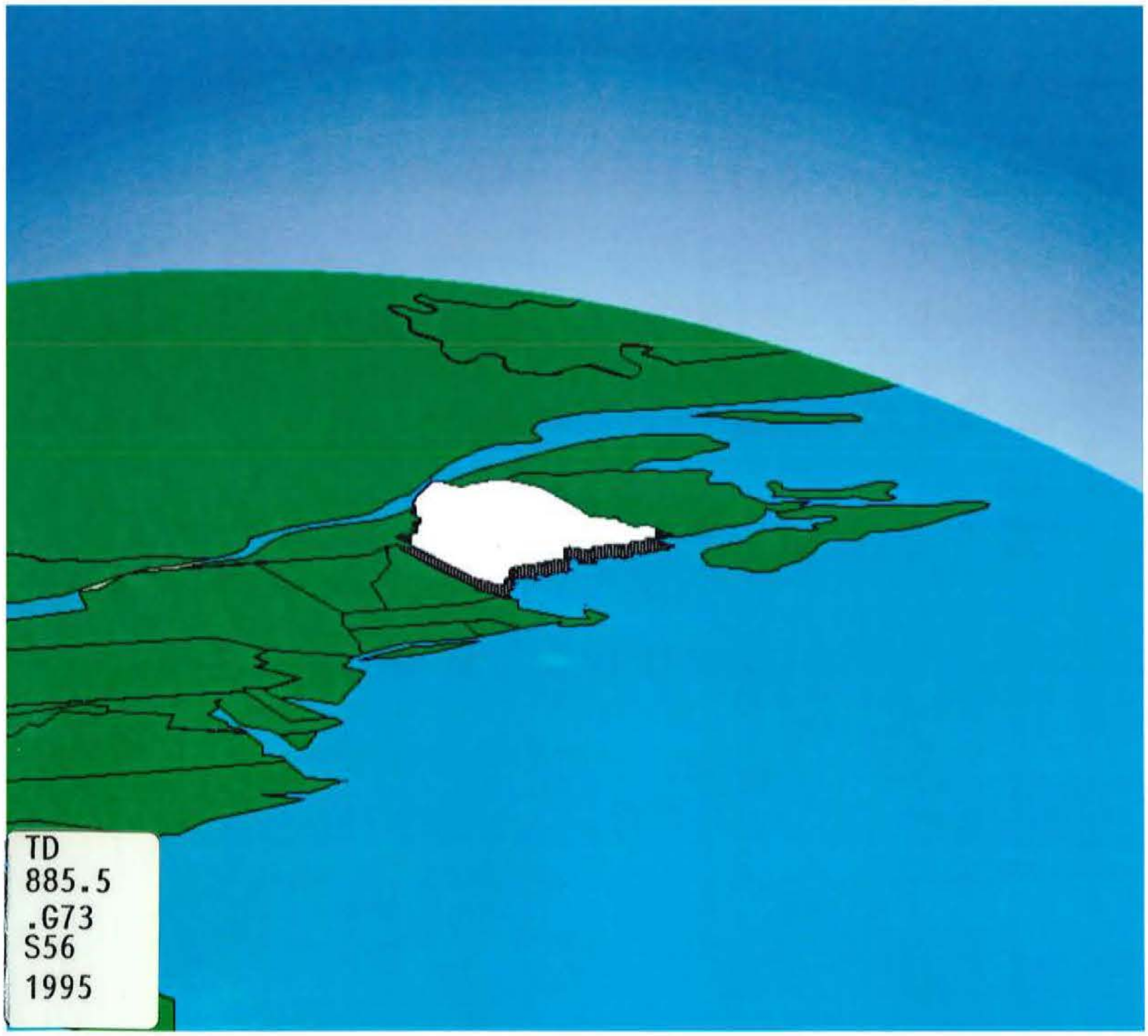
Maine's Greenhouse Gas Emissions

Inventory for 1990



Maine State Planning Office

University of Maine

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A Report on

Maine's Greenhouse Gas Emissions:

Inventory for 1990

June 1995

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EXECUTIVE DEPARTMENT
STATE PLANNING OFFICE

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GREENHOUSE GAS INVENTORY REPORT

STATE OF MAINE

AUGUST 1995

INTRODUCTION

This inventory is the result of a cooperative effort between the State Planning Office and the Margaret Chase Smith Center for Public Policy. Its completion marks an important juncture between understanding greenhouse gas emissions and determining Maine's appropriate response to global climate change. Sound planning must have, as its foundation, good information. The inventory in this report provides the basis for formulating opinions, making decisions, and identifying opportunities for change.

The question of climate change and its cause has been the source of debate for some time. While the absolute impact human activities are having on our global climate will continue to be debated, there is little question that carbon dioxide levels are increasing significantly and that this increase is largely due to our reliance on fossil fuels. Evidence grows that global warming is and will continue to be one of the results.

In reading through the notes compiled by members of the Climate Change Task Force, a diverse membership, I found a reflection of the many reasons we are all at the table to learn more about climate change and greenhouse gas emissions here in Maine. I share with you a few comments made by members of the Task Force when asked why they felt it was important to participate.

* Environmental policy making too often develops into a polarized debate. Especially in light of the changing political landscape. I believe it is important to sustain an ongoing dialogue with diverse groups on a variety of issues. My participation in the Climate Change Task Force is intended to offer constructive input from the business community on an important environmental issue.

* Climate change is not only about now, it's about the future. The legacy we leave our children has much to do with how well and how earnestly we wrestle with the current problems that have long-term effects.

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* Phase I (inventory) establishes the foundation which will influence the direction we choose to move to address greenhouse gas emissions and climate change. The collaborative process we have used to date holds great promise towards helping us to find ways to reduce greenhouse gasses which will also create jobs and stimulate the Maine economy. Advanced technology already offers a number of solutions to the problem. We need to be thinking ahead, identifying opportunities for Maine and for the country and we need to be aggressive and innovative in capturing this green production for Maine.

* The Maine business community has a significant interest in all environmental issues; climate change is a topic that will impact Maine businesses in the years ahead. My presence is intended to serve as a two-way conduit, for information coming out of the task force for the larger business community to digest, and as an opportunity for the business community to voice its perspectives on the issue to other task force members.

* The United States signed the Framework Convention on Climate Change in 1992 and President Clinton urged all citizens to participate in the U.S. Climate Change Action Plan. Maine, therefore, should do its part.

As Director of the State Planning Office, the lead State agency coordinating Maine's activities relating to climate change, I take great pleasure in presenting Maine's Greenhouse Gas Inventory Report.

Evan D Richert

Evan D. Richert, Director
State Planning Office

gasintro.

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Executive Summary

Introduction

Concentrations of greenhouse gases in the atmosphere are increasing worldwide. The concentration of carbon dioxide (CO_2), for example, has increased by 25% in the last century. The presence of greenhouse gases (e.g., CO_2, methane, nitrous oxide, ozone and chlorofluorocarbons) in our atmosphere cause what is referred to as the greenhouse effect, a natural mechanism that keeps our planet warm.

However, elevated levels of greenhouse gases may cause global warming or other types of global climate change that could result in melting of polar ice caps, loss of biodiversity, sea level rise, change in precipitation distribution, increased storm frequency and intensity or changes in cloud cover. Because of these potential impacts, nations from around the world are taking a serious look at how cooperative research and planning may address greenhouse gas emissions.

Maine, along with the U.S., is responding to this complex challenge. A necessary first step towards managing our greenhouse gas emissions is to inventory them. We must know what our emissions are and from what sources and activities they are derived. Maine has extensive information on some air pollutants, such as ozone, volatile organic compounds and nitrogen oxides. While these have been studied extensively because of their potential effects on public health, little attention has been given to the three major greenhouse gases: CO_2, methane and nitrous oxide. This inventory provides that information.

The methods used to estimate emissions in Maine come from the *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (E.P.A. 1995). The methods and calculations therein are based on the most current and widely accepted scientific procedures. This inventory focuses on the three major greenhouse gases and uses 1990 as the base year

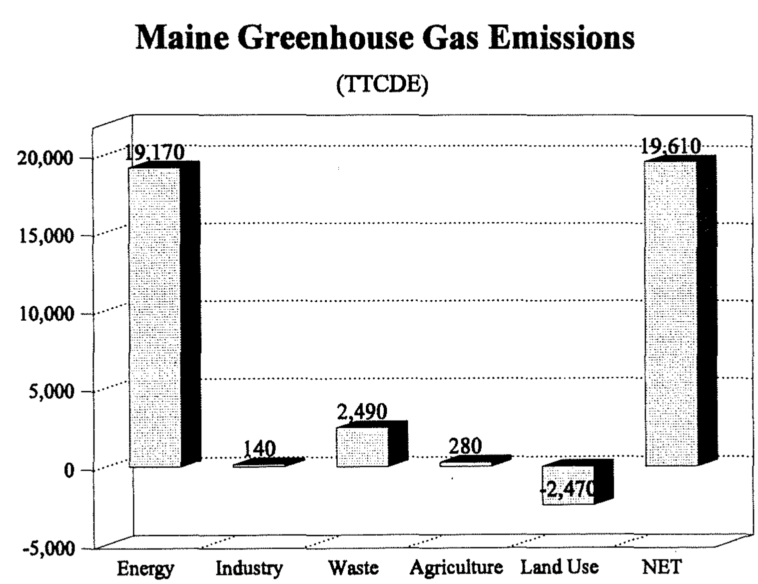

Figure ES-1

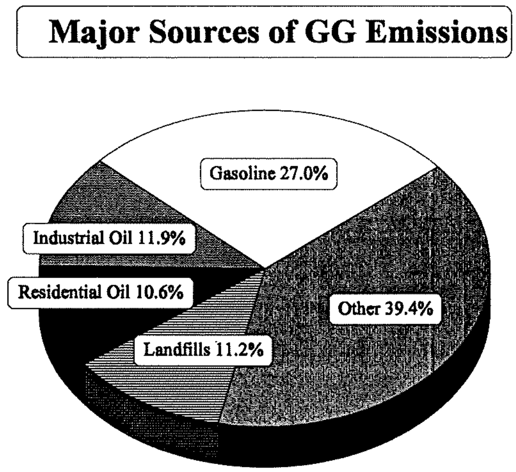

Figure ES-2

Maine Emissions

Total greenhouse gas emissions from all Maine sources in 1990 was 22,080 thousand tons of carbon dioxide equivalents (TTCDE). Maine forests acted as a CO_2 sink by absorbing 2,470 TTCDE. Thus, net emissions of greenhouse gases from Maine in 1990 were 19,610 TTCDE (Figure ES-1). This was less than 0.4% of the net U.S. emissions in 1990 (5,295,000 TTCDE).

Not surprisingly, activities involving Energy Use, namely the generation of CO_2 by the combustion of fossil fuels, were responsible for the majority of the total greenhouse gas emissions (87%). Waste management activities (primarily landfills) that produced methane were the second largest source of greenhouse gas emissions (11% of the total). Industrial (non-energy related) and Agricultural activities were minor sources of emissions.

Other Important Findings

♦ Per capita greenhouse gas emissions in Maine (16 TCDE) were slightly lower than the U.S. average (21 TCDE).

♦ Unlike the U.S. as a whole, Maine's Utility sector was a minor contributor to Energy Use emissions because of its reliance on nuclear, hydro and biomass power.

♦ Nearly half of the Energy Use emissions came from the Transportation sector.

♦ The single largest source of greenhouse gas emissions from Maine was gasoline consumption, which alone contributed 27% of the total emissions. The second largest source (12%) was residual oil use for the Industrial sector's power generation. The third largest source (11%) was distillate oil (home heating oil) use in the Residential sector. These three sources combined were responsible for 50% of the total emissions (Figure ES-2).

♦ Maine forests were a net sink for CO_2 in 1990. In the long term, their impact on reducing Maine greenhouse gas emissions will vary over time depending on a variety of factors. These include forest structure, management and use of wood as a power source in lieu of fossil fuels.

Accuracy of Emission Figures

It is important to remember that the measurement of gaseous emissions, originating in the relatively uncontrolled environments typical of natural and man-made emissions sources, is not a precise science. That is not to say the figures presented in this report are inaccurate. The task force felt that it would be appropriate to indicate the measure of confidence attached to the various estimates included in this report. Overall, using the state-of-the-art, standardized protocol recommended by the Intergovernmental Panel on Climate Change (IPCC 1994), the results are the best available estimates.

A Stepping Stone to Phase II - Policy to Address the Emissions Issue

This Phase I Inventory provides us with a solid foundation from which to develop greenhouse gas emission long-range forecasts for Maine and to identify policy options and implementation opportunities aimed at reducing emissions. From the inventory we will launch into the identification, evaluation and feasibility assessment of a variety of state mitigation strategies. This will set the stage for public input and review and the development of a State Action Plan. It is the hope of the State Climate Change Task Force that the plan will offer Maine a unique opportunity to not only reduce greenhouse gas emissions, but to develop a Maine economy around exporting the technology that other states will need in order to implement similar plans.

1. Introduction

Background

Smog, ozone, carbon monoxide, radon, smoke. These are all commonly-known air pollutants that directly affect human health. Some of them are easy to detect and their effects on our health can be measured. There are other types of air pollutants that may not be a direct health threat, yet through their effects on our environment, pose a very real threat to our society. The effects of these pollutants on the environment are not easy to detect or predict. One class of these air pollutants is called *greenhouse gases* and they are responsible for the Greenhouse Effect.

What is the Greenhouse Effect?

The Greenhouse Effect is a natural phenomenon that keeps our planet warm. It gets its name from glass greenhouses, which have a similar warming mechanism. Solar energy warms the plants and soil in the greenhouse and the glass roof holds in that heat energy. The same principles work inside a car that is parked in the sun. Similarly, certain gases in our atmosphere (like carbon dioxide) absorb heat energy and prevent it from escaping into space. Without these greenhouse gases, the average world temperature would be 55°F lower!

What is a greenhouse gas?

Greenhouse gases occur naturally and have always been a part of the earth's atmosphere. A greenhouse gas is one that absorbs radiant heat energy. Some examples are carbon dioxide (CO_2), methane, nitrous oxide, ozone and chlorofluorocarbons (CFC's). Water vapor is also a greenhouse gas, but it is much too abundant for humans to manage. Not all greenhouse gases are equal. For example, a molecule of ozone absorbs 2,000 times as much heat energy as a molecule of CO_2 (see Special Focus 2). However, CO_2 has more of an influence on the Greenhouse Effect because it is much more abundant in the atmosphere than ozone. CFC's are the only greenhouse gases that are produced solely by humans. All other greenhouse gases have both natural and human sources.

Why are we concerned about the Greenhouse Effect?

Human activity has caused significant increases in most greenhouse gases in the past 100 years. The CO_2 concentration in the atmosphere is increasing exponentially at a rate of 0.5 % per year[1], mainly as a result of fossil fuel combustion and deforestation (Bolin 1986). Methane concentration is increasing even faster (1% per year) because of increases in fossil fuel combustion, number of landfills, and cattle production (Cicerone and Oremland 1988). Atmospheric nitrous oxide concentration is increasing at a rate of 0.2% per year mainly from fertilizer use and fossil fuel combustion (Kroeze 1994).

These additional, human-derived greenhouse gases cause an Augmented Greenhouse Effect. Scientists agree that this Augmented Greenhouse Effect will have an impact on global climate, although there is no consensus on the exact nature and extent of the damage. Potential environmental impacts include global warming, loss of biodiversity, melting of polar ice caps, sea level rise leading to loss of coastal habitats, alteration of precipitation patterns, increased storm frequency and intensity, reduced soil moisture and changes in cloud cover (Manabe and Wetherald 1985, Pastor and

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[1] In the equation $C_t = C_o e^{rt}$, C_t is the concentration of CO_2 at time t, C_o is the initial concentration, and r is the growth rate.

Post 1988, Overpeck et al. 1990, 1991). Such extensive climatic changes will in turn affect many aspects of our society: agriculture, forestry, water demand and use, international trade, economics, energy demand and others.

As a result of these risks, many nations of the world, including the United States, have committed themselves to limiting emissions of greenhouse gases in an effort to put off or prevent these consequences. Furthermore, the Clinton Administration has issued a challenge to the states to do their part in this global effort (Clinton and Gore, 1993)

To that end, the Maine State Planning Office has organized a Climate Change Task Force whose purpose is to address the issue of greenhouse gas management. Several key organizations are represented on the Task Force including Maine Department of Environmental Protection, Maine Public Utilities Commission, Maine Department of Transportation, Maine Chamber of Commerce and Industry, Natural Resources Council of Maine and the Margaret Chase Smith Center for Public Policy.

In order to make decisions about managing greenhouse gases in Maine, we must first inventory the emissions and identify sources and sinks of greenhouse gases.

The objective of this inventory was to quantify the major emissions of greenhouse gases from Maine in 1990. This is the first inventory of its kind and will serve as the baseline reference with which to compare future inventories. It will serve as an information source for citizens and legislators alike as they struggle with issues of greenhouse gas management and climate change. It will also become part of the national greenhouse gas emission inventory which will allow us to compare Maine's emissions with those from other states.

Approach

To estimate emissions we used the standardized protocol recommended by the Environmental Protection Agency in the *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (1995). The methods are based on those developed by the Intergovernmental Panel on Climate Change (IPCC 1994).

The general procedure entails first determining which of the major greenhouse gas-producing activities occur within the state. Then data is collected that represents the level of each of those activities in the state. The activity level is multiplied by an emissions factor that represents the amount of greenhouse gas generated per unit activity.

The accuracy of the estimates is limited by the availability of appropriate information as well as our knowledge of the emission factors for specific activities. There is an urgent need for more research in this area and more detailed assessments of Maine's natural resources and economic activities.

Not all fluxes and transfers of carbon are documented in this inventory. Only those that are derived from human activity and that can be managed or manipulated by humans. For example, water vapor in the atmosphere acts as a greenhouse gas, but it would be impossible to manage or regulate the ubiquitous sources of this gas, so it is not included in this inventory. Another example is the natural flow of carbon to and from wetlands. Each year CO_2 is removed from the atmosphere and stored in plant biomass. At the same time wetlands release CO_2 and methane from decomposition of organic matter. These natural fluxes have always existed and provide us with the natural greenhouse effect that keeps the earth warm and so are not included in this inventory (see Special Focus 1). However, if the amount of greenhouse gas emissions from wetlands increased above the natural level because of human activity, then it would be contributing to the Augmented Greenhouse Effect. These deviations from natural emissions would be included in the inventory.

Our goal was to quantify those fluxes that contribute to the Augmented Greenhouse Effect. So we have quantified four types of processes:

[1] processes that transfer C from permanent storage into the global C cycle as CO_2 or methane (e.g., fossil fuel combustion and cement production),

[2] processes that transfer C from long-term storage into the global C cycle as CO_2 and methane (e.g., forest conversion, wetland conversion and C storage by forests),

[3] processes that convert atmospheric CO_2 into methane (e.g., landfilling, animal production, manure management and crop burning),

[4] processes that convert various forms of N into nitrous oxide (e.g., fertilizer use and crop burning).

These types of processes are evaluated in this report because they represent either direct additions of greenhouse gases to the atmosphere (#'s 1, 2 and 4 above) or conversions of weaker greenhouse gases into stronger greenhouse gases (#3 above).

Let's discuss some examples of these processes. Combustion of fossil fuels is a relevant process because it takes C that has been stored in the earth's crust for millions of years and releases it into the atmosphere as CO_2 and methane. This is an absolute increase in both atmospheric CO_2 and methane. In contrast, CO_2 release from combustion of biomass, such as a tree, is not a relevant process because the C in the tree was already a part of the global C cycle. Although this CO_2 will temporarily increase the atmospheric CO_2 concentration, it will eventually be reabsorbed by the growing tree that replaced the burned tree. Thus, the tree is considered a renewable C source.

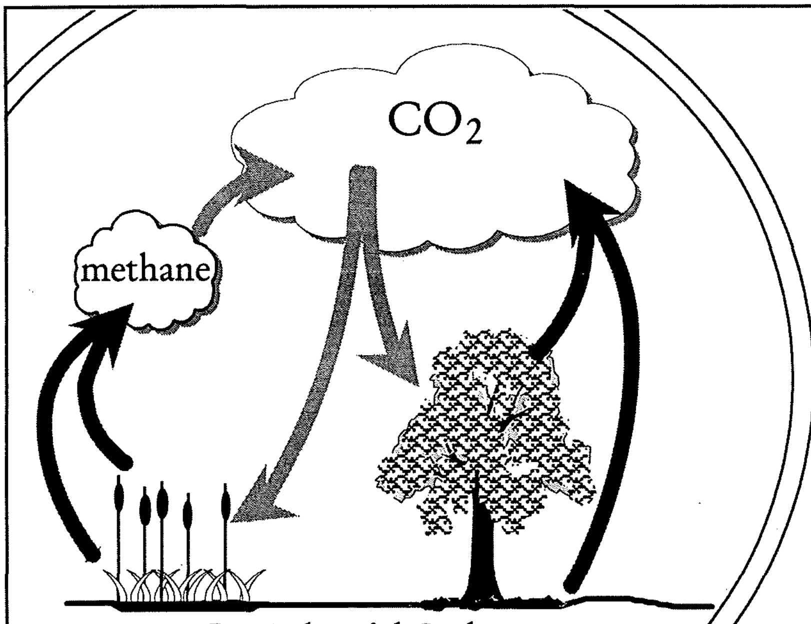
Methane has a greater global warming potential than CO_2 (see Special Focus 2), therefore, any process that converts CO_2 into methane will tend to increase the greenhouse effect. Grazing animals, such as cattle, consume plant carbon that normally would have decomposed naturally into CO_2, and convert a portion of that C into methane. In this way the human activity of animal production has contributed to the Augmented Greenhouse Effect.

In Chapter 2 the state emissions are summarized and compared with the U.S. as a whole. In chapters 3 through 7, the different sources of greenhouse gases are described and discussed in detail. The Glossary defines many of the terms used in this Inventory. Appendix A contains detailed descriptions of the calculations as well as sources of information. Confidence levels for the emission estimates are listed in Appendix B. Appendix C contains a list of references that could be used by other state or local governments for constructing their own greenhouse gas inventory.

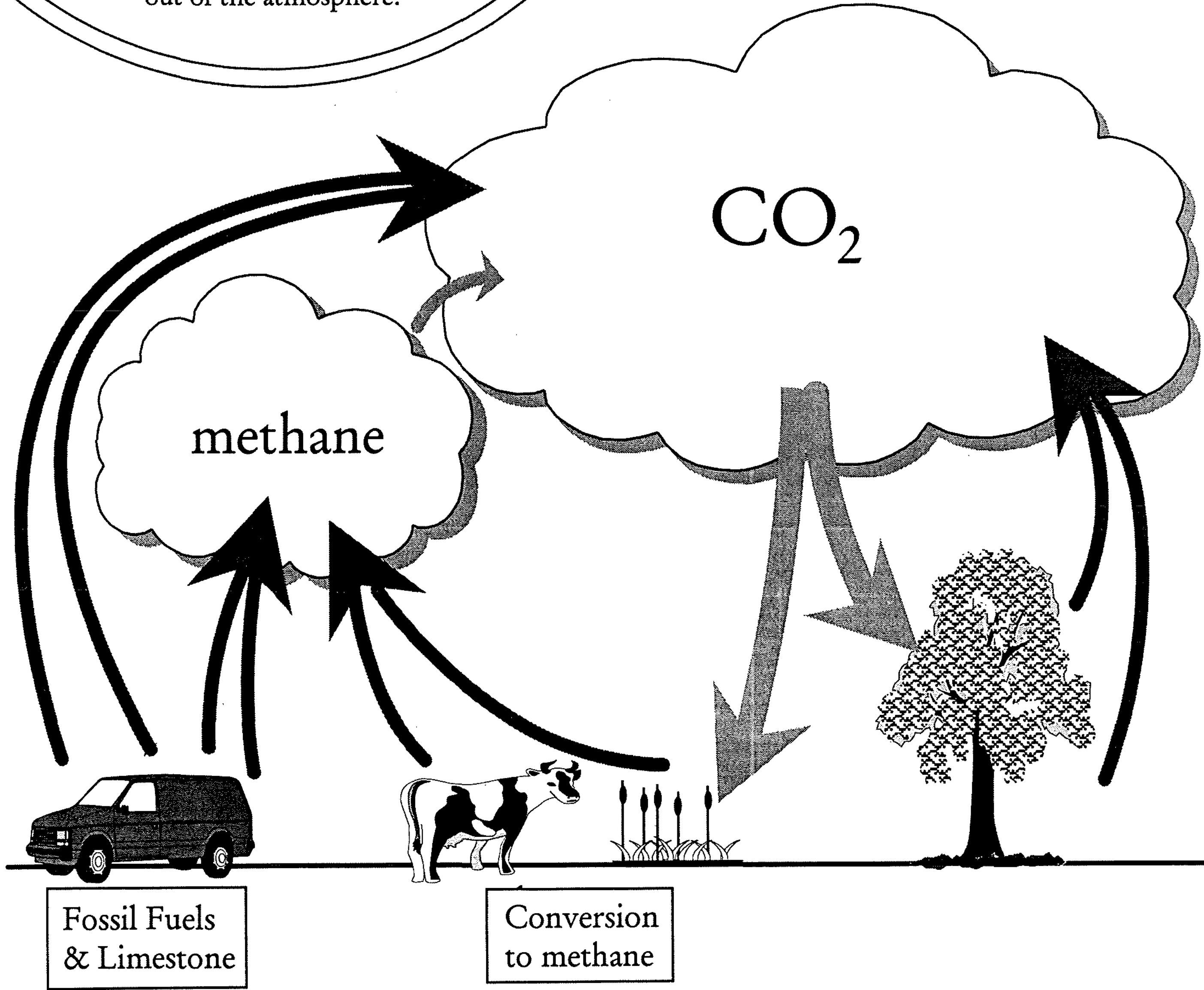
Special Focus 1:
The Global Carbon Cycle

Atmospheric CO_2 is absorbed by plants and transformed into organic C during photosynthesis. When plants die and decompose, organic carbon is transformed into either CO_2 or methane once again. Carbon cycles through the biosphere and is transformed along the way.

Up until the past century the cycle was balanced. Currently, the carbon cycle is out of balance. Human activity has caused two important changes: (1) the addition of "fossil" carbon to the global cycle from fossil fuel combustion and limestone use, and (2) increased conversion of organic C to methane instead of CO_2.



Pre-Industrial Cycle:
Fluxes into the atmosphere balanced fluxes out of the atmosphere.



2. Maine Emissions

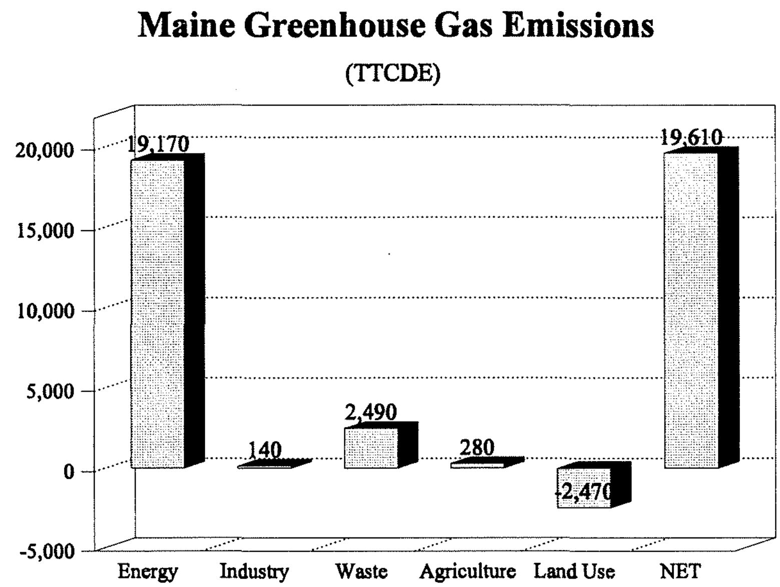


Figure 2-1

Greenhouse gas (GG) emissions from Maine in 1990 totaled 22,080 thousand tons carbon dioxide equivalents (TTCDE; see Special Focus 2). Maine forests acted as a net sink for atmospheric CO_2 by storing 2,470 TTCDE. So the net contribution to the Greenhouse Effect by Maine in 1990 was 19,610 TTCDE (Figure 2-1). Emissions were partitioned into five source categories: Energy Use (fossil and biomass fuel consumption), Industrial processes (cement manufacture), Waste Management (landfills and wastewater treatment), Agricultural practices (animal and manure management, fertilizer use and crop burning), and land use (forest C storage, forest and wetland conversion). Energy Use was the greatest source of emissions, contributing 19,170 TTCDE or 87% of total emissions (Figure 2-1). Waste management was the second greatest source, supplying 11% of the total emissions. Industrial