine the Impact of Energy Costs

	Current Regional Fossil Fuel and Power Prices Used in the Core Analysis		EIA-Projected 2010 Fossil Fuel and Power Prices Under Kyoto Protocol*	
	Lower Wood Cost	Higher Wood Cost (Core Analysis)	Lower Wood Cost	Higher Wood Cost
Coal	$0.88 - $1.73/MBtu	$0.88 - $1.73/MBtu	$10.03/MBtu	$10.03/MBtu
Oil	$2.23 - $4.61/MBtu	$2.23 - $4.61/MBtu	$9.65/MBtu	$9.65/MBtu
Natural gas	$1.85-$3.20/MBtu	$1.85-$3.20/MBtu	$8.65/MBtu	$8.65/MBtu
Wood waste	$1.30/MBtu	$2.36/MBtu***	$3.50/MBtu**	$7.35/MBtu***
Purchased electricity	$35 - $97/MWh	$35 - $97/MWh	$73.41/MWh	$73.41/MWh

* For the "1990-7%" case (EIA 1998a) – data in Table B3 of that reference
** Highest cost examined by ORNL in recent biomass supply studies (see text)
*** Estimated by NCASI to be equivalent to natural gas prices on a Btu in steam basis

The results of the fuel cost sensitivity analysis for the 12 mills are summarized in Table 18. The results indicate that rising fuel costs promote investment of capital in energy-saving technology because the energy-savings payback is higher. The data in the table also document, however, that while higher energy costs may promote the installation of technologies that reduce fossil fuel use, the savings from reduced fossil fuel consumption are small compared to the increased overall cost to the industry in the form of higher energy costs. Considering both energy costs and the costs for reducing CO_2 emissions, it would be more expensive for the industry to make the reductions in a high energy price environment than to do so at current energy prices.

For the 12 mills in this analysis, the total annual costs for meeting the Kyoto Protocol target in the high energy cost scenario, including the industry's higher energy bill, are more than double those estimated at current prices, while the estimated capital costs are at least 60% greater than those projected at current energy prices. The estimates in the table confirm that under these high energy price conditions most of the overall impact on the industry is due to the higher energy prices, rather than the costs for reducing the industry's emissions. Even if fossil fuel and power prices were increased to reflect a cost of carbon emissions of only $25/metric ton carbon, a cost much lower than projected by most researchers as being adequate for the U.S. to meet its Kyoto Protocol target, energy costs for the industry could increase by more than $500 million/year.[1]

Table 18. Impacts of Energy Costs* on Compliance Costs for 12 Mills Assuming that Excess Power can be Sold at 50% of Purchase Prices

	Current Regional Fossil Fuel and Power Prices		EIA-Projected 2010 Fossil Fuel and Power Prices Under Kyoto Protocol	
	Lower Wood Cost	Higher Wood Cost (Core Analysis)	Lower Wood Cost	Higher Wood Cost
Capital cost ($million)	251	251	405	453
Annual cost of capital ($million/yr)	40.8	40.8	65.9	73.7
Annual energy costs before implementing CO_2-reducing technologies ($million/yr)	268	288	917	990
Energy cost savings due to CO_2–Reducing technologies ($million/yr)	27	27	139	142
Annual energy costs after savings ($million/yr)	241	261	778	848
Total annual cost (annualized capital and energy costs)	282	302	844	922

* Energy cost scenarios as described in Table 17

For these 12 mills, nine of which had the option of using more biomass to reduce CO_2 emissions, compliance costs were insensitive to increasing the cost of wood waste to $2.36/MBtu from $1.30/MBtu when all other energy costs remain at current levels. The reason is that, for these 12 mills, the savings in fuel costs were not large enough to compensate for the capital costs required to burn more biomass. A variety of other options provided more cost-effective, albeit individually smaller, reductions in emissions. It is reasonable to expect that, across the industry, some mills would find a $1/MBtu swing in wood waste costs adequate to impact their decisions on converting or installing boilers to use more biomass, but the results from these 12 mills suggest that the impact on overall industry compliance costs would not be highly significant. It is important to note, however, that the analysis did not include scenarios wherein biomass fuels were used to generate power for export using either conventional or emerging technologies (e.g., biomass gasification combined cycle technology). The sensitivity of the analysis to wood waste costs might be different under such conditions.

[1] If fossil fuel and power costs rose to reflect a carbon cost of $25/metric ton carbon, the increased energy costs for the industry can be approximated by applying this carbon cost to the industry's carbon emissions, which are projected to be 26.1 million metric tons carbon per year after the industry meets the Kyoto Protocol target.

To further examine the impacts of wood waste costs on the 90 mills in NCASI's database, a separate analysis was performed using the same four scenarios shown in Table 17. In this case, all 90 mills were examined to determine the marginal costs for reducing emissions by modifying or replacing fossil fuel-fired boilers. Using the current energy price scenarios in Table 17 and the marginal cost associated with the industry meeting the emissions target at current energy prices (25$/metric ton carbon), only 12% of the eligible boilers would be modified or replaced to increase wood waste burning at a wood waste cost of $1.30/MBtu. This drops to 4% at a wood waste cost of $2.36/MBtu, so only 8% of the eligible boilers would be impacted if wood waste costs increased to $2.36/MBtu from $1.30/MBtu. This suggests that the results of the core cost analysis were not significantly impacted by the assumed wood waste price of $2.36/MBtu, a finding consistent with the results of the 12-mill sensitivity analysis.

Not surprisingly, for the two scenarios involving EIA-projected high fossil fuel and power prices, the attractiveness of using additional wood waste increased dramatically when wood waste prices dropped to $3.50/MBtu from $7.35/MBtu. Under the EIA high price scenario and a marginal carbon reduction cost of $25/metric ton carbon or less, over 60% of eligible boilers would be modified or converted at a wood waste price of $3.50/MBtu, whereas less than 10% would be modified or converted at a wood waste cost of $7.35/MBtu.

5.3 Meeting the Emissions Target by Reducing to a Common Marginal Cost Under Conditions of Lower or Mixed Trends in Fossil Fuel and Power Costs

Although not included in NCASI's analysis, it is important to consider the implications of lower fossil fuel and power costs or mixed trends in these costs on the industry's ability to reduce carbon emissions. Such an analysis seems especially appropriate given (a) the sensitivity of NCASI's estimates to high energy costs and excess power markets, and (b) current projections of energy costs. EIA has examined several energy price scenarios that do not involve forced reductions in greenhouse gas emissions. EIA's most recent analysis suggests declining coal and electricity prices and increasing gas and (eventually) oil prices through the year 2020 (EIA 1998d). This would also be a costly environment in which to reduce greenhouse gas emissions, because much of the CO_2 reduction projected by NCASI is from sales of excess power generated by GTCC technology. Higher gas prices and lower electricity prices would make these reductions much more costly. However, if other supplies of gas for GTCC systems became available, they could, depending on cost, reduce the costs for the industry to comply with Kyoto Protocol target. In this regard, new technologies such as biomass gasification could gain special significance in the industry's future efforts to reduce greenhouse gas emissions.

5.4 Worst-Case Scenario Application of Kyoto Protocol Target – Apply Target to Each Mill

In order to examine the impacts of a "worst-case" interpretation of the application of the Kyoto Protocol target, NCASI examined the costs for every mill to reduce its own emissions to 7% below its 1990 emissions. Estimates of 1990 carbon dioxide emissions for each mill were calculated based on 1990 fossil fuel use data from NCASI and 1991 purchased power data from AF&PA (1990 data were not available). The carbon dioxide emission factors used to estimate emissions are those listed in Table 11.

Costs for each mill to meet its specific carbon dioxide emission target were estimated by applying the remaining reduction measures (those not already applied to tune the model) as necessary to reduce projected 2010 emissions and summing the associated costs.

The individual results calculated for each of the 90 pulp and paper mills were scaled up to predict overall costs to the pulp and paper industry based on the adjusted percentage of the total U.S. production in the various product categories represented within the data set (e.g., represented by the mills included in the analysis, as discussed earlier). These results are presented in Table 19. Also shown in the table are comparable cost estimates for meeting the target at pulp and paper mills under the common-marginal-cost scenario described above.

Table 19. A Comparison of the Costs for the Industry to Meet Mill-Specific Kyoto Protocol Targets vs. a Target for the "Bubbled" Industry -- Pulp and Paper Mills Only

	Capital Investment ($ Billion)	Annual Cost* ($ Million/year)
Apply mill-specific target equal to 93% of mill's 1990 emissions	>10.8	>609
Allow industry to meet "bubbled" target by reducing emissions at a constant marginal cost	5.0	-255

* Excess power sold for 50% of purchase price; includes operating costs and annual cost of capital

It is important to note that since carbon dioxide emission reduction targets are based on emissions in 1990, some mills may not be capable of meeting their target by implementing the emission reduction measures identified as part of this analysis. In this analysis, four mills out of the 90 studied were unable to meet the target regardless of cost. There are a number of factors accounting for the high cost, and in some cases the inability, to meet mill-specific targets of 7% below individual mill 1990 emissions, including:

- Production rate increases since 1990, and associated increases in total quantities of fuel and energy required to support increased production levels
- Changes in the grades of products manufactured, and associated changes in fuel and energy required to produce the new product grades
- Implementation of energy efficiency technology options prior to the baseline emission year (1990), so that few cost effective emission reduction measures are currently available for further reductions

In the analysis results presented in Table 19, the costs for the four mills unable to meet the target were assumed to be zero. For this reason, the costs in Table 19 are understated and are shown as "greater than" values. The results indicate that capital costs more than double and annualized costs increase by over $800 million/year for the pulp and paper sector alone if the target is applied mill-by-mill rather than to the "bubbled" industry.

Due to the lack of detailed mill-specific fuel and energy use data for the solid wood product sectors of the industry, the costs for individual facilities in these categories to meet facility-specific emission targets could not be estimated as described above for pulp and paper mills.

5.5 Correcting Compliance Costs to Reflect Business-As-Usual Improvements

Elsewhere in this report, data are presented documenting the industry's continued progress in reducing greenhouse gas emissions per unit of product. This continuing improvement has been extrapolated into the future for purposes of estimating needed reductions to meet the Kyoto Protocol target. However, the cost modeling used the CO_2 that would have been emitted had the industry remained at 1995 emissions per unit of production as a starting point. Accordingly, the estimated costs from the modeling must be reduced by the amount associated with the fraction of the reductions that are expected to occur under the business-as-usual scenario. The industry will, of course, incur the costs to accomplish the full reduction, but only the costs associated with reductions beyond those that would have occurred under business-as-usual conditions can be attributed to efforts to comply with the Kyoto Protocol target.

Mid-1990s annual emissions related to pulp and paper manufacture and wood products manufacture were 26.3 and 3.7 million metric tons, respectively. Under the mid-range growth scenario, pulp and paper production is projected to increase from 90.8 million metric tons in 1995 to 114 million metric tons in 2010 and 132 million metric tons in 2020. Accordingly, if pulp and paper-related emissions increased with production, emissions would be projected to increase from 26.3 million metric tons carbon in 1995 to 33.0 million tons in 2010 and 38.1 million tons in 2020. The mid-range growth scenario has wood products production growing from 112.4 million cubic meters in 1994 to 143 million cubic meters in 2010 and 166 million cubic meters in 2020. If emissions grew with production, they would be projected to grow from 3.7 million metric tons carbon in the mid-1990s to 4.7 million tons in 2010 and 5.5 million tons in 2020. Adding the contributions from pulp and paper manufacture to those from wood products manufacture yields an estimate of what the overall industry's projected emissions would be if they grew proportionally to production. Under this scenario, industry emissions would be projected to be 37.7 million metric tons in 2010 and 43.6 million metric tons in 2020.

Earlier in this report, normal business-as-usual improvements in emissions per unit of production were projected to result in overall industry carbon emissions of 37.8 million metric tons in 2010 and 43.8 million metric tons in 2020. These are essentially the same numbers as projected if emissions grew proportionally with production. The numbers are the same in spite of the gradual improvements in business-as-usual emission factors because of the additional carbon emissions related to new or expected environmental requirements. The two projections are so close that it is unnecessary to apply a correction factor to the estimated reduction costs to account for business-as-usual improvements. Accordingly, the costs in Tables 15 and 16 are entirely attributable to reductions made for purposes of meeting the Kyoto Protocol target.

5.6 The Opportunity Cost Impact of Investing in CO_2 Reduction Technology

In this analysis, it has been estimated that at an annual growth rate of 1.5% the forest products industry could meet the Kyoto Protocol target in 2010 at a cost of $6 to 8 billion in capital, and annual costs varying from less than -$250 million/year to more than +$1 billion/year depending on future power and fuel costs and the industry's ability to compete as power suppliers in a deregulated environment. These annual costs, however, understate the cost impact on the industry.

The true impact of investments for CO_2 reduction can only be understood when compared to the return the capital would have yielded at payback thresholds demanded of current investments by forest products industry companies. Unfortunately, the large uncertainty in annualized costs makes it difficult to estimate the opportunity cost associated with the $6 billion in capital required to meet the emissions target in 2010. It is clear, however, that a $6 billion capital outlay for CO_2 reduction is a substantial diversion of capital, especially during a time when the industry is still in the process of coping with the estimated $2.8 billion in capital outlays needed to comply with the Cluster Rule, and is also facing several billion dollars in additional capital requirements related to regulations still under development (AF&PA 1998c).

5.7 Comparison of NCASI Cost Estimates to Company-Derived Estimates

NCASI invited companies with mills among the 90 in its database to examine NCASI's estimates and to provide company-derived estimates of costs that could be compared to NCASI's. Because NCASI employed a model cost curve approach, it was not surprising that a number of mills indicated that NCASI's model assumed the addition of technologies that were either already in place or were inappropriate for various reasons. Such responses could not be used to examine the reasonableness of NCASI's approach. Other companies, however, provided cost and emissions reduction estimates for individual CO_2 reducing technologies or for combinations of technologies. This information is summarized in Appendix I. The cost data provided to NCASI document that NCASI's estimates of individual project costs and impacts were sometimes too high and sometimes too low. The size of the differences between the NCASI and company estimates varies considerably, with some of the differences being very large, but NCASI's estimates of capital costs and emissions reductions do not appear to be systematically biased high or low. Comparisons of annualized costs were not attempted due to the large uncertainties in these cost estimates (discussed earlier).

5.8 General Observations on Costs for Compliance

Taken in its entirety, the foregoing discussion supports a number of observations regarding the costs for the forest products industry to meet the Kyoto Protocol target. First, it can be estimated with a reasonable degree of confidence that compliance with the target in 2010 will require at least $6 billion in capital, increasing to approximately $8 to $13 billion in 2020.

Second, estimated annualized and marginal costs for CO_2 reduction are very sensitive to assumptions about power costs, fuel costs, and the profitability of selling GTCC-generated power to the grid. If it is assumed that the industry will find relatively few opportunities for selling excess power for a reasonable profit or that such sales will be discouraged because of doubts about the ownership of the credits for displaced power or by other disincentives, then a reasonable estimate of the annualized and marginal costs can be obtained by eliminating GTCC systems from the analysis. Under these conditions, annualized costs in 2010 are estimated to be approximately $1 billion/year while the marginal cost (at the point where the industry meets the target) is $177/metric ton carbon. In 2020, these increase to approximately $2 billion/year and $205/metric ton carbon, respectively.

On the other hand, if it is assumed that (a) the obstacles to using GTCC systems will be minimal, (b) power and fuel prices will remain constant (or change in a direction favorable to GTCC), and (c) there will be numerous opportunities for selling excess power at a sale price of 50% or more of the current purchase price, the annualized and marginal costs are much lower. Under these conditions, annualized compliance costs in both 2010 and 2020 are approximately -$250 million/year. Marginal costs for reducing emissions are $25/metric ton carbon in 2010, increasing to $35/metric ton in 2020.

Accordingly, estimates of annualized costs and marginal costs must encompass large ranges. At current energy prices, estimated annualized costs in 2010 range from -$250 million/year to +$1 billion/year. Marginal cost estimates range from $25/metric ton carbon to $177/metric ton carbon.

Third, a limited examination of the potential impact of higher energy prices suggests that although capital costs would increase if emissions reductions were made in a high-price environment, the direct impact of higher energy costs could be more significant than the costs for making the reductions. Annualized operating costs and marginal costs attributable to CO_2 emission reductions would actually decrease in a high energy cost environment due to the higher value attached to energy savings. These decreases, however, would not be great enough to compensate for the underlying increases in energy costs. If energy prices rose to levels projected by EIA for a Kyoto Protocol-driven economy with limited carbon trading and no carbon sinks, capital costs for the industry would increase by perhaps 50 to 100%, while total annual costs (including the increased costs for energy) could more than double compared to what they are estimated to be at current energy prices.

Fourth, the costs for reducing CO_2 emissions must be understood in the context of the competition for capital and the expected returns on capital. When capital is invested at less than the normal threshold rate of return, an opportunity cost is imposed which impacts the industry's ability to remain competitive. Although many of the potential investments in CO_2-reducing technologies provide a modest return on investment, the returns are almost always below the threshold expected of comparable investments in the forest products industry. Accordingly, they impose opportunity costs which, on $6+ billion of invested capital, are expected to be considerable.

Finally, the cost estimates in this report have been developed under the assumption that mills which reduce purchased power consumption or export power to the grid will be granted credits for having displaced marginal regional grid power (and the associated marginal emissions). This assumption is particularly important because of the large contribution of GTCC power exports to the reductions needed to meet the CO_2 reduction target. Displacing marginal power is a “best-case” assumption because, according DOE’s Energy Information Administration, marginal power emission factors are always higher than average emission factors for purchased power (see Table 11). Ultimately, there are important public policy considerations that will have to be addressed to resolve the issue of how to provide credit for actions that reduce emissions by either reducing purchased power consumption or by providing “cleaner” power to the grid. Consequently, there is considerable uncertainty regarding the credit forest products companies will receive for such actions.

6.0 VARIABILITY IN COSTS WITHIN AND BETWEEN INDUSTRY SECTORS

The 90 pulp and paper mills included in this analysis were screened to find those having the least mixed production. This screening process yielded 21 bleached kraft mills, 11 unbleached kraft mills, 10 mechanical pulping mills, and 13 recycled paperboard/containerboard mills. For each mill, the costs incurred at a marginal cost of $50 per metric ton of carbon were determined. This is close to, albeit somewhat higher than, the marginal cost estimated to be adequate to meet the industry’s Kyoto Protocol target at current energy prices. In all cases it was assumed that excess power could be sold for 50% of the price at which it could be purchased from the regional grid. The results are shown in Figure 11.

An analysis of variance performed at the 0.05 significance level suggested that there were no significant differences between the four groups of mills with respect to compliance costs per ton of production ($P = 0.10$). In examining some of the mills at the extremes of these ranges, it appears that the reasons for the large ranges within categories include (a) the types of fossil fuels being used, (b) the costs (or savings) associated with converting to lower emitting fuels (natural gas or biomass), (c) differences in energy efficiency between mills in a given sector, and, most importantly (d) the projected feasibility of installing GTCC technology and selling excess power to the grid.

In Figure 12, the data are plotted according to the technology option selected rather than the production subcategory. Analysis of variance indicates that there are highly significant differences between the three groups ($P < 0.001$). The data clearly illustrate that mills with unusually high costs tend to be those using “conventional” technologies, while those with unusually low costs tend to be using GTCC technology. This finding reinforces the observation that the output of this analysis, especially in terms of annualized costs, is highly sensitive to conditions that impact the costs and returns related to the sale of excess power.

Given the limited number of mills in this analysis, it is not possible to know with certainty whether differences can be expected in average costs for different sectors of the industry. However, it appears that even if there are differences in the averages, individual mills will be far more impacted by the types and amounts of fossil fuels being used, site-specific opportunities for reducing energy consumption, and site-specific opportunities for selling excess power to the grid, especially when the power is generated by highly efficient, low carbon-emitting technology, such as GTCC.

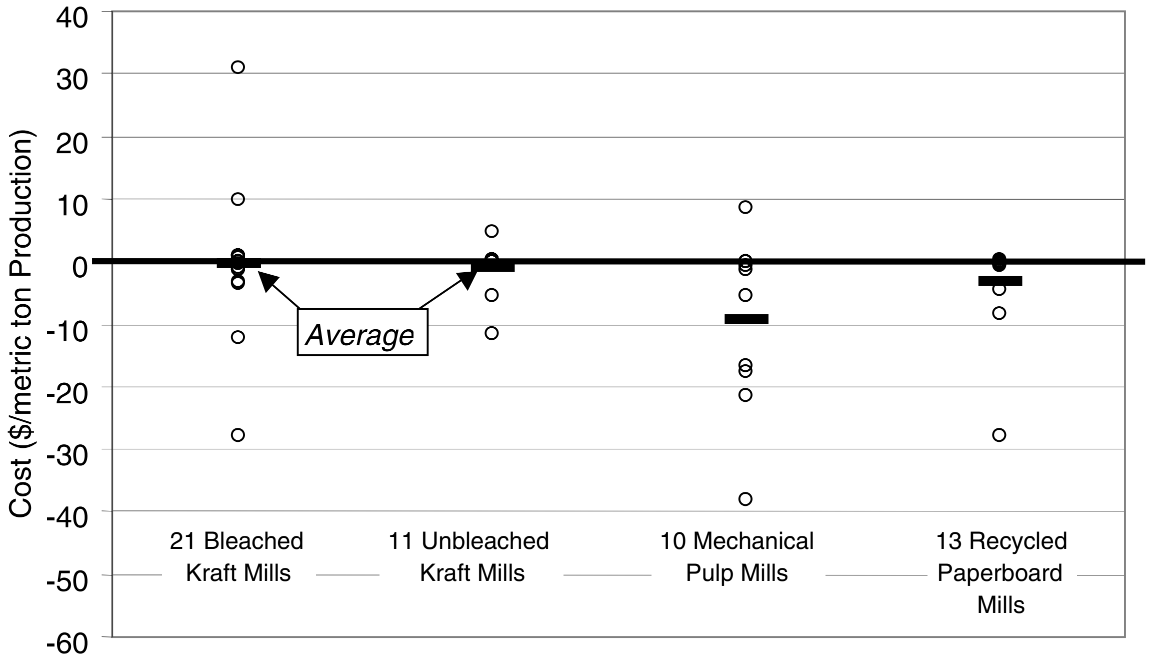

Figure 11. Variability in Compliance Costs (Per Ton of Product) Within and Between Industry Sectors

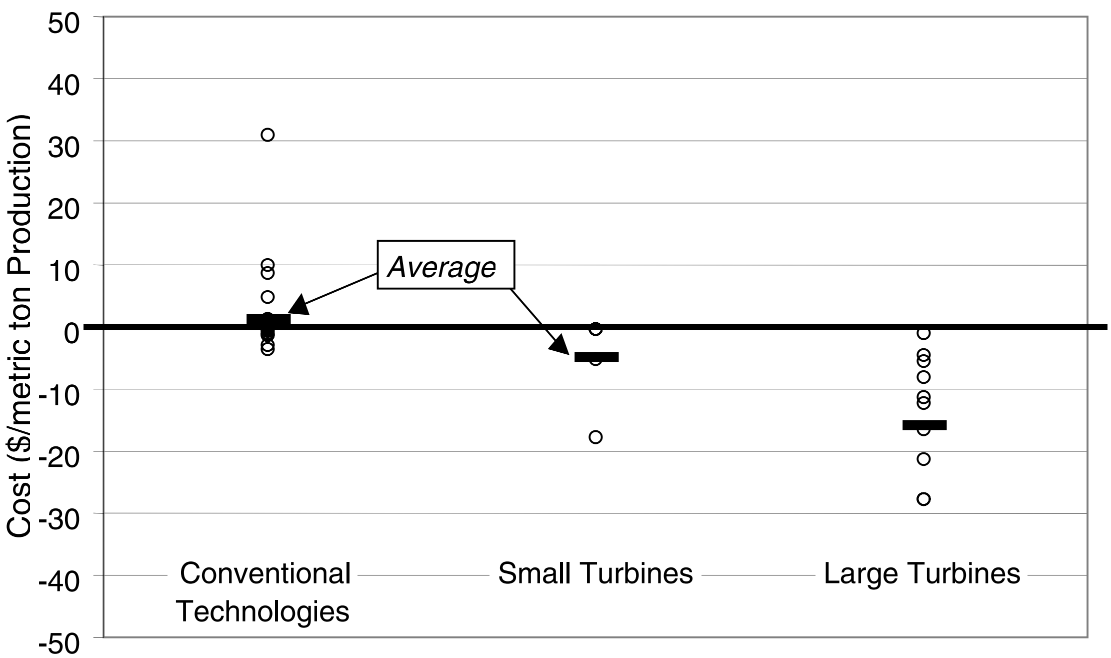

Figure 12. Variability in Compliance Costs (Per Ton of Product) With Different Technologies

7.0 TRANSPORTATION-RELATED EMISSIONS

A number of life cycle studies on paper products have examined transportation-related CO_2 emissions associated with pulp and paper products. EPA has examined this issue for newspaper, office paper, tissue paper, corrugated boxes, folding boxes, boxboard, and paper towels and estimated that the CO_2 emissions involved in transporting raw materials to the mill range from 0.02 to 0.05 metric tons carbon per metric ton product. In the same analysis, EPA notes that "[they] expect that the transportation energy from factory to consumer would represent a very small fraction of the total process and transportation energy" (US EPA 1998).

The Environmental Defense Fund (EDF) has also published estimates of the CO_2 emitted in transporting raw materials to mills (EDF 1995). For newsprint, corrugating medium, office paper, paperboard, and bleached kraft board, emissions of CO_2 from raw material transportation ranged from 0.02 (for recycled paper and board mills) to 0.04 (for bleached kraft grades) tons of carbon per metric ton product. In its life cycle analysis of recycling, EDF also examined the emissions associated with transport of product to market and found it to contribute 0.004 metric tons of carbon per ton of product, confirming the view that this represents a relatively small fraction of transportation-related CO_2 emissions.

Using a transportation CO_2 emissions factor of 0.04 metric tons carbon per metric ton product and a mid-1990s pulp and paper production figure of 90 million metric tons yields an estimate of transportation emissions from the pulp and paper industry of 3.6 million metric tons carbon. In the mid-1990s, the emissions from all other pulp and paper manufacturing-related sources were approximately 26.3 million metric tons carbon. Adding transportation-related emissions, therefore, would increase estimated CO_2 releases from pulp and paper manufacturing by 14%. Although a comparable analysis was not performed for wood products operations, it is not unreasonable to expect that adding transportation-related emissions would have a generally similar effect on the wood products sector.

While not insignificant, transportation-related emissions were not included in this analysis for several reasons. First, with current data, there was no way to distinguish between those transportation emissions under mill control and those under the control of outside shippers and suppliers. Second, if improvements in fuels or fuel economy reduced these emissions, it was unclear whether the mill, the fuel producer, or the vehicle manufacturer would get credit for the reduction.

Depending on whether transportation-related emissions proved more or less expensive to reduce than the emissions included in this study, including these emissions could either increase or decrease the costs for meeting the Kyoto Protocol target.

8.0 CARBON DIOXIDE EMISSIONS FROM KRAFT MILL LIME KILNS

The CO_2-carbon contained in a kraft mill's lime kiln flue gas originates predominantly from two sources. The first source is fossil fuels used in the lime kiln. These fossil fuel-derived carbon emissions are addressed in NCASI's analysis presented earlier. The second source is black liquor. The black liquor carbon in kraft mill lime kiln emissions is the carbon that, instead of leaving the recovery furnace as biomass CO_2, is combined with sodium in the recovery furnace to produce sodium carbonate. The sodium carbonate is then converted to calcium carbonate in the slaker to yield sodium hydroxide, which is subsequently used for pulping. The black liquor carbon, now contained in the calcium carbonate, is liberated when the calcium carbonate is burned in the lime kiln to generate lime needed in the slaker. Because the carbon originated as biomass, it is considered to have a zero emission factor and is not considered in this analysis.

There is an additional source of lime-related CO_2 emissions that occurs off-site and could be considered an indirect emission. This is the CO_2 associated with the manufacture of make-up lime, used to compensate for losses of calcium at various points in the calcium recovery loop discussed above (i.e., the causticizing loop). This source was not included in NCASI's analysis.

It is possible to estimate how important this source of CO_2 might be to the industry's emissions profile. EPA's CO_2 emission factors for lime production range from 600 to 1600 kg CO_2 /metric ton lime (1200 to 3200 lb CO_2 /short ton) (US EPA 1995). These represent emissions of approximately 150 to 400 kg carbon/metric ton of lime (300 to 800 lb carbon/short ton). The total lime requirement for recovery of cooking chemicals is in the range of approximately 200 to 300 kg lime/metric ton pulp (400 to 600 lb/short ton) (Hough 1985). Under normal circumstances, over 95% of this is supplied by recycling within the recausticizing loop. If it is assumed that a mill might require as much as 5% make-up lime (12.5 kg make-up lime/metric ton pulp) and that the corresponding off-site emissions are 300 kg carbon/metric ton lime, it can be calculated that 3.75 kg carbon per ton of pulp is emitted off site. Total kraft pulp production in the mid-1990s was approximately 50 million metric tons/year (55 million short tons/year). Therefore, the annual indirect emissions from this source for the industry in the mid-1990s were less than 0.2 million metric tons of carbon compared to the total emissions of approximately 30 million metric tons. Excluding this source of indirect emissions, therefore, appears to have a negligible impact on the estimates for reducing emissions.

9.0 THE IMPACTS OF RETIRING LESS EFFICIENT CAPACITY ON CARBON EMISSIONS

To illustrate how the closing of older, less efficient mills might impact CO_2 emissions, an analysis was conducted using 1995 CO_2 emissions data for mills in two different product categories: bleached kraft and recycled paperboard and containerboard. In each category, data for a group of mills were used to estimate the impact of facility closure that occurs as part of a normal business cycle. These two categories were selected because (a) they represent very different mill energy balances, and (b) NCASI had data for at least 10 mills in each category (10 bleached kraft mills and 14 recycled paperboard/containerboard mills) that had reasonably comparable product and production process profiles.

The analysis was performed as a sensitivity analysis. It was assumed that one mill in each group would be permanently shut down, and that the production would be absorbed by other mills. The mill to be shut down was assumed to be the one with the highest fossil fuel use, and therefore the highest direct CO_2 emissions, per ton of product. It was also assumed that the mills absorbing the production would, on average, emit CO_2 at a rate equivalent to the 50^{th} percentile value for the group. NCASI did not attempt to determine whether the "closed" mill was, in fact, the least efficient or profitable mill in each group. Indeed, a mill can be a high emitter of CO_2 by virtue of its selection of fuels and yet be highly efficient and profitable. Because this approach assumes that the least profitable capacity will always be associated with the highest emissions per ton, it represents a "best-case" analysis. To the extent that this assumption is inaccurate, the analysis will overstate the effects of mill closures on reducing industry emissions.

The mills included in each group were selected from mills whose 1995 CO_2 emissions had previously been estimated for other purposes. Only those mills whose production fell entirely within either of the two categories were included in the exercise. The mills were ranked according to their estimated 1995 production-normalized CO_2 emissions. The 10 mills in the bleached kraft category and the 14 mills in the recycled paperboard/containerboard category were ranked by their total emissions.

The CO_2 emissions reductions associated with mill closure were calculated by multiplying the "closed" mill's production by the difference between that mill's value and the group's 50^{th} percentile value for CO_2 emissions per ton of product. Calculations were performed for both direct and total CO_2 emissions.

The mill closure scenario results for the bleached kraft mill group, summarized in Table 20, show that the percent reduction in direct CO_2 emissions (8.0%) is slightly greater than, and the percent reduction in total CO_2 emissions (5.4%) is slightly less than, the percent of production (6.0%) affected by the closure scenario. The same relationships were also observed in the results for the recycled paperboard and containerboard mill group, summarized in Table 21.

Table 20. Mill Closure Illustration for the Bleached Kraft Category

Number of mills included in analysis	10
Total production, metric tons/yr	4,250,000
Closed mill production, metric tons/yr	255,000
Closed mill production, % of group total	6.0%
CO_2 emissions, kg carbon/metric ton	
Closed mill	862
Group 50th percentile	436
CO_2 emissions reduction due to closure,	
Metric tons carbon/yr	109,000
% CO_2 reduction in category	5.4%

Table 21. Mill Closure Illustration for the Recycled Paperboard/Containerboard Category

Number of mills included in analysis	14
Total production, metric tons/yr	1,303,000
Closed mill production, metric tons/yr	120,000
Closed mill production, % of group total	9.2%
CO_2 emissions, kg carbon/metric ton	
Closed mill	400
Group 50th percentile	213
CO_2 emissions reduction due to closure,	
Metric tons carbon/yr	22,400
% CO_2 reduction in category	7.4%

The results of this exercise suggest that the reduction in CO_2 emissions due to mill closure may be roughly proportional to the amount of production affected. Facilities that previously produced some 7200 metric tons of paper and board per day were idled in the period from 1991 through 1995 (Lockwood-Post Directory 1996). On an annual basis, this represents approximately 0.7% of the average annual total industry production over this time frame (AF&PA 1997b). Assuming that reductions in industry CO_2 emissions per ton are directly proportional to the fraction of production being closed, this suggests that over the same period emissions per ton would have decreased on the order of 0.7% per year as a result of mill closures (recognizing that this assumes that the closed production was also the most highly emitting production).

Elsewhere in this report, NCASI has analyzed the reductions that the industry has made in emissions per ton of production. In that analysis, a model has been developed that represents the best fit of existing emissions data. For the period from 1991 to 1995, this model shows annual improvements in direct emissions per ton averaging approximately 0.8% compared to perhaps as much as 0.7% due to capacity retirement estimated above. Therefore, although great caution is warranted in interpreting the results of the closure analysis, it appears that as the industry modernizes, the retiring of more highly emitting capacity might be a significant contributor to the continuing improvements being made in the industry's emissions per ton. The relative importance of this factor compared to other factors known to be contributing to the continued improvements is not known, however.

It is important to note that NCASI's estimates of future emissions under a business-as-usual scenario are based on an extrapolation of historical emissions factors. These factors have been improving (i.e., getting smaller) for a variety of reasons, including increased biomass utilization, increased energy efficiency, and retirement of less efficient capacity. Because NCASI's analysis is based on emission factors extrapolated from historical data reflecting these and other factors, it explicitly incorporates all of these factors without needing to understand their relative importance. Very recently, market conditions have resulted in an unusually large amount of capacity being retired. Because it is not possible to know whether, or for how long, this increased pace of capacity closure will continue, it was not addressed in NCASI's analysis, except to the extent that emission reduction targets were based on lower production growth rates than experienced over the last decade.

10.0 OTHER STUDIES OF THE COSTS FOR MEETING THE KYOTO PROTOCOL

A number of studies have been performed to estimate the costs for the U.S. to meet the Kyoto Protocol target of 7% below 1990 emissions. The U.S. DOE Energy Information Agency (EIA) has included a comparative analysis of many of them in its own study, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity* (EIA 1998a). In this section, EIA's review of these other studies is summarized and the studies are compared, where possible and appropriate, to the study presented herein.

EIA examined a number of studies addressing two scenarios. The first involved meeting the Kyoto Protocol target "without the benefit of sinks, offsets, international carbon permit trading, or the Clean Development Mechanism." (The Clean Development Mechanism, or CDM, allows developed countries to claim credits for reductions they accomplish via projects in developing countries.) Carbon trading within the US, however, was allowed under this scenario. The second scenario was similar to the first except that it allowed sinks, offsets, and carbon trading among the 34 countries listed in Annex I of the Kyoto Protocol. (The Annex I countries are generally the developed countries. See Appendix A.) Trading outside of the Annex I countries was not allowed under the second scenario, nor was the Clean Development Mechanism. NCASI's study did not consider sinks, offsets, or any trading outside of the industry. Only the first of EIA's two scenarios, therefore, can be compared to NCASI's study. Even then, there are at least two key differences between NCASI's study and the studies conducted or reviewed by EIA. First, NCASI did not attempt to model the impact of the Kyoto Protocol on energy prices. Where Kyoto-driven prices were addressed in NCASI's analysis, NCASI used EIA's projections. Second, NCASI's analysis allowed carbon trading only within the forest products industry, not across the entire country.

EIA also reviewed the Administration's analysis of the costs for meeting the Kyoto protocol (Clinton Administration 1998). EIA concluded that the Administration's analysis did not provide sufficient data to be included in its detailed comparisons. EIA did, however, use information contained in the

Administration's analysis to develop a carbon price which can be compared, at least in general terms, to those developed in the other studies. The studies reviewed by EIA are described briefly in Table 22.

Table 22. Studies Reviewed by EIA Having Assumptions Generally Comparable to Those in NCASI's Study

Short Identifier	Study Title/Date	Organization(s)
MIT	"CO_2 Emission Limits: Economic Adjustments and the Distribution of Burdens" – 1997	Performed by the Massachusetts Institute of Technology – funded by the Department of Energy
EPRI	"On Stabilizing CO_2 Concentrations – Cost Effective Emissions Reduction Strategies" – 1997	Performed by EPRI, the electric power industry's research organization
CRA	"After Kyoto: The Cost of Cutting Greenhouse Emissions" – 1998	Performed by Charles River Associates with (according to EIA) partial support from "industry groups including the American Petroleum Institute"
EIA	"The Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity" – 1998	Performed by EIA for the Committee on Science of the U.S. House of Representatives
PNNL	"Modeling Future Greenhouse Gas Emissions: The Second Generation Model Description" – 1998	Performed by the Pacific Northwest National Laboratory of DOE
WEFA	"Global Warming: The High Cost of the Kyoto Protocol, National and State Impacts"	Performed by WEFA Inc. with support from the American Petroleum Institute
ADMIN	"The Kyoto Protocol and the President's Policies to Address Climate Change: Administration Economic Analysis"	Performed for the Clinton Administration and developed, in part, using the PNNL model

Table 23 shows, for the various studies examined by EIA, the carbon price estimated to be necessary for the U.S. to meet the Kyoto Protocol target under scenario one, described above (no sinks, no offsets, no international carbon permit trading, and no CDM, but carbon trading allowed within U.S.).

EIA determined that it could identify several significant factors responsible for the differences in the results of the six studies it examined. It concluded that most of the major differences were due to differences in the assumed business-as-usual (BAU) rate of economic or emissions growth (EIA 1998a). This is consistent with NCASI's finding that across the range of plausible projected industry growth rates, the required reductions (in terms of tons of carbon) could easily change by a factor of two, with the likely impact on compliance costs being greater than a factor of two since reductions become more costly as they become larger.

NCASI's estimate of required reductions from projected 2010 BAU emissions are fairly consistent with those projected for the U.S. by other investigators. NCASI has estimated that 2010 BAU emissions would have to be reduced by 31% to meet the industry's Kyoto Protocol target. EIA estimates that U.S. (national) emissions would need to be reduced by 30% from 2010 BAU emissions to meet the U.S. target (EIA 1998a), while WEFA's estimate of needed U.S. reductions from 2010 BAU emissions is 37% (WEFA 1998). Charles River Associates, Inc. has estimated that U.S. emissions would have to be reduced by 31% (CRA 1998).

Table 23. The Cost of Carbon Necessary to Ensure Compliance with the Kyoto Protocol Target

Study	Carbon Price in 2010 ($/metric ton)
MIT	266
EPRI	280
CRA	295
EIA	348
PNNL	221
WEFA	265
ADMIN	192*
NCASI	25 – 177**

* Developed by EIA from information contained in the Administration's analysis

** Marginal cost of carbon reductions at the point where the forest products industry meets the target (assuming current fossil fuel and power costs)

NCASI's estimated marginal costs for the forest products industry appear to be lower than those suggested for the overall U.S. economy by these other studies. The ability to compare marginal costs, however, is limited for several reasons. The marginal costs estimates by NCASI assume current fossil fuel and power prices. NCASI examined the impact of higher energy costs on only twelve mills, too few to develop a reliable estimate of marginal cost, yet all of the other studies were based on energy prices driven higher by efforts to comply with the Kyoto Protocol. In addition, NCASI found that estimated marginal costs for the forest products industry are extremely sensitive to assumptions about fuel costs, power costs, and the potential for profitable sale of excess power. With these large uncertainties, it is impossible to know whether the apparent difference in marginal costs is significant. Given the importance of marginal costs in a carbon credit trading program, this issue might be an appropriate subject of additional study.

11.0 THE POSSIBLE ROLE OF EMERGING TECHNOLOGY

In estimating the costs for reducing CO_2 emissions, only commercially available technologies have been considered. This is because of the large uncertainty associated with characterizing the costs and effectiveness of emerging technologies. There are at least two emerging technologies, however, that warrant at least a semi-quantitative examination in this report due the level of interest and development activity surrounding them and their potential impact on the industry's greenhouse gas emissions profile. These are black liquor and biomass gasification/combined cycle technology and impulse drying.

11.1 Gasification/Combined Cycle Technology

A key finding of this study has been the potential importance of technologies that allow the industry to take advantage of site-specific opportunities for selling excess power generated by economical, highly efficient, and low-carbon emitting technology. Among the existing technologies, gas turbine combined cycle technology is of particular interest. A potential new opportunity, however, is emerging which involves the coupling of black liquor or wood waste (biomass) gasification with GTCC technology. Black liquor and biomass gasification have been a matter of interest and research in the forest products industry since the 1970s. Indeed, there are a number of air-blown atmospheric-pressure wood waste gasifiers operating in Europe and providing gas to lime kilns (Larson and Raymond 1997).

A number of factors have contributed to a greatly increased level of interest in recent years. First, due to advances in technology, black liquor and biomass gasification/combined cycle technologies are approaching the point of being (and is some cases, are) commercially available (Larson and Raymond 1997). Second, indications are that gasification/combined cycle technologies will offer improved overall energy conversion efficiencies compared to conventional technologies (AF&PA 1998d) while being cost competitive with conventional technologies (Larson, Kreutz, and Consonni 1998b; Larson et al. 1998). Third, the U.S. industry's recovery furnace population is aging. Figure 13, developed from data collected in an NCASI/EPA 1994 Recovery Furnace Survey, documents that most of the industry's furnaces were installed before 1980. In fact, over one-half of the U.S. industry's recovery furnaces were first installed before 1973, making the median age over 25 years. By the year 2010, approximately 60% of the currently installed recovery furnaces will be at least 35 years old. The opportunity to replace aging Tomlinson furnaces with new, more efficient, cost-effective technology is a significant factor in the current interest in black liquor gasification/combined cycle technologies. An added factor has been the potential benefits that black liquor and biomass gasification technologies might bring to the industry's greenhouse gas emissions profile (AF&PA 1998d).

Together, these factors have caused the U.S. forest products industry to launch, through AF&PA, the "Forest Products Industry Gasification Combined Cycle Initiative," intended to assist the industry, the U.S. Department of Energy and others interested in making black liquor and biomass gasification/ combined cycle technologies cost-effective technologies for the forest products industry (AF&PA 1998d).

These technologies are not yet developed to the point where their costs or benefits can be assessed as accurately as conventional technologies. Therefore, they have not been considered in the development of estimated costs to meet Kyoto Protocol target developed elsewhere in this report. Because of their potential importance to the industry's ability to meet the target, however, it is important to examine them at a conceptual level to characterize the range of impacts they might have. Several studies of black liquor and biomass gasification have been performed that allow the potential impacts of the technologies on the industry's greenhouse gas emission profile to be characterized. These include Industra 1997; Larson et al. 1997; AF&PA 1998d; Consonni et al. 1998; Kreutz, Larson, and Consonni 1998; Larson, Kreutz, and Consonni 1998a, 1998b; and Larson et al. 1998. For purposes of this report we have relied primarily on Larson, Kreutz, and Consonni 1998a and Larson, et al. 1998 because these analyses provide the most detail on scenarios of potential interest to this effort.

In Larson, Kreutz, and Consonni 1998a, comparisons are made between bleached kraft mills producing 1240 to 1300 air-dried metric tons of pulp per day and having a number of different combinations of recovery systems and power boiler configurations. These include (a) Tomlinson recovery furnaces with supplemental conventional biomass and fossil fuel boiler capacity as needed to meet process steam requirements, (b) Tomlinson recovery furnaces with additional steam requirements met with biomass gasifiers with gas turbines, (c) oxygen black liquor gasifier/gas turbine systems with additional steam provided by a conventional bark boiler, and (d) oxygen black liquor gasifier/gas turbine systems with additional steam provided by biomass gasifiers with gas turbines. In all cases, back-pressure turbines are used to produce electricity from steam before it is used in the process as a 50/50 split of 10-bar (~150 psi) and 4-bar (~60 psi) steam.

Of the various biomass gasifiers in Larson, Kreutz, and Consonni 1998a, this analysis has been limited to the indirectly-heated biomass gasifier coupled with a 25-MW gas turbine. Although there are other gasification technologies, this analysis, like that in Larson et al. 1998a, focuses on oxygen black liquor gasification technology coupled with a 70-MW gas turbine. Larson et al. 1998 examined the potential impacts of black liquor gasification on the recovery cycle. At least one of the chemical recovery processes under study has the potential to increase the load to the lime kiln by 40% or more. To examine the scenario where a mill might experience such an increase, we have added 40% to the natural gas requirements in the lime kiln in some of the following examples. Alternative approaches to chemical recovery offer the hope of eliminating this penalty (Consonni et.al. 1998).

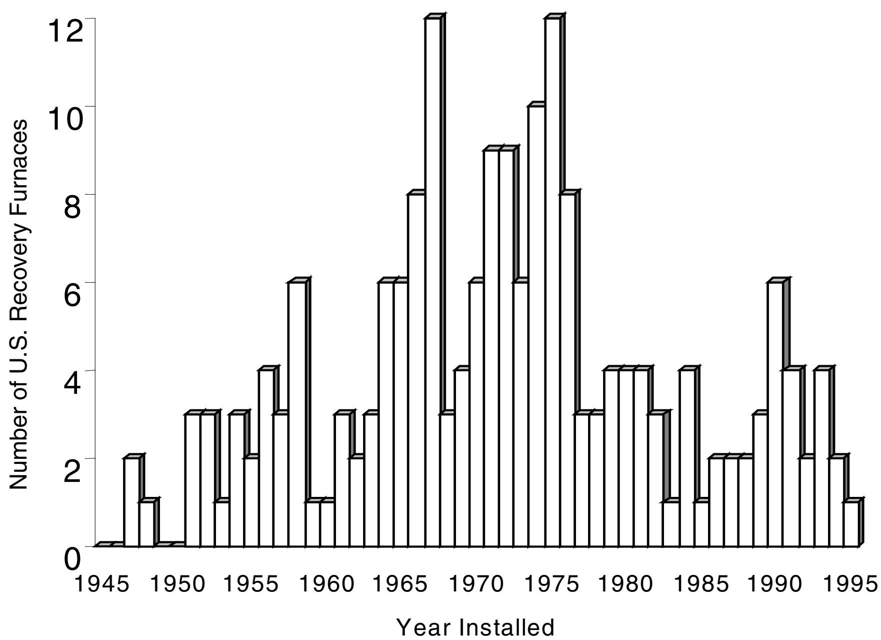

Figure 13. Recovery Furnace Ages in the U.S. Kraft Industry

Much of the impact of gasfication/combined cycle technology is related to its ability to greatly increase the amount of electricity available for export from the mill. To the extent that this displaces electricity that would have been generated by an electrical utility burning fossil fuels, it reduces overall carbon dioxide emissions. NCASI's analysis has determined that a forest products industry-weighted utility emission factor for electricity purchased or displaced from the grid is 140.5 tons carbon per 10^9 watt-hr. This factor has been used to examine the off-site implications of the electricity exports projected in Larson, Kreutz, and Consonni 1998a. (Note: This is an average for utility base loads. If marginal power emission factors were used, as was the case for the remainder of this study, the estimated impacts would be approximately 50% greater. See Table 11.)

Finally, several scenarios have been added to those in Larson, Kreutz, and Consonni 1998a to address the possibility, perhaps unlikely, that a mill would choose to burn fossil fuels to fill the process steam deficit caused by gasification/combined cycle systems. The Larson, Kreutz, and Consonni 1998a analysis is based on the application of gasification/combined cycle technology in a mode intended to maximize the generation of electricity. It is possible, however, to design and operate such systems to generate relatively less electricity but relatively more process steam. Consequently, the examples developed herein probably represent the maximum steam deficit situation

Based on data available to NCASI for U.S. bleached kraft market pulp mills, it is reasonable to use base-case conditions of direct (on-site) carbon dioxide emissions of 0.1 metric tons of carbon per metric ton of production and indirect carbon dioxide emissions (emitted at utilities generating the electricity purchased by the mills) of 0.07 tons carbon per metric ton of production. For purposes of this study, using a base case 1300 tpd kraft mill, it is estimated that the base case mill emits 130 tons carbon per day or 45,500 metric tons of carbon per year from the mill site, with an additional 31,900 metric tons of carbon being emitted at the utility to generate the electricity needed by the mill. In the following discussion, the scenarios examined in Larson, Kreutz, and Consonni 1998a, as modified and expanded by NCASI, are used to characterize the potential impacts of various gasification/ combined cycle systems on the direct and indirect CO_2 emissions for this model mill. The following analysis must be considered approximate, however, because it involves comparisons of different model and base case mills having different energy balances and capacities. Without detailed energy balances on well-defined and comparable mills, direct comparisons are not possible. None-the-less, the following comparisons can shed light on the general magnitude of the impacts of these technologies on mills like those included in NCASI's database for this study.

Case 1. Keep the Tomlinson recovery furnace but replace the biomass boiler with gasification/ combined cycle technology having increased biomass capacity compared to the base-case conventional biomass boiler.

In this case, the amount of biomass is increased to satisfy process steam demands. As a result, the amount of electricity available for export is increased by 452 kWh/metric ton pulp (=700-248) compared to the base case in the Larson, Kreutz, and Consonni 1998a analysis. Otherwise, the mill is unchanged. The only impact on the mill's greenhouse gas profile, therefore, is an indirect impact at the utility where the amount of CO_2 released is now less because of the mill's additional electricity export. Using the industry-weighted average utility emission factor of 140.5 metric tons carbon per 10^9 watt-hour, it is estimated that off-site emissions will be reduced by 28,900 metric tons of carbon annually compared to the base case. On-site emissions would remain unchanged from the base case. If the steam deficit were made up by burning fossil fuels rather than by increasing the amount of biomass being burned, direct emissions would increase but the reduction in off-site emissions would still be 28,900 metric tons of carbon less than the base case.

Case 2. Replace the Tomlinson recovery furnace with an oxygen black liquor gasification/combined cycle system with a 70-MW gas turbine and make up the steam deficit by increasing the burning of wood waste in a conventional wood waste boiler.

In this case, the mill replaces a Tomlinson recovery furnace with a gasification/combined cycle system. The steam deficit related to the use of the gasification/combined cycle system is overcome by increasing the amount of wood waste burned in conventional power boilers. Larson, Kreutz, and Consonni 1998a calculated that the mill with black liquor gasification/ combined cycle technology can export 1520 kWh/ton more electricity than the base-case mill (=1768-248). Because biomass fuels carry a zero CO_2 emission factor, the only impact on power-related greenhouse gas emissions is a reduction in off-site emissions from the utility that no longer has to produce the 1520 kWh/ton. Using the industry-weighted utility emission of 140.5 tons carbon per 10^9 watt-hours of electricity, it can be calculated that the utility's emissions are reduced by 97,200 tons per year compared to the base case.

One of the methods being studied for recovering cooking chemicals in black liquor gasification-based systems involves an increased load on the lime kiln and an associated increase in natural gas consumption. Larson et al. 1998 explained a variety of methods for estimating the size of the increase and alternative recovery methods to eliminate this impact. For purposes of this report, we will consider the case where lime mud loads are increased by 40% with the assumption that natural gas requirements will escalate by the same amount. Data available to NCASI suggest that a representative figure for natural gas consumption for lime burning at a bleached kraft mill might be 1.75 GJ/metric ton of pulp (1.5 MBtu/short ton). A 40% increase amounts to an additional 0.7 GJ/metric ton of pulp (0.6 MBtu/short ton) for the black liquor gasification case. Using a CO_2 emission factor of 13.72 kg carbon per GJ in fuel (14.47 metric tons carbon per 10^9 Btu in fuel), the additional natural gas can be estimated to contribute 4400 tons of carbon to the mill's direct emissions annually. If gas from the gasification system was used in the kiln rather than in the gas turbine and the amount of biomass was not increased to compensate for this diversion of gasifier output, the mill's direct emissions would be reduced compared to the natural gas firing case, but the amount of electricity available for export would also decline, reducing the credit for avoided electricity production at the utility.

Case 3. Replace the Tomlinson recovery furnace with an oxygen black liquor gasification/combined cycle system with a 70-MW gas turbine and make up the steam deficit by increasing the burning of fossil fuel in a conventional boiler.

In this case, the mill replaces a Tomlinson recovery furnace with a gasification/combined cycle system. This case is different from Case 2, however, in that the steam deficit related to the use of the gasification/combined cycle system is overcome by burning fossil fuels in a conventional boiler. Larson, Kreutz, and Consonni 1998a showed that in order to meet constant process steam requirements, a 1250 to 1300 metric ton per day kraft mill using oxygen black liquor gasification/combined cycle technology would have to burn an additional 0.465 tons of dry wood waste per ton of pulp in a conventional biomass boiler (=0.783-0.318) compared to the Tomlinson boiler base case. Using typical boiler efficiencies and emission factors, it can be calculated that the additional steam could also be produced by burning 0.248 tons of coal per ton of pulp instead of the 0.465 tons of dry wood waste per ton of pulp. This coal burning would increase on-site emissions of CO_2 by 82,800 tons of carbon per year compared to the base case. If natural gas was used instead of coal to offset the process steam deficit, on-site emissions would increase by 49,000 tons of carbon per year.

The additional natural gas required for the lime kiln would also be the same as for Case 2, so that on-site carbon dioxide emissions would increase by 4400 tons of carbon annually compared to the base case as a result of increased loading on the lime kiln.

The amount of additional electricity available for export would be the same as calculated for Case 2. This means that off-site emissions would be reduced by an estimated 97,200 tons of carbon per year compared to the base case.

Case 4. Replace the Tomlinson recovery furnace with an oxygen black liquor gasification/combined cycle system with a 70-MW gas turbine and make up the steam deficit by installing a wood waste gasification/combined cycle system with adequate capacity to meet the mill's process steam needs.

Except for the impact on the lime kiln fuel requirements, Larson, Kreutz, and Consonni (1998a) have modeled this scenario and have estimated that excess power available for export will be 1930 kWh/ton (=2178-248) more than that available from the base case of a

Tomlinson recovery furnace and conventional biomass boiler. Using the industry-weighted utility carbon dioxide emission factor of 140.5 metric tons carbon per 10^9 watt-hours, it can be calculated that an additional 123,400 tons of carbon annually are reduced at the utility site compared to the base case.

The increase in on-site carbon dioxide emissions related to increased load on the lime kiln remains the same as in Case 3, 4400 tons of carbon per year.

Case 5. Replace the Tomlinson recovery furnace with an oxygen black liquor gasification/combined cycle system with a 70-MW gas turbine and make up the steam deficit by installing a wood waste gasification/combined cycle system with adequate capacity to meet the mill's process steam needs, plus implement a chemical recovery approach that avoids the increased load on the lime kiln.

This is the same as Case 4 except that there is no penalty for burning additional natural gas in the lime kiln resulting from the gasification-based recovery system. Accordingly, the on-site emissions will be equal to the base case and the indirect emissions will be reduced by 123,400 metric tons per year compared to the base case.

The impacts of the base case and five scenarios are summarized in Table 24. The results allow several observations about the potential importance of gasification/combined cycle technologies to the greenhouse gas emissions from the forest products industry.

First, it is clear that the most dramatic impact of these gasification/combined cycle technologies on the greenhouse gas emissions from pulp and paper manufacture results from their ability to export "zero CO_2" electricity to the grid where it displaces "high CO_2" electricity generated by utilities. Not only does the mill have the advantage of using biomass fuels to generate "zero CO_2" electricity, it does so while enjoying the efficiencies of combined cycle technology and cogeneration. The fact that gasification/combined cycle technology yields relatively more electricity and less process steam from the fuel (compared to conventional cogeneration) causes the mill to need additional fuel, but allows the mill to export even more electricity.

Because electricity export is such a key feature of gasification/combined cycle technology, its cost effectiveness is highly dependent on electricity prices. Kreutz, Larson, and Consonni 1998, however, have calculated that even at electricity prices as low as 2.5 to 3 cents/kWh (and perhaps even lower), black liquor gasification/combined cycle technology is cost competitive with Tomlinson furnace-based recovery systems.

The impact of gasification/combined cycle technology on direct (on-site) emissions is less clear. The analysis in Table 24 suggests that the on-site emissions from a mill using gasification/combined cycle technology could conceivably be higher than those from a comparable mill using conventional technology. A mill might see such increases if (a) fossil fuels are used to generate the steam needed to fill the process steam deficit that could occur upon switching to gasification/combined cycle technology, and (b) lime kiln fuel requirements increase due to black liquor gasification-based chemical recovery.

Conversely, such increases could be avoided if (a) the mill uses additional biomass to fill the process steam deficit, and (b) one of a number of alternative chemical recovery schemes now being researched provide a way to eliminate the load increases on the lime kiln. It might even be feasible for a mill to use part of the gasifier output to replace fossil fuels being used in the lime kiln or elsewhere and actually reduce on-site emissions of CO_2. The lost income from foregone electricity exports resulting from this diversion of gasifier output would have to be balanced against the costs of displaced fossil fuels on a case-by-case basis.

Table 24. Potential Impacts of Gasification Technologies on Industry CO_2 Emissions

Case	Direct Emissions		Indirect Emissions*		Total Emissions	
	Annual Metric Tons	Change from Base Case, kg/ton	Annual Metric Tons	Change from Base Case, kg/ton	Annual Metric Tons	Change from Base Case, kg/ton
Base Case: Tomlinson furnace and conventional wood waste and fossil fuel boilers – based on mills in NCASI's database	45,500	0	31,900	0	77,400	0
Case 1: Tomlinson furnace plus gasification/combined cycle wood waste system with increased capacity to make up steam deficit	45,500	0	3,000	-64	48,500	-64
Case 2: Oxygen-black liquor gasification/combined cycle system plus make up the steam deficit by increasing the burning of wood waste in conventional boilers plus burn more natural gas to meet higher kiln load	49,900	+10	-65,300	-214	-15,400	-204
Case 3: Oxygen-black liquor gasification/combined cycle system plus make up the steam deficit by burning more coal or natural gas in conventional boiler plus burn more natural gas to meet higher kiln load	98,900 to 132,700	+117 to +192	-65,300	-214	33,600 to 67,400	-96 to -22
Case 4: Oxygen-black liquor gasification/combined cycle system plus make up the steam deficit by installing a wood waste gasification/ combined cycle system with adequate capacity to meet the mill's process steam needs plus burn more natural gas to meet higher kiln load	49,900	+10	-91,500	-271	-41,600	-262
Case 5. Oxygen-black liquor gasification/combined cycle system plus make up the steam deficit by installing a wood waste gasification/ combined cycle system with adequate capacity to meet the mill's process steam needs plus implement a chemical recovery approach that avoids the increased load on the lime kiln	45,500	0	-91,500	-271	-46,000	-271

* Assuming credits based on average grid emission factors; if marginal grid emission factors were used, the benefits of generating excess electricity would be 50% greater

Given the uncertainties about technological advances yet to be made and the approaches that will be used to integrate gasification/combined cycle technologies with existing power and chemical recovery systems, it is difficult to characterize the potential significance of the technology to the industry's future greenhouse emissions profile. Based on the scenarios examined in Table 24, it does not seem unreasonable to speculate that the technology will probably have a relatively small impact on direct emissions from kraft mills. Indirect emission reductions on the order of 100 to 200+ kg/ton pulp, however, do not seem unreasonable, with reductions of 150 to 300+ kg/ton pulp being possible if power sales are credited against marginal power emission factors at the local utility.

At a 1.5% per year growth rate, total U.S. kraft pulp production in 2010 can be estimated to be approximately 60 million metric tons. Since 60% of the U.S. industry's recovery furnaces will be over 35 years old by 2010, it does not seem unreasonable to speculate that as much as 50% of the industry's capacity, or 30 million metric tons of pulp, might be candidates for gasification/combined cycle technology by 2010. At a reduction of 100 to 300 kg carbon/ton pulp, it would appear that an industry-wide CO_2 reduction of 3 to 9 million metric tons of carbon is possible under these circumstances. Elsewhere in this report, the required reductions in carbon dioxide emissions from 2010 business-as-usual levels have been estimated to be 11.7 million metric tons per year. Thus, if gasification/combined cycle technology were applied to all retiring recovery furnaces, it might satisfy one-half or more of the reduction needed to meet the forest product industry's Kyoto Protocol target (including wood products). The contributions of the technology would be even greater if applied to biomass at wood products operations, or if found to provide CO_2 reductions of greater than 300 kg carbon/ton pulp.

AF&PA has estimated that implementing these technologies at all kraft pulp mills (using biomass to satisfy the steam deficit) could result in the industry's going from being a net emitter of over 20 million tons of carbon to being a net sink for 18 million tons of carbon per year (not counting sequestration in forests, products, and wastes) (AF&PA 1998d). Based on these various analyses, it seems clear that even a modest penetration of gasification/combined cycle technologies into the forest products industry could have a significant impact on the industry's ability to meet Kyoto Protocol target. Because the Kyoto Protocol target is an emissions cap, the industry's ability to remain below the cap in the years after 2010 will depend increasingly on technologies like gasification/combined cycle.

11.2 Impulse Drying

The evaporation of water from the sheet in the dryer section is among the most energy intensive aspects of paper, paperboard, and market pulp production. One means of reducing this energy demand is to reduce the amount of water leaving the press section and entering the drying section of the machine. Impulse drying is a technology nearing commercialization that appears to have the potential to reduce the moisture content of the sheet entering the press section by from 5% to perhaps as much as 15% (although the effectiveness of impulse drying will vary depending on the grade being produced and the way the technology is integrated into press/drying sections). Impulse drying also improves some physical properties of the sheet. Of particular importance in linerboard production are improvements in STFI, ring crush, and smoothness (Orloff 1998). The Institute of Paper Science and Technology and Beloit Corporation, with support from the U.S. Department of Energy, have advanced the technology to the point where the first press-to-reel sheets of linerboard were produced in September 1998 on a 1250 to 1500 foot-per-minute pilot machine (Orloff 1998).

Impulse drying involves the use of a high temperature press roll which, through mechanisms that are still not completely understood, forces water out of the sheet in a more energy-efficient manner than can be accomplished in the drying section. One of the mechanisms appears to be the development of a high pressure steam region in the sheet adjacent to the high temperature press roll that helps to force liquid water out of the opposite side of the sheet. Unfortunately, another effect of this internal pressure in the sheet is delamination, the separation of one side of the sheet from the other. Recent equipment advances have allowed the integration of impulse drying with extended nip press technology, which can be used to control the decompression in the sheet leaving the press nip. The combined technology appears to be capable of overcoming the sheet delamination problems that plagued early efforts at impulse drying (Orloff 1998; Orloff et.al. 1998).

The impact that impulse drying could have on the industry's greenhouse gas emissions profile will depend on its effectiveness on different grades, the approaches used to integrate it into mill press sections, and the extent to which it is employed. The following analysis examines scenarios wherein impulse drying reduces the moisture content of the sheet entering the dryer section by 5 to 15% and the technology is applied to 10% of the industry's paper and paperboard production by the year 2010.

If the moisture content in the sheet going into drying section is reduced to 50% from 55% (a conservative assumption given the results of some of the pilot work), the amount of water that must be evaporated in the press section is reduced by 0.222 tons of water per ton of paper. Smook suggests that a modern, well-designed, well-maintained dryer system will use approximately 1.3 tons of dryer steam per ton of water evaporated (Smook 1997). For purposes of this exercise, it is assumed that an average mill might use 1.4 tons steam per ton of water evaporated. Using a steam heat content of 2734 Joules per gram of steam (1177 Btu/pound), this is equivalent to a savings of 0.85 GJ per metric ton paper (0.73 MBtu/short ton). NCASI has estimated that the CO_2 emission factor for mill-generated steam from the industry's current mix of fossil fuels is 22.5 kg carbon per GJ in steam (23.7 metric tons carbon per 10^9 Btu). It is projected, therefore, that a 5% decrease in sheet moisture entering the drying section would reduce on-site CO_2 emissions by 0.019 metric tons carbon per metric ton paper (0.017 metric tons per short ton). If impulse drying reduced the moisture of the sheet by 15% (to 45% from 60% moisture) the on-site reductions in CO_2 emissions would be 0.059 metric tons carbon per metric ton paper (0.053 metric tons carbon per short ton).

Impulse drying can result in increased electricity demand due to the energy required to heat the impulse dryer press roll. Under one scenario, it has been estimated that the heat content of the fuel required by the utility to produce the needed electricity would amount to approximately 20% of the heat content of the steam saved at the mill (IPST 1993). If impulse dryer press roll heating were accomplished by other means (by burning of natural gas, for instance), the electricity demand would be reduced but the on-site demand for fossil fuels (and corresponding CO_2 emissions) would increase. Using the 20% factor cited above and an increase in sheet dryness of 5%, it is estimated that the utility's fuel use would increase by 0.170 GJ/metric ton paper (0.146 MBtu/short ton). If the utility requires 0.00949 GJ fuel to produce a kilowatt-hour (0.009 MBtu/kWh), the electricity demand can be estimated to be 17.9 kWh/metric ton (16.3 kWh/short ton). NCASI has determined that the paper industry-weighted utility CO_2 emission factor for purchased electricity is 140.5 metric tons carbon per 10^9 Btu of electricity. Accordingly, for the case where sheet solids are increased by 5%, the utility's CO_2 emissions can be estimated to increase by 0.0025 metric tons carbon per metric ton paper (0.0023 metric tons carbon per short ton). If sheet solids are increased by 15%, the utility CO_2 emissions are estimated to increase by 0.0077 metric tons carbon per metric ton paper (0.0070 metric tons carbon per short ton).

Using the figures developed above for the 5% dryness improvement scenario, it can be estimated that the use of impulse drying on machines producing 13 million metric tons per year (about 10% of the projected 2010 paper and paperboard production in the US) would reduce the industry's on-site emissions of CO_2 by 0.25 million metric tons of carbon per year. The industry's CO_2 total emissions (on-site plus indirect) would be reduced by 0.22 million metric tons of carbon per year. If a 15% dryness improvement is assumed, the annual reductions in on-site and total CO_2 emissions become 0.76 and 0.66 million metric tons of carbon, respectively.

Elsewhere in this report, NCASI estimates that by the year 2010 the forest products industry (pulp, paper, market pulp, and wood products) would need to reduce CO_2 emissions by approximately 12 million metric tons of carbon per year to meet the Kyoto Protocol target in 2010. Based on the analysis above, it would seem possible for impulse drying to contribute 5% or more of the required reductions.

12.0 SOURCES OF UNCERTAINTY AND POSSIBLE BIAS

In estimating the costs for reducing CO_2 emissions to Kyoto Protocol target, a variety of assumptions and simplifications have been required. Most of these involved choices from a range of alternatives, so that it was possible to select what appeared to be a mid-range case. While some of these selections were highly uncertain, it is NCASI's judgment that it is reasonable to assume that the errors introduced in these cases were random, and not identifiable sources of bias.

In other instances, it was necessary to advance the analysis using assumptions or simplifications that could not be considered mid-range cases. Many of these involved choosing between only a few feasible alternatives. Although it is not possible to quantify the amount of bias introduced by these choices, it is usually possible to identify the direction in which the choice would have influenced the results. This section reviews what are suspected to be the major sources of uncertainty and possible bias and NCASI's assessment as to the direction and, where possible, the magnitude of the bias introduced.

- Biomass is considered to have a CO_2 emission factor of zero.

  NCASI has followed the normal convention of using a zero CO_2 emission factor for biomass carbon. Were a non-zero factor used, the costs for reducing CO_2 emissions to Kyoto Protocol target would probably be substantially larger.

- Uncertainties in power and fuel prices and in the impacts of utility deregulation inject large uncertainties into estimates of annualized and marginal costs.

  Although capital cost estimates appear reasonably robust, this study documents that uncertainties in future operating costs preclude the development of a narrow range of estimated annualized and marginal costs. The uncertainties in future operating costs are related to a number of factors. First, much of the needed reduction is projected to come from credits obtained for sales of excess power (displacing power and related emissions from regional utilities). The extent to which this will prove to be economically feasible is highly uncertain. Deregulation in the electric power industry is expected to cause declining power prices in the future, making sales of excess power less attractive. Competition is projected to cause natural gas prices to increase, further eroding the attractiveness of investments in GTCC technology to produce power for export. On the other hand, deregulation will probably cause utilities to more aggressively seek out low cost producers of power for resale, suggesting that some mills may find utilities more receptive to purchasing excess power, and alternative sources of gas for GTCC systems (e.g., biomass gasification) may emerge.

- The methods and fuels used by utilities to produce electricity are assumed to remain constant.

  Due to the large uncertainty associated with predicting future power generation practices, NCASI has assumed that the practices will remain as they are now. It is likely, however, that a combination of pressures will result in utilities reducing CO_2 emissions in spite of the cost pressures of deregulation. This could have a variety of impacts on the costs for the industry to reduce greenhouse gas emissions. To the extent that purchased power would carry a lower CO_2 burden, the industry would reduce emissions related to purchased power while incurring a cost equal only to the increase in power costs passed on by the utility to cover their costs for reducing emissions. This cost might or might not be lower than the cost for the facility to make the same reductions internally. At the same time, projects that reduce emissions by reducing purchased power or exporting low-emitting power to the grid would be less effective since they would result in smaller avoided emissions at the utility. Given these uncertainties, it is not possible to know whether compliance costs would be higher or lower if purchased power were assumed to carry a lower CO_2 load.

- The primary analysis assumed that the industry would meet its target by reducing emissions at each mill to a point where the marginal cost for making additional reductions was the same for all mills.

  The constant-marginal-cost approach to estimating compliance costs is essentially equivalent to assuming the existence a perfectly efficient intra-industry carbon trading program. To the extent that such efficiencies can never be achieved, the cost estimates would be understated.

- When facilities reduced purchased power consumption or increased power exports to the grid, it was assumed that the facilities received carbon credits equal to the carbon that would have been emitted by the regional utilities when generating marginal power.

  The cost estimates in this report have been developed under the assumption that mills which reduce purchased power consumption or export power to the grid will be granted credits for having displaced marginal regional grid power (and the associated marginal emissions). This assumption is particularly important because of the large contribution of GTCC power exports to the reductions needed to meet the CO_2 reduction target. Displacing marginal power is a "best-case" assumption because current marginal power emission factors are always higher than average emission factors for purchased power. If companies received less credit, the costs for compliance would be higher.

- This analysis has completely ignored the credits that might be available due to sequestration of carbon in industry forest land, products, or wastes.

  Because it is still not certain whether or how credit will be given for carbon sequestered in forests, products, or wastes, these possibilities were not included in this analysis. It is clear from work elsewhere that the impacts of sequestration on the industry's greenhouse gas emissions profile could be enormous (Skog and Nicholson 1998). The extent to which including sequestration in this analysis would reduce compliance costs would depend on the carbon accounting system used to define and assign sequestration credits.

- The analysis was limited to commercially available technology.

  Because of uncertainties about the costs and emissions implications of emerging technologies, they were not included in this analysis. A semi-quantitative analysis was performed for two such technologies: gasification/combined cycle and impulse drying. That analysis suggests that new technology could become an important part of an industry strategy to reduce greenhouse gas emissions, especially over longer time frames as the industry struggles to remain under the permanent emissions cap established by the Kyoto Protocol.

- Reductions in process steam requirements were assumed to reduce the amount of cogenerated electricity and increase purchased electricity requirements proportionally.

  Cogeneration capacity was calculated for each mill by estimating the mill's electricity requirements, subtracting the amount of purchased electricity, and assuming that the balance was produced by cogeneration at the mill. Reductions in process steam requirements were assumed to reduce the amount of cogenerated electricity and increase purchased electricity requirements proportionally. The primary impact of this assumption is to overstate, for many mills, the impacts of process steam savings on purchased electricity requirements (and indirect emission increases). This is because unless all process steam is used for cogeneration, the mill would have the option of running the turbine at capacity until steam use was reduced to the point where the turbine could not supply all of the mill's process steam requirements. The result of this assumption is to increase the costs for meeting the emissions target.

- Only those mills producing virgin fiber were assumed to have the opportunity to use biomass fuels.

  The only sources of biomass considered in this study were wood waste and black liquor. Furthermore, it was assumed that only mills processing virgin fiber would have access to these biomass fuels. In a Kyoto Protocol-driven environment, however, non-integrated mills and recycling mills might find it feasible to compete for these or other biomass fuels (non-recyclable paper, perhaps). Using the assumption that these options would only be pursued if more attractive than those considered in this analysis, the estimates herein would tend to overstate the costs for these types of mills to meet the target.

- The sequential-technology-implementation curves were not "smoothed" for the case of an industry bubble. Instead, each mill encountered each technology step in order of its cost effectiveness.

  The sequential-technology-implementation curves for each mill were understood to be cost-response models because, for the most part, they were not based on the actual technologies in place at each mill. In other words, they were assumed to be reasonable representations of the incremental costs that would be incurred to make additional reductions, even though the specific technologies in the model might not be appropriate. For the case where each mill was required to meet the target individually, these curves were smoothed to eliminate the technology "steps." In applying the models to the industry-bubble case, however, when a reduction was required at a mill, the next most cost effective technology (on a $/ton carbon basis) was implemented, even if it provided a much greater reduction than was required and therefore imposed a much larger cost than required to achieve the needed reduction. This would tend to overstate the minimum costs for meeting the industry bubble at a given point in time. On the other hand, given that the target is a permanent cap, it is not unreasonable to assume that a mill would implement the next most cost effective technology even if it provides more reduction than required at the moment.

- Transportation emissions were not analyzed in this study.

  This report does not analyze the significance of transportation-related emissions to the industry's ability to meet the target and does not estimate the relative cost effectiveness of reducing these emissions as part of a CO_2 reduction strategy. The report concludes that these emissions could increase the industry's overall emissions by 15%.

- It was assumed that all sectors of the industry would grow at 1.5% per year through the year 2020.

  This is below the growth rate of the industry over the last decade, but it appears to be reasonable for the next few years. It is also consistent with projections made by a number of other organizations. Changes in assumed growth have very large impacts on the required reductions and the resultant costs. Although it appears to be a reasonable mid-range assumption, it is probably among the largest sources of uncertainty in this analysis. The impacts of higher (2.5%) and lower (1%) growth rates are dealt with only semi-quantitatively.

- Required reductions have been estimated by extrapolating current trends in emissions per unit of production.

  The reductions from business-as-usual have been estimated by assuming that the industry will continue to reduce its emissions per ton of production along the trend lines at work from 1982 to 1997. These show continued, but diminishing, reductions in emissions. These improvements involve a balancing of a number of factors, some of which tend to increase emissions, others which tend to do the opposite. These factors include increasing use of biomass, continuing improvements in energy use efficiency, continuing gains in boiler efficiencies, addition of cogeneration capacity and gas-fired turbines, retirement of less energy efficient production capacity, relatively faster growth in recycled paper production, fossil fuel switching in response to environmental or cost pressures, and an expanding economy for most of the period. Extrapolating the trend lines to 2020 involves an assumption that these and other forces will change in the same way as in the past. There are many reasons to expect that circumstances between now and 2020 will be very different than the recent past, but predicting the impact of the myriad possible scenarios on the industry's emissions per unit of production is beyond the scope of this study. It is likely that one of the main sources of uncertainty in this analysis is the assumption that these trends can be extrapolated to 2010 and 2020. The extrapolations, however, yield estimates of needed reductions that are reasonably consistent with those that have been projected for the overall U.S.

- The baseline production statistics for individual mills were increased by 25% so that the total 1995 direct emissions from the individual mills, when extrapolated to the whole industry, equaled the overall industry emissions calculated from overall industry fuel consumption data.

  Individual mills were analyzed by preparing an energy/production process model based on the best information available to NCASI's consultant, EKONO, Inc. It allowed a fairly mill-specific examination of the energy demands of each mill given its actual product line. The production information for this model was obtained from a variety of sources. Each mill model was calibrated by adjusting it until the predicted direct emissions were close to those calculated by NCASI from fuel use data. When the baseline emissions from these mills were extrapolated to the industry, the result was found to be approximately 25% high compared to the industry-wide CO_2 emissions computed from overall industry fossil fuel use data. Because it was not possible to identify the exact cause of the discrepancy, and because it was important that the extrapolated baseline emissions for the 90 mills equal the total based on the industry's fuel use data (since the Kyoto Protocol target were based on those data), it was decided to adjust the production of the 90 mills by an equal fraction across the board so that the production at the 90 mills represented a large enough fraction of the industry that the scaled-up emissions equaled that estimated from industry fuel use data. The unadjusted production from the 90 mills represented about 31% of the industry total, while the adjusted production represented about 39%. There is no way of knowing whether the adjusted scale-up factors provide a better estimate of overall cost, only that they yield a lower estimate.

- The analysis was conducted assuming that the industry's product and furnish mix would be unchanged.

  There are a variety of forces at work that suggest that the industry in 2020 will be producing a different mix of products and using a different mix of furnishes than now exists. For example, recycling rates are projected to increase, escalating wood prices will force adjustments in furnishes, and slowly growing product lines will represent a lower fraction of the industry's future output. It was beyond the scope of this study, however, to attempt to predict and examine the impacts of such shifts. Without such an analysis, it is not possible to know whether such changes will increase or decrease costs for reducing CO_2 emissions.

- The rate of closure of older, less efficient capacity is assumed to be comparable to that seen in the recent past.

  In this report, NCASI examined in a very general way the potential importance of mill closures to the industry's greenhouse gas emissions. That analysis suggests that the rate of closure of old, less-efficient capacity could be an important factor contributing to the continued improvements in the industry's emissions per ton of production. Global over-capacity and industry consolidation have recently caused the rate of closure to increase compared to the last decade. If that closed capacity is either (a) shifted offshore, (b) shifted to lower-emitting U.S. mills, or (c) a combination of both, the impact would probably be to allow the industry to reduce its overall emissions at a lower compliance cost (not including the not-insignificant cost for closing capacity).

- Because mill-specific electricity consumption data were not available for 1990, the Kyoto Protocol target for emissions was calculated using 1991 data.

  This would result in the cost estimates be slightly lower than they should be because the 1991 data were probably higher than the 1990 data. This is confirmed by the overall industry statistics, which show electricity purchases to be slightly higher in 1991 than in 1990.

- Only 1982 through 1997 data were used to calculate business-as-usual emissions.

  It is clear from the AF&PA data that trends in industry energy use changed beginning in 1982. For this reason, it was decided to use only 1982 through 1997 data to extrapolate business-as-usual emissions. NCASI feels that this approach represents a reasonable attempt to minimize the amount of bias introduced into the estimates.

- CO_2 generated in the manufacture of make-up lime has not been considered in this analysis.

  CO_2 associated with the manufacture of make-up lime would contribute to emissions. Its contribution, however, has been shown to be small (less than 1% of overall emissions).

- When the analysis involved installing technologies that reduced the need for fossil fuel at the mill, except for lime kiln fuel, the marginal fossil fuels to be displaced were chosen based on the cost of the fuel rather than the impact of the fuel on CO_2 emissions.

  Faced with the need to reduce CO_2 emissions, a mill might choose to displace a cheaper but more highly-emitting fossil fuel. This would result in larger emissions reductions, but at a higher cost.

- The wood products sector of the industry was modeled using only one model facility to represent each major product category in that sector.

  Due to a lack of data needed to analyze the wood products sector of the industry in the same detail as the pulp and paper sector, NCASI used only a single model facility to represent each product category in the wood products sector. This introduces significant uncertainty in the estimates for this sector. The models were constructed with the objective of avoiding bias, but without better facility-level data, it is not possible to know whether the models are biased or not. The wood products sector is responsible for approximately 12% of the forest products industry's emissions. Therefore, unless the lack of resolution in the wood products sector is accompanied by a significant source of bias, the impact on the overall industry estimates would appear to be modest.

- Emission factors for wood products facilities were assumed to remain constant.

  Because of limited data, the CO_2 emissions factor for wood products facilities was assumed to remain constant through 2020. The three data points available, however, suggest that emissions per unit of production may have been increasing from the late-1980s through the mid-1990s. Using a constant emissions factor results in lower compliance costs compared to using an emission factor that increases with time.

- Capital costs were annualized using a 10% per year cost of capital.

  The cost of capital varies within companies (depending, for instance, on financial conditions and type of project) as well as between companies (depending on the company's debt to equity ratio and many other factors). An annual interest rate of 10% was used based on information provided by AF&PA and developed by an independent consultant in a recent study of the cost of capital in the pulp and paper industry. Companies have told NCASI that while some companies may have a lower cost of capital, many others have a higher cost, especially for non-strategic investments like those for energy efficiency improvements. Using a higher cost of capital would increase the annualized and marginal costs for reducing CO_2 emissions and using a lower cost of capital would lower these costs.

- The main analysis was based on current fossil fuel and electricity prices.

  Due to the uncertainties in future energy prices, NCASI used current prices for most of this analysis. A limited sensitivity analysis indicated that higher energy prices would make energy-saving projects more cost effective, but the savings would be far less than the additional energy costs themselves. If energy prices were increased artificially as part of a greenhouse gas reduction policy, they would reasonably be considered part of the cost for reductions and would make these reductions more expensive than they would be at lower energy prices. On the other hand, if energy prices increased for reasons unrelated to greenhouse gas policy, it would probably not be fair to consider the increased energy costs to be part of the cost for reducing greenhouse gas emissions. In this case, a side-effect of the higher prices would be to reduce the compliance costs attributable to greenhouse gas reduction policies compared to the same reductions at lower energy costs.

- The core cost analysis was performed assuming that additional wood waste would be available only at a price of $2.36/MBtu.

  Due to increased haul distances and competition for low-carbon emission fuels, it was assumed that wood waste costs would increase from $1.30 to $2.36/MBtu for additional wood waste burned to reduce CO_2 emissions. While this assumption might increase estimated compliance costs, sensitivity analyses suggested that the impact on the cost estimates from the core analysis was small.

- The analysis did not allow examination of combinations of gas turbine systems and other conventional technologies.

  Due to the method used to analyze GTCC systems, combinations of GTCC systems and conventional energy efficiency technologies were not considered. Costs of achieving similar levels of emission reductions via either small GTCC systems, large GTCC systems, or conventional energy efficiency technologies were estimated and compared, and the least expensive of the three was selected for implementation. This methodology has the potential to over-estimate the costs to meet the emission reduction target.

13.0 CONCLUSIONS

1. At an annual growth rate of 1.5%, and assuming a carbon accounting system based on total (direct plus indirect) emissions, the forest products industry will have to reduce 2010 business-as-usual CO_2 emissions by 31% to comply with the Kyoto Protocol target of 7% below 1990 emissions. In 2020, the required reduction from business-as-usual emissions increases to 40%.

2. Under a common-marginal-cost scenario (i.e., the cost for removing the next ton of carbon is the same for all mills), the capital costs for reducing emissions from projected 2010 levels are estimated to be $6 to 8 billion. Annualized costs have been found to be highly variable depending on assumptions about energy costs and the potential for selling excess power to the grid. Uncertainty about the impacts of utility deregulation contribute to the large range in estimated annualized costs. Plausible scenarios can be developed yielding annualized costs ranging from less than -$250 million/year to more than +$1 billion/year.

3. At the point where the reductions are large enough to meet the Kyoto Protocol target in 2010, the estimated incremental costs for reductions are also highly variable. At current energy prices, the range of marginal costs is approximately $25 to $177/metric ton of carbon depending on the profitability of excess power sales.

4. The costs for remaining under the Kyoto Protocol target escalate rapidly with time. Between 2010 and 2020, the capital costs for reducing emissions increase by approximately 50%. The range in estimated annualized costs in 2020 is even greater: -$250 million/year to +$2 billion/year.

5. Transportation-related emissions were not addressed in this study. Other studies, however, suggest that including transportation-related emissions would increase estimated forest products industry-related emissions of CO_2 by approximately 15%. The compliance cost impact of including these emissions is unknown.

6. The analysis suggests that under a system employing mill-specific targets (i.e., each mill must reduce emissions to 7% below its 1990 emissions), capital costs for the industry are doubled, and annualized costs are $800 million/year greater than those associated with a framework wherein each mill reduces emissions to a common marginal cost per unit of CO_2 reduced until a "bubbled" industry-wide target is met.

7. If fossil fuel and power prices increase as the result of public policies to reduce greenhouse gas emissions in the U.S. to the Kyoto Protocol target, the increased costs for energy could be larger than the costs incurred by the industry for reducing emissions. Even at a carbon cost of only $25/metric ton, a cost much lower than projected by most researchers as being adequate for the U.S. to comply with the Kyoto Protocol, energy costs for the industry would increase by more than $500 million/year.

8. Differences in projected mill compliance costs are largely explained by the ability for individual mills to generate excess power and sell it to the grid for a satisfactory profit. The types of fuels being used and the baseline energy efficiency of the mill also appears to be important. Differences based on type of production do not appear to be nearly as significant.

9. A brief analysis of biomass/black liquor gasification combined cycle and impulse drying technologies was conducted. Based on the examination of five mill scenarios using data generated by other researchers, it appears that biomass/black liquor gasification combined cycle technology could reduce indirect emissions by 100 to 300+ kg carbon/ton pulp. If applied at all mills with recovery furnaces at least 35 years old, this could satisfy one-half or more of the reductions needed by the industry by 2010. The potential significance of impulse drying will

depend on its effectiveness and extent of use, factors still to be determined. The importance of such technologies increases with time as the industry searches for way to remain under the permanent cap of the Kyoto Protocol.

10. Although comparisons are limited by differences in assumptions and methodology, NCASI's results are generally consistent with those of a number of other studies. Particularly important, however, is the limited ability to compare NCASI's marginal cost estimates for the forest products industry with those developed by others for the U.S. economy.

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APPENDIX A

EXCERPTS FROM

REPORT OF THE CONFERENCE OF THE PARTIES ON ITS THIRD SESSION, HELD AT KYOTO FROM 1 TO 11 DECEMBER 1997

ADDENDUM

PART TWO: ACTION TAKEN BY THE CONFERENCE OF THE PARTIES AT ITS THIRD SESSION

(THE KYOTO PROTOCOL)

UNITED
NATIONS

Framework Convention
on Climate Change

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CONFERENCE OF THE PARTIES

REPORT OF THE CONFERENCE OF THE PARTIES ON ITS THIRD SESSION, HELD AT KYOTO FROM 1 TO 11 DECEMBER 1997

Addendum

PART TWO: ACTION TAKEN BY THE CONFERENCE OF THE PARTIES AT ITS THIRD SESSION

CONTENTS

II. RESOLUTION ADOPTED BY THE CONFERENCE OF THE PARTIES

Resolution

I. DECISIONS ADOPTED BY THE CONFERENCE OF THE PARTIES

Decision 1/CP.3

Adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change

The Conference of the Parties,

Having reviewed Article 4, paragraph 2(a) and (b), of the United Nations Framework Convention on Climate Change at its first session and having concluded that these subparagraphs are not adequate,

Recalling its decision 1/CP.1 entitled “The Berlin Mandate: Review of the adequacy of Article 4, paragraph 2(a) and (b), of the Convention, including proposals related to a protocol and decisions on follow-up”, by which it agreed to begin a process to enable it to take appropriate action for the period beyond 2000 through the adoption of a protocol or another legal instrument at its third session,

Recalling further that one aim of the process was to strengthen the commitments in Article 4, paragraph 2(a) and (b) of the Convention, for developed country/other Parties included in Annex I, both to elaborate policies and measures, and to set quantified limitation and reduction objectives within specified time-frames, such as 2005, 2010 and 2020, for their anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol,

Recalling also that, according to the Berlin Mandate, the process will not introduce any new commitments for Parties not included in Annex I, but reaffirm existing commitments in Article 4, paragraph 1, and continue to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7,

Noting the reports of the Ad Hoc Group on the Berlin Mandate on its eight sessions,[1]

Having considered with appreciation the report presented by the Chairman of the Ad Hoc Group on the Berlin Mandate,

Taking note with appreciation of the report of the Chairman of the Committee of the Whole on the outcome of the work of the Committee,

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[1] FCCC/AGBM/1995/2 and Corr.1, and 7 and Corr.1; FCCC/AGBM/1996/5, 8, and 11; FCCC/AGBM/1997/3, 3/Add.1 and Corr.1, 5, 8 and 8/Add.1.

Recognizing the need to prepare for the early entry into force of the Kyoto Protocol to the United Nations Framework Convention on Climate Change,

Aware of the desirability of the timely commencement of work to pave the way for a successful outcome of the fourth session of the Conference of the Parties, to be held in Buenos Aires, Argentina,

1. Decides to adopt the Kyoto Protocol to the United Nations Framework Convention on Climate Change, annexed hereto;

2. Requests the Secretary-General of the United Nations to be the Depositary of this Protocol and to open it for signature in New York from 16 March 1998 until 15 March 1999;

3. Invites all Parties to the United Nations Framework Convention on Climate Change to sign the Protocol on 16 March 1998 or at the earliest opportunity thereafter, and to deposit instruments of ratification, acceptance or approval, or instruments of accession where appropriate, as soon as possible;

4. Further invites States that are not parties to the Convention to ratify or accede to it, as appropriate, without delay, so that they may become Parties to the Protocol;

5. Requests the Chairman of the Subsidiary Body for Scientific and Technological Advice and the Chairman of the Subsidiary Body for Implementation, taking into account the approved programme budget for the biennium 1998-1999 and the related programme of work of the secretariat,[2] to give guidance to the secretariat on the preparatory work needed for consideration by the Conference of the Parties, at its fourth session, of the following matters, and to allocate work thereon to the respective subsidiary bodies as appropriate:

(a) Determination of modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties to the Protocol included in Annex I to the Convention, as provided for under Article 3, paragraph 4, of the Protocol;

(b) Definition of relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability of emissions trading, pursuant to Article 17 of the Protocol;

(c) Elaboration of guidelines for any Party to the Protocol included in Annex I to the Convention to transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing

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[2] FCCC/CP/1997/INF.1.

anthropogenic removals by sinks of greenhouse gases in any sector of the economy, as provided for under Article 6 of the Protocol;

(d) Consideration of and, as appropriate, action on suitable methodologies to address the situation of Parties listed in Annex B to the Protocol for which single projects would have a significant proportional impact on emissions in the commitment period;

(e) Analysis of the implications of Article 12, paragraph 10, of the Protocol;

6. Invites the Chairman of the Subsidiary Body for Scientific and Technological Advice and the Chairman of the Subsidiary Body for Implementation to make a joint proposal to those bodies, at their eighth sessions, on the allocation to them of preparatory work to enable the Conference of the Parties serving as the meeting of the Parties to the Protocol, at its first session after the entry into force of the Protocol, to accomplish the tasks assigned to it by the Protocol.

12th plenary meeting
11 December 1997

Annex

KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The Parties to this Protocol,

Being Parties to the United Nations Framework Convention on Climate Change, hereinafter referred to as "the Convention",

In pursuit of the ultimate objective of the Convention as stated in its Article 2,

Recalling the provisions of the Convention,

Being guided by Article 3 of the Convention,

Pursuant to the Berlin Mandate adopted by decision 1/CP.1 of the Conference of the Parties to the Convention at its first session,

Have agreed as follows:

Article 1

For the purposes of this Protocol, the definitions contained in Article 1 of the Convention shall apply. In addition:

1. "Conference of the Parties" means the Conference of the Parties to the Convention.

2. "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.

3. "Intergovernmental Panel on Climate Change" means the Intergovernmental Panel on Climate Change established in 1988 jointly by the World Meteorological Organization and the United Nations Environment Programme.

4. "Montreal Protocol" means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended.

5. "Parties present and voting" means Parties present and casting an affirmative or negative vote.

6. "Party" means, unless the context otherwise indicates, a Party to this Protocol.

7. "Party included in Annex I" means a Party included in Annex I to the Convention, as may be amended, or a Party which has made a notification under Article 4, paragraph 2(g), of the Convention.

Article 2

1. Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:

(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

(i) Enhancement of energy efficiency in relevant sectors of the national economy;

(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;

(iii) Promotion of sustainable forms of agriculture in light of climate change considerations;

(iv) Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;

(v) Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and application of market instruments;

(vi) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol;

(vii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector;

(viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy;

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

3. The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol, if it decides that it would be beneficial to coordinate any of the policies and measures in paragraph 1(a) above, taking into account different national circumstances and potential effects, shall consider ways and means to elaborate the coordination of such policies and measures.

Article 3

1. The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

2. Each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.

3. The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

4. Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

5. The Parties included in Annex I undergoing the process of transition to a market economy whose base year or period was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session shall use that base year or period for the implementation of their commitments under this Article. Any other Party included in Annex I undergoing the process of transition to a market economy which has not yet submitted its first national communication under Article 12 of the Convention may also notify the Conference of the Parties serving as the meeting of the Parties to this Protocol that it intends to use an historical base year or period other than 1990 for the implementation of its commitments under this Article. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall decide on the acceptance of such notification.

6. Taking into account Article 4, paragraph 6, of the Convention, in the implementation of their commitments under this Protocol other than those under this Article, a certain degree of flexibility shall be allowed by the Conference of the Parties serving as the meeting of the Parties to this Protocol to the Parties included in Annex I undergoing the process of transition to a market economy.

7. In the first quantified emission limitation and reduction commitment period, from 2008 to 2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five. Those Parties included in Annex I for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990 shall include in their 1990 emissions base year or period the aggregate anthropogenic carbon dioxide equivalent emissions by sources minus removals by sinks in 1990 from land-use change for the purposes of calculating their assigned amount.

8. Any Party included in Annex I may use 1995 as its base year for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the purposes of the calculation referred to in paragraph 7 above.

9. Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol, which shall be adopted in accordance with the provisions of Article 21, paragraph 7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period referred to in paragraph 1 above.

10. Any emission reduction units, or any part of an assigned amount, which a Party acquires from another Party in accordance with the provisions of Article 6 or of Article 17 shall be added to the assigned amount for the acquiring Party.

11. Any emission reduction units, or any part of an assigned amount, which a Party transfers to another Party in accordance with the provisions of Article 6 or of Article 17 shall be subtracted from the assigned amount for the transferring Party.

12. Any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 12 shall be added to the assigned amount for the acquiring Party.

13. If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods.

14. Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred

to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

Article 4

1. Any Parties included in Annex I that have reached an agreement to fulfil their commitments under Article 3 jointly, shall be deemed to have met those commitments provided that their total combined aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of Article 3. The respective emission level allocated to each of the Parties to the agreement shall be set out in that agreement.

2. The Parties to any such agreement shall notify the secretariat of the terms of the agreement on the date of deposit of their instruments of ratification, acceptance or approval of this Protocol, or accession thereto. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of the agreement.

3. Any such agreement shall remain in operation for the duration of the commitment period specified in Article 3, paragraph 7.

4. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization, any alteration in the composition of the organization after adoption of this Protocol shall not affect existing commitments under this Protocol. Any alteration in the composition of the organization shall only apply for the purposes of those commitments under Article 3 that are adopted subsequent to that alteration.

5. In the event of failure by the Parties to such an agreement to achieve their total combined level of emission reductions, each Party to that agreement shall be responsible for its own level of emissions set out in the agreement.

6. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Protocol, each member State of that regional economic integration organization individually, and together with the regional economic integration organization acting in accordance with Article 24, shall, in the event of failure to achieve the total combined level of emission reductions, be responsible for its level of emissions as notified in accordance with this Article.

Article 5

1. Each Party included in Annex I shall have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. Guidelines for such national systems, which shall incorporate the

methodologies specified in paragraph 2 below, shall be decided upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session.

2. Methodologies for estimating anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

3. The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each such greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

Article 6

1. For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

(a) Any such project has the approval of the Parties involved;

(b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;

(c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and

(d) The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

2. The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article, including for verification and reporting.

3. A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition under this Article of emission reduction units.

4. If a question of implementation by a Party included in Annex I of the requirements referred to in this Article is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

Article 7

1. Each Party included in Annex I shall incorporate in its annual inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, submitted in accordance with the relevant decisions of the Conference of the Parties, the necessary supplementary information for the purposes of ensuring compliance with Article 3, to be determined in accordance with paragraph 4 below.

2. Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol, to be determined in accordance with paragraph 4 below.

3. Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party. Each such Party shall submit the information required under paragraph 2 above as part of the first national communication due under the Convention after this Protocol has entered into force for it and after the adoption of guidelines as provided for in paragraph 4 below. The frequency of subsequent submission of information required under this Article shall be determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol, taking into account any timetable for the submission of national communications decided upon by the Conference of the Parties.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the preparation of the information required under this Article, taking into account guidelines for the preparation of

national communications by Parties included in Annex I adopted by the Conference of the Parties. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall also, prior to the first commitment period, decide upon modalities for the accounting of assigned amounts.

Article 8

1. The information submitted under Article 7 by each Party included in Annex I shall be reviewed by expert review teams pursuant to the relevant decisions of the Conference of the Parties and in accordance with guidelines adopted for this purpose by the Conference of the Parties serving as the meeting of the Parties to this Protocol under paragraph 4 below. The information submitted under Article 7, paragraph 1, by each Party included in Annex I shall be reviewed as part of the annual compilation and accounting of emissions inventories and assigned amounts. Additionally, the information submitted under Article 7, paragraph 2, by each Party included in Annex I shall be reviewed as part of the review of communications.

2. Expert review teams shall be coordinated by the secretariat and shall be composed of experts selected from those nominated by Parties to the Convention and, as appropriate, by intergovernmental organizations, in accordance with guidance provided for this purpose by the Conference of the Parties.

3. The review process shall provide a thorough and comprehensive technical assessment of all aspects of the implementation by a Party of this Protocol. The expert review teams shall prepare a report to the Conference of the Parties serving as the meeting of the Parties to this Protocol, assessing the implementation of the commitments of the Party and identifying any potential problems in, and factors influencing, the fulfilment of commitments. Such reports shall be circulated by the secretariat to all Parties to the Convention. The secretariat shall list those questions of implementation indicated in such reports for further consideration by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the review of implementation of this Protocol by expert review teams taking into account the relevant decisions of the Conference of the Parties.

5. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, with the assistance of the Subsidiary Body for Implementation and, as appropriate, the Subsidiary Body for Scientific and Technological Advice, consider:

(a) The information submitted by Parties under Article 7 and the reports of the expert reviews thereon conducted under this Article; and

(b) Those questions of implementation listed by the secretariat under paragraph 3 above, as well as any questions raised by Parties.

6. Pursuant to its consideration of the information referred to in paragraph 5 above, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take decisions on any matter required for the implementation of this Protocol.

Article 9

1. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall periodically review this Protocol in the light of the best available scientific information and assessments on climate change and its impacts, as well as relevant technical, social and economic information. Such reviews shall be coordinated with pertinent reviews under the Convention, in particular those required by Article 4, paragraph 2(d), and Article 7, paragraph 2(a), of the Convention. Based on these reviews, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take appropriate action.

2. The first review shall take place at the second session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. Further reviews shall take place at regular intervals and in a timely manner.

Article 10

All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, without introducing any new commitments for Parties not included in Annex I, but reaffirming existing commitments under Article 4, paragraph 1, of the Convention, and continuing to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7, of the Convention, shall:

(a) Formulate, where relevant and to the extent possible, cost-effective national and, where appropriate, regional programmes to improve the quality of local emission factors, activity data and/or models which reflect the socio-economic conditions of each Party for the preparation and periodic updating of national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties, and consistent with the guidelines for the preparation of national communications adopted by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change:

(i) Such programmes would, *inter alia*, concern the energy, transport and industry sectors as well as agriculture, forestry and waste management. Furthermore, adaptation technologies and methods for improving spatial planning would improve adaptation to climate change; and

(ii) Parties included in Annex I shall submit information on action under this Protocol, including national programmes, in accordance with Article 7; and other Parties shall seek to include in their national communications, as appropriate, information on programmes which contain measures that the Party believes contribute to addressing climate change and its adverse impacts, including the abatement of increases in greenhouse gas emissions, and enhancement of and removals by sinks, capacity building and adaptation measures;

(c) Cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies;

(d) Cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies, and promote the development and strengthening of endogenous capacities and capabilities to participate in international and intergovernmental efforts, programmes and networks on research and systematic observation, taking into account Article 5 of the Convention;

(e) Cooperate in and promote at the international level, and, where appropriate, using existing bodies, the development and implementation of education and training programmes, including the strengthening of national capacity building, in particular human and institutional capacities and the exchange or secondment of personnel to train experts in this field, in particular for developing countries, and facilitate at the national level public awareness of, and public access to information on, climate change. Suitable modalities should be developed to implement these activities through the relevant bodies of the Convention, taking into account Article 6 of the Convention;

(f) Include in their national communications information on programmes and activities undertaken pursuant to this Article in accordance with relevant decisions of the Conference of the Parties; and

(g) Give full consideration, in implementing the commitments under this Article, to Article 4, paragraph 8, of the Convention.

Article 11

1. In the implementation of Article 10, Parties shall take into account the provisions of Article 4, paragraphs 4, 5, 7, 8 and 9, of the Convention.

2. In the context of the implementation of Article 4, paragraph 1, of the Convention, in accordance with the provisions of Article 4, paragraph 3, and Article 11 of the Convention, and through the entity or entities entrusted with the operation of the financial mechanism of the Convention, the developed country Parties and other developed Parties included in Annex II to the Convention shall:

(a) Provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in advancing the implementation of existing commitments under Article 4, paragraph 1(a), of the Convention that are covered in Article 10, subparagraph (a); and

(b) Also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of advancing the implementation of existing commitments under Article 4, paragraph 1, of the Convention that are covered by Article 10 and that are agreed between a developing country Party and the international entity or entities referred to in Article 11 of the Convention, in accordance with that Article.

The implementation of these existing commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among developed country Parties. The guidance to the entity or entities entrusted with the operation of the financial mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before the adoption of this Protocol, shall apply mutatis mutandis to the provisions of this paragraph.

3. The developed country Parties and other developed Parties in Annex II to the Convention may also provide, and developing country Parties avail themselves of, financial resources for the implementation of Article 10, through bilateral, regional and other multilateral channels.

Article 12

1. A clean development mechanism is hereby defined.

2. The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

3. Under the clean development mechanism:

(a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and

(b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The clean development mechanism shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the clean development mechanism.

5. Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:

(a) Voluntary participation approved by each Party involved;

(b) Real, measurable, and long-term benefits related to the mitigation of climate change; and

(c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

6. The clean development mechanism shall assist in arranging funding of certified project activities as necessary.

7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.

8. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

9. Participation under the clean development mechanism, including in activities mentioned in paragraph 3(a) above and in the acquisition of certified emission reductions, may involve private and/or public entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

10. Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

Article 13

1. The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Protocol.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall keep under regular review the implementation of this Protocol and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Protocol and shall:

(a) Assess, on the basis of all information made available to it in accordance with the provisions of this Protocol, the implementation of this Protocol by the Parties, the overall effects of the measures taken pursuant to this Protocol, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(b) Periodically examine the obligations of the Parties under this Protocol, giving due consideration to any reviews required by Article 4, paragraph 2(d), and Article 7, paragraph 2, of the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge, and in this respect consider and adopt regular reports on the implementation of this Protocol;

(c) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(d) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(e) Promote and guide, in accordance with the objective of the Convention and the provisions of this Protocol, and taking fully into account the relevant decisions by the Conference of the Parties, the development and periodic refinement of comparable methodologies for the effective implementation of this Protocol, to be agreed on by the Conference of the Parties serving as the meeting of the Parties to this Protocol;

(f) Make recommendations on any matters necessary for the implementation of this Protocol;

(g) Seek to mobilize additional financial resources in accordance with Article 11, paragraph 2;

(h) Establish such subsidiary bodies as are deemed necessary for the implementation of this Protocol;

(i) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(j) Exercise such other functions as may be required for the implementation of this Protocol, and consider any assignment resulting from a decision by the Conference of the Parties.

5. The rules of procedure of the Conference of the Parties and financial procedures applied under the Convention shall be applied mutatis mutandis under this Protocol, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

6. The first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of the entry into force of this Protocol. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held every year and in conjunction with ordinary sessions of the Conference of the Parties, unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

7. Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to this Protocol, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

8. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Protocol and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to this Protocol as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure, as referred to in paragraph 5 above.

Article 14

1. The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Protocol.

2. Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention on arrangements made for the functioning of the secretariat, shall apply mutatis mutandis to this Protocol. The secretariat shall, in addition, exercise the functions assigned to it under this Protocol.

Article 15

1. The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Convention shall serve as, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol. The provisions relating to the functioning of these two bodies under the Convention shall apply mutatis mutandis to this Protocol. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of the Convention.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Protocol, any member of the Bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

Article 16

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, as soon as practicable, consider the application to this Protocol of, and modify as appropriate, the multilateral consultative process referred to in Article 13 of the Convention, in the light of any relevant decisions that may be taken by the Conference of the Parties. Any multilateral consultative process that may be applied to this Protocol shall operate without prejudice to the procedures and mechanisms established in accordance with Article 18.

Article 17

The Conference of the Parties shall define the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for emissions trading. The Parties included in Annex B may participate in emissions trading for the purposes of fulfilling their commitments under Article 3. Any such trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments under that Article.

Article 18

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, approve appropriate and effective procedures and mechanisms to determine and to address cases of non-compliance with the provisions of this Protocol, including through the development of an indicative list of consequences, taking into account the cause, type, degree and frequency of non-compliance. Any procedures and mechanisms under this Article entailing binding consequences shall be adopted by means of an amendment to this Protocol.

Article 19

The provisions of Article 14 of the Convention on settlement of disputes shall apply mutatis mutandis to this Protocol.

Article 20

1. Any Party may propose amendments to this Protocol.

2. Amendments to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed amendment to this Protocol shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed amendments to the Parties and signatories to the Convention and, for information, to the Depositary.

3. The Parties shall make every effort to reach agreement on any proposed amendment to this Protocol by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to this Protocol.

5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

Article 21

1. Annexes to this Protocol shall form an integral part thereof and, unless otherwise expressly provided, a reference to this Protocol constitutes at the same time a reference to any annexes thereto. Any annexes adopted after the entry into force of this Protocol shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Any Party may make proposals for an annex to this Protocol and may propose amendments to annexes to this Protocol.

3. Annexes to this Protocol and amendments to annexes to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed annex or amendment to an annex shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed annex or amendment to an annex to the Parties and signatories to the Convention and, for information, to the Depositary.

4. The Parties shall make every effort to reach agreement on any proposed annex or amendment to an annex by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the annex or amendment to an annex shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted annex or amendment to an annex shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

5. An annex, or amendment to an annex other than Annex A or B, that has been adopted in accordance with paragraphs 3 and 4 above shall enter into force for all Parties to this Protocol six months after the date of the communication by the Depositary to such Parties of the adoption of

the annex or adoption of the amendment to the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex or amendment to the annex. The annex or amendment to an annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

6. If the adoption of an annex or an amendment to an annex involves an amendment to this Protocol, that annex or amendment to an annex shall not enter into force until such time as the amendment to this Protocol enters into force.

7. Amendments to Annexes A and B to this Protocol shall be adopted and enter into force in accordance with the procedure set out in Article 20, provided that any amendment to Annex B shall be adopted only with the written consent of the Party concerned.

Article 22

1. Each Party shall have one vote, except as provided for in paragraph 2 below.

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to this Protocol. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 23

The Secretary-General of the United Nations shall be the Depositary of this Protocol.

Article 24

1. This Protocol shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations which are Parties to the Convention. It shall be open for signature at United Nations Headquarters in New York from 16 March 1998 to 15 March 1999. This Protocol shall be open for accession from the day after the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2. Any regional economic integration organization which becomes a Party to this Protocol without any of its member States being a Party shall be bound by all the obligations under this Protocol. In the case of such organizations, one or more of whose member States is a Party to this Protocol, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Protocol. In such cases, the organization and the member States shall not be entitled to exercise rights under this Protocol concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Protocol. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 25

1. This Protocol shall enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession.

2. For the purposes of this Article, “the total carbon dioxide emissions for 1990 of the Parties included in Annex I” means the amount communicated on or before the date of adoption of this Protocol by the Parties included in Annex I in their first national communications submitted in accordance with Article 12 of the Convention.

3. For each State or regional economic integration organization that ratifies, accepts or approves this Protocol or accedes thereto after the conditions set out in paragraph 1 above for entry into force have been fulfilled, this Protocol shall enter into force on the ninetieth day following the date of deposit of its instrument of ratification, acceptance, approval or accession.

4. For the purposes of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

Article 26

No reservations may be made to this Protocol.

Article 27

1. At any time after three years from the date on which this Protocol has entered into force for a Party, that Party may withdraw from this Protocol by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Protocol.

Article 28

The original of this Protocol, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

DONE at Kyoto this eleventh day of December one thousand nine hundred and ninety-seven.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have affixed their signatures to this Protocol on the dates indicated.

Annex A

Greenhouse gases

Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Hydrofluorocarbons (HFCs)
Perfluorocarbons (PFCs)
Sulphur hexafluoride (SF_6)

Sectors/source categories

- Energy
  - Fuel combustion
    - Energy industries
    - Manufacturing industries and construction
    - Transport
    - Other sectors
    - Other
  - Fugitive emissions from fuels
    - Solid fuels
    - Oil and natural gas
    - Other

- Industrial processes
  - Mineral products
  - Chemical industry
  - Metal production
  - Other production
  - Production of halocarbons and sulphur hexafluoride
  - Consumption of halocarbons and sulphur hexafluoride
  - Other

- Solvent and other product use

- Agriculture
  - Enteric fermentation
  - Manure management
  - Rice cultivation
  - Agricultural soils
  - Prescribed burning of savannas
  - Field burning of agricultural residues
  - Other

Waste

Solid waste disposal on land
Wastewater handling
Waste incineration
Other

Annex B

Party	Quantified emission limitation or reduction commitment (percentage of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

* Countries that are undergoing the process of transition to a market economy.

Decision 2/CP.3

Methodological issues related to the Kyoto protocol

The Conference of the Parties,

Recalling its decisions 4/CP.1 and 9/CP.2,

Endorsing the relevant conclusions of the Subsidiary Body for Scientific and Technological Advice at its fourth session,[1]

1. *Reaffirms* that Parties should use the Revised 1996 Guidelines for National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change to estimate and report on anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol;

2. *Affirms* that the actual emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride should be estimated, where data are available, and used for the reporting of emissions. Parties should make every effort to develop the necessary sources of data;

3. *Reaffirms* that global warming potentials used by Parties should be those provided by the Intergovernmental Panel on Climate Change in its Second Assessment Report ("1995 IPCC GWP values") based on the effects of the greenhouse gases over a 100-year time horizon, taking into account the inherent and complicated uncertainties involved in global warming potential estimates. In addition, for information purposes only, Parties may also use another time horizon, as provided in the Second Assessment Report;

4. *Recalls* that, under the Revised 1996 Guidelines for National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change, emissions based upon fuel sold to ships or aircraft engaged in international transport should not be included in national totals, but reported separately; and urges the Subsidiary Body for Scientific and Technological Advice to further elaborate on the inclusion of these emissions in the overall greenhouse gas inventories of Parties;

5. *Decides* that emissions resulting from multilateral operations pursuant to the Charter of the United Nations shall not be included in national totals, but reported separately; other emissions related to operations shall be included in the national emissions totals of one or more Parties involved.

12th plenary meeting
11 December 1997

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[1] FCCC/SBSTA/1996/20, paras. 30 and 54.

APPENDIX B

AMERICAN FOREST AND PAPER ASSOCIATION

POSITION STATEMENT ON GLOBAL CLIMATE CHANGE

DECEMBER 1997

AF&PA POSITION ON GLOBAL CLIMATE CHANGE

Climate change is by definition a global issue. An international agreement on climate change must be based on economic and internationally agreed solutions promoting sustainable development. No response to this issue can be truly effective without simultaneous global participation and defined parallel commitments by both developed and developing countries. Concerted action involving all countries is essential to an effective response. Consequently, any agreement must include the foregoing considerations and must maintain the global competitiveness of the U.S. paper and forest products industry by incorporating the following principles:

1. All efforts to reduce emissions must be based on sound science that is subject to periodic review by peers and all stakeholders, including the forest products industry.

2. The treaty and implementing regulations must recognize that emissions from biomass fuels do not contribute additional greenhouse gases to the atmosphere.

3. One-for-one credit for carbon storage that takes place in forests, and in the wood and paper products manufactured must be available to offset greenhouse gas emissions.

4. There must be equal application of treaty provisions regarding manufacturing facilities in both developed and developing countries.

5. There must be a verifiable requirement that the treaty's provisions will be equitably enforced by all signatories to the treaty and a mechanism to ensure that advantages gained from violations can be offset.

6. There must be recognition of the lengthy capital investment cycles of basic manufacturing industries in any timetables for emissions reductions contemplated by the treaty or implementing regulations.

7. Active forest management practices must not be prescribed or proscribed in the treaty or in implementing regulations.

8. Emissions reductions credits must be made available through a program of "joint implementation" between developed and developing nations, and within the United States.

9. Incentives for related research, development and technology implementation, including government/industry research partnerships, tax incentives, and anti-trust exemptions, must be made available by the U.S. government.

10. The U.S. government must provide flexibility that allows environmental trade-offs between attaining certain environmental objectives to be made.

11. The U.S. government must recognize emissions from recycling facilities as net zero contributors to greenhouse gas emissions or provide additional incentives to reduce emissions from this manufacturing activity, which is desirable from an environmental point of view.

12. All sectors of the U.S. economy – agriculture, utilities, industry, commerce, small business, transportation, and individuals – must make a recognizable contribution to a program to reduce greenhouse gases.

APPENDIX C

AMERICAN FOREST AND PAPER ASSOCIATION ENERGY USE STATISTICS

FOSSIL FUEL AND PURCHASED ELECTRICITY AT PULP AND PAPER MILLS

	units	1972	1980	1981	1982	1983	1984	1985
Purchased electricity	trillion BTUs	93.7	134.9	140	133.4	139.6	148.8	144.2
Coal	trillion BTUs	224.7	226.9	246.4	252	301.1	329.5	337
Residual fuel oil	trillion BTUs	447.4	348.3	263.6	231.9	205.6	165.3	150
Distillate fuel oil	trillion BTUs	22.0	8.1	7.9	5.8	5.9	7.2	8.4
Liquid petroleum gases	trillion BTUs	2.6	3.9	2.1	2.5	2.3	3.2	3.4
Natural gas	trillion BTUs	443.9	384.5	403.2	341.1	315.2	335.1	307.5

	units	1986	1987	1988	1989	1990	1991	1992
Purchased electricity	trillion BTUs	146.7	147.8	154.5	154	158.8	160.5	168.6
Coal	trillion BTUs	343.4	335.1	329.8	331.1	338.1	330.9	332.6
Residual fuel oil	trillion BTUs	188.8	159.8	178.5	178.7	150.9	154.6	160.1
Distillate fuel oil	trillion BTUs	8	8.5	8.9	8.6	6.9	5.3	6.1
Liquid petroleum gases	trillion BTUs	2.9	2.7	2.6	2.7	3.4	7.4	7.8
Natural gas	trillion BTUs	287.8	345.4	332.4	359.4	401.7	439.5	450.6

	units	1993	1994	1995	1996	1997		
Purchased electricity	trillion BTUs	173.2	167.3	157.9	161.7	171.4		
Coal	trillion BTUs	333.1	325.4	327.8	357	353		
Residual fuel oil	trillion BTUs	174.2	156.1	142.9	141	162		
Distillate fuel oil	trillion BTUs	7.1	7.8	7	8	18		
Liquid petroleum gases	trillion BTUs	2.9	2	2.1	1.8	1.6		
Natural gas	trillion BTUs	439.6	438.5	450.8	468	499		

APPENDIX D

ESTIMATED CARBON DIOXIDE EMISSIONS FROM U.S. PULP AND PAPER MILLS (AS MILLION METRIC TONS CARBON)

	1972	1980	1981	1982	1983	1984	1985
Purchased electricity	3.87	5.58	5.76	5.52	5.78	6.15	5.95
Coal	5.75	5.80	6.30	6.45	7.70	8.43	8.62
Residual fuel oil	9.61	7.48	5.66	4.98	4.42	3.55	3.22
Distillate fuel oil	0.44	0.16	0.16	0.12	0.12	0.14	0.17
Liquid petroleum gases	0.04	0.07	0.04	0.04	0.04	0.05	0.06
Natural gas	6.42	5.56	5.83	4.94	4.56	4.85	4.45
Total direct and indirect	26.14	24.66	23.75	22.04	22.62	23.18	22.47
Total on-site	22.27	19.08	18.00	16.52	16.84	17.03	16.52
Total short tons of production-millions	65.0	72.6	71.1	69.4	75.6	80.4	78.9
Total metric tons of production-millions	59.1	66.0	64.6	63.1	68.8	73.1	71.7

	1986	1987	1988	1989	1990	1991	1992
Purchased electricity	6.04	6.11	6.38	6.36	6.56	6.63	6.96
Coal	8.78	8.57	8.44	8.47	8.65	8.46	8.51
Residual fuel oil	4.06	3.43	3.84	3.84	3.24	3.32	3.44
Distillate fuel oil	0.16	0.17	0.18	0.17	0.14	0.11	0.12
Liquid petroleum gases	0.05	0.05	0.04	0.05	0.06	0.13	0.13
Natural gas	4.16	5.00	4.81	5.20	5.81	6.36	6.52
Total direct and indirect	23.25	23.33	23.69	24.09	24.46	25.01	25.69
Total on-site	17.21	17.22	17.30	17.73	17.90	18.38	18.72
Total short tons of production-millions	85.0	86.5	87.3	87.6	89.2	91.4	96.4
Total metric tons of production-millions	77.3	78.6	79.4	79.6	81.0	83.1	87.6

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	1993	1994	1995	1996	1997
Purchased electricity	7.15	6.91	6.52	6.68	7.08
Coal	8.52	8.32	8.39	9.13	9.03
Residual fuel oil	3.74	3.35	3.07	3.03	3.48
Distillate fuel oil	0.14	0.16	0.14	0.16	0.36
Liquid petroleum gases	0.05	0.03	0.04	0.03	0.03
Natural gas	6.36	6.35	6.52	6.77	7.22
Total direct and indirect	25.97	25.12	24.68	25.80	27.20
Total on-site	18.82	18.21	18.15	19.12	20.12
Total short tons of production-millions	97.6	98.6	99.9	101.6	106.5
Total metric tons of production-millions	88.7	89.6	90.8	92.4	96.8

Note: Production is the total of paper and paperboard plus dried pulp

APPENDIX E

ENERGY USE AT U.S. LUMBER AND WOOD PRODUCTS MILLS (SIC24) BY FUEL TYPE

	units	1988	1991	1994
Net electricity	trillion BTUs	56	61	68
Coal	trillion BTUs	2	2	2
Residual fuel oil	trillion BTUs	3	2	2
Distillate fuel oil	trillion BTUs	23	16	25
Liquid petroleum gases	trillion BTUs	3	4	4
Natural gas	trillion BTUs	35	41	48
Subtotal	trillion BTUs	122	126	149
Other (presumably bark and wood)		285	325	341
Fossil plus purchased electricity	trillion BTUs	122	126	
Renewables	trillion BTUs	285	325	
Sum	trillion BTUs	407	451	
Percent renewables		70.0	72.1	
Purchased electricity (shown because KWH used to calculate CO_2 emissions)	billion KWH	16.4	17.9	19.8

SOURCE - U.S. Department of Energy, Manufacturing Consumption of Energy, 1988, 1991 and 1994

APPENDIX F

CARBON DIOXIDE EMISSION ESTIMATES FOR U.S. LUMBER AND WOOD PRODUCTS MILLS (FACILITIES IN SIC 24)

	1988	1991	1994
Net electricity	2.30	2.51	2.78
Coal	0.05	0.05	0.05
Residual fuel oil	0.06	0.04	0.04
Distillate fuel oil	0.46	0.32	0.50
Liquid petroleum gases	0.05	0.07	0.07
Natural gas	0.51	0.59	0.69
Total	3.44	3.59	4.14
On-site	1.13	1.07	1.36
Indirect	2.30	2.51	2.78

Emissions expressed as millions of metric tons of C

APPENDIX G

LUMBER AND PANEL PRODUCTION STATISTICS

	1988	1991	1994
Softwood lumber - million bd ft	36904	33281	32487
Struct. panels-million ft - 3/8 basis	27203	24265	27124
Particleboard - million ft -3/4 basis	3829	3772	4542
MDF - million ft - 3/4 basis	939	958	1251
Hardboard - million ft - 1/8 basis	5118	4895	5300

Conversion factors - from the *1993-94 North American Factbook of Wood Technology* published by Miller Freeman

Lumber	2358 cubic meters/million board feet
3/8 Panels	885 cubic meters/million feet
3/4 Panels	1770 cubic meters/million feet
1/8 Panels	295 cubic meters/million feet

	1988	1991	1994
Lumber - million cubic meters	87.0	78.5	76.6
Struct. panels-million cubic meters	24.1	21.5	24.0
Particleboard - million cubic meters	6.8	6.7	8.0
MDF-million cubic meters	1.7	1.7	2.2
Hardboard-million cubic meters	1.5	1.4	1.6
Total - million cubic meters	121.0	109.8	112.4

1998 production figures directly from *Forest Industries 1991-29 North American Fact Book* published by Miller Freeman

1991 and 1994 production figures from *1996 Directory of the Wood Products Industry* published by Miller Freeman

The 1991 and 1994 lumber numbers are a total of West Inland, West Coast, South, and 1700 million bd ft added for “other” lumber included in the 1988 figure

APPENDIX H

PULP AND PAPER MILLS USED IN COST STUDY

Company	City	State
Appleton Papers Incorporated	West Carrollton	OH
Appleton Papers Incorporated	Combined Locks	WI
Blandin Paper Company	Grand Rapids	MN
Boise Cascade Corporation	Jackson	AL
Boise Cascade Corporation	DeRidder	LA
Boise Cascade Corporation	St. Helens	OR
Boise Cascade Corporation	Wallula	WA
Caraustar Industries (Chattanoga Paperboard)	Chattanoga	TN
Champion International Corporation	Cantonment (Pensacola)	FL
Champion International Corporation	Bucksport	ME
Champion International Corporation	Sartell	MN
Champion International Corporation	Deferiet	NY
Champion International Corporation	Roanoke Rapids	NC
Champion International Corporation	Hamilton	OH
Champion International Corporation (Donahue)	Houston (Sheldon)	TX
Champion International Corporation (Donahue)	Lufkin	TX
Consolidated Papers Incorporated	Stevens Point	WI
Consolidated Papers Incorporated	Wisconsin Rapids/Biron	WI
Consolidated Papers (Niagara of Wisconsin)	Niagara	WI
E.B.Eddy Paper Incorporated	Port Huron	MI
Erving Paper Mills Incorporated	Erving	MA
Fox River Paper Company	Appleton	WI
Fraser Papers Incorporated (Flambeau)	Park Falls	WI
Georgia-Pacific Corporation	Palatka	FL
Georgia-Pacific Corporation	Port Hudson	LA
Georgia-Pacific Corporation	Woodland	ME
Georgia-Pacific Corporation	New Augusta	MS
Georgia-Pacific Corporation	Delair	NJ
Georgia-Pacific Corporation	Kalamazoo	MI
Georgia-Pacific Corporation	Bellingham	WA
P.H. Glatfelter Company	Spring Grove	PA
Gulf States Paper Corporation	Demopolis	AL

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Company	City	State
Inland Paperboard & Packaging Incorporated	Rome	GA
Inland Paperboard & Packaging Incorporated	Orange	TX
International Paper Company	Mobile	AL
International Paper Company	Pine Bluff	AR
International Paper Company	Jay	ME
International Paper Company	Moss Point	MS
International Paper Company	Vicksburg	MS
International Paper Company	Ticonderoga	NY
International Paper Company	Georgetown	SC
International Paper Company (Beckett)	Hamilton	OH
International Paper Company (Weston Paper)	Terre Haute	IN
Rayonier	Fernandina Beach	FL
Little Rapids Corporation (Shawano)	Shawano	WI
MacMillan Bloedel Packaging Incorporated	Pine Hill	AL
Manistique Papers Incorporated	Manistique	MI
Mead Corporation	Stevenson	AL
Mead Corporation	Chillicothe	OH
Mead Corporation (Gilbert Paper)	Menasha	WI
Newark Atlantic Paperboard Corporation	Lawrence	MA
Potlatch Corporation	McGehee	AR
Potlatch Corporation	Lewiston	ID
Potlatch Corporation	Brainerd	MN
Potlatch Corporation	Cloquet	MN
Rock-Tenn Company	Chattanooga	TN
Rock-Tenn Company	Dallas	TX
Rock-Tenn Company	Lynchburg	VA
Sonoco Products Company	Lancaster	OH
Sonoco Products Company	Hartsville	SC
Sonoco Products Company	Newport	TN
Southeast Paper Company	Dublin	GA
Smurfit-Stone Container Corporation	Snowflake	AZ
Smurfit-Stone Container Corporation	Panama City	FL
Smurfit-Stone Container Corporation	Hodge	LA
Smurfit-Stone Container Corporation	Ontonagon	MI
Smurfit-Stone Container Corporation	Coshocton	OH

(Continued on next page.)

Company	City	State
Smurfit-Stone Container Corporation	York	PA
Smurfit-Stone Container Corporation	Carthage	IN
Smurfit-Stone Container Corporation	Wabash	IN
Smurfit-Stone Container Corporation	Circleville	OH
Smurfit-Stone Container Corporation	Philadelphia	PA
Smurfit-Stone Container Corporation	Tacoma	WA
Smurfit-Stone Container Corporation	Newberg	OR
Smurfit-Stone Container Corporation	Oregon City	OR
Union Camp Corporation	Prattville (Montgomery)	AL
Union Camp Corporation	Franklin	VA
Westvaco Corporation	Luke	MD
Westvaco Corporation	Tyrone	PA
Westvaco Corporation	North Charleston	SC
Weyerhaeuser Company	Columbus	MS
Weyerhaeuser Company	New Bern	NC
Weyerhaeuser Company	Valliant	OK
Weyerhaeuser Company	North Bend	OR
Weyerhaeuser Company	Springfield	OR
Weyerhaeuser Company	Cosmopolis	WA
Weyerhaeuser Company	Rothschild	WI
Willamette Industries Incorporated	Albany	OR
Name withheld		GA
Name withheld		WI

APPENDIX I

COMPANY DATA USED TO CHECK NCASI'S COST ESTIMATES

OVERVIEW

NCASI invited companies with mills among the 90 included in this study to provide independent, company-derived estimates of costs to install and operate technologies to reduce direct or indirect CO_2 emissions. Information was received for 19 mills, but relatively little of it was in a form that could be compared quantitatively to NCASI estimates. In this appendix, the data are summarized to the extent possible. The summaries focus on capital cost estimates and estimates of emissions reductions. No attempt has been made to summarize the information on annualized or marginal costs because of limitations and uncertainties regarding the estimation of these parameters (discussed in the body of the report). Details on the company estimates is not included because NCASI agreed to keep such details confidential.

SUMMARY COMPARISON OF PROJECT CAPITAL COSTS

Figure I1 compares NCASI's capital cost estimates for individual projects to those provided by companies. The diagonal line is the line of equality. Where companies provided data on multiple carbon emission-reducing technologies that had been implemented at a single mill, the data were compared to NCASI's model for the mill, which also implemented multiple technologies. That comparison is described separately.

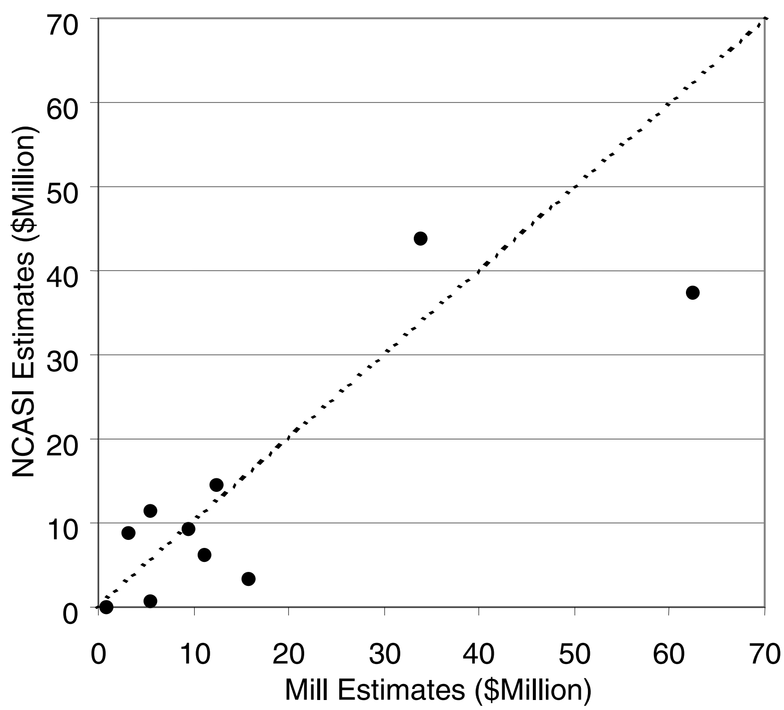

Figure I1. Comparison of Mill and NCASI Estimates of Individual Project Capital Costs

The figure does not appear to suggest that NCASI's estimates of individual project capital costs contain a high or low bias, although some of NCASI's estimates are considerably different than the company estimates. To determine whether NCASI's approach was providing biased estimates of project capital costs, NCASI statistically tested the average percent difference between the NCASI and company estimates to see if it was different from zero. The average percent difference was not statistically different from zero at a 0.05 significance level (P=0.99), providing evidence that NCASI's approach was not yielding biased estimates of capital costs.

SUMMARY COMPARISON OF CAPITAL COSTS FOR MULTIPLE TECHNOLOGIES TO ACCOMPLISH A GIVEN PERCENT REDUCTION

Three mills provided a list of changes that had been implemented since 1995 as well as the associated costs and impacts. In all three cases, NCASI's model-derived capital cost estimates, at a comparable percent reduction from baseline emissions, were substantially higher than the company data. For the three mills, NCASI's estimates were, on average, 267% greater than the company data (relative standard deviation of 0.8). Due to the large standard deviation and small sample size, however, the average difference was not statistically different from zero at a 0.05 level of significance (P=0.33).

SUMMARY COMPARISON OF ESTIMATED EMISSION REDUCTIONS

Where company data sets allowed NCASI to calculate an emissions reduction, these were compared to the emissions reductions estimated by NCASI from the model mill for the same technology. The company-estimated and NCASI-estimated carbon reductions are plotted in Figure I2. Again, there does not appear to be evidence of bias, and the average percent difference between the two estimates is not statistically different from zero at a significance level of 0.05 (P=0.70).

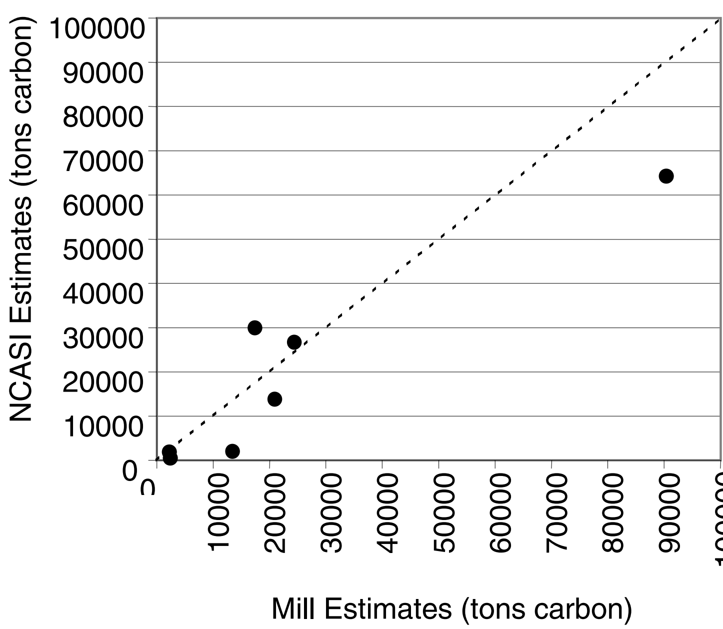

Figure I2. Comparison of Mill and NCASI Estimates of Annual Carbon Emission Reductions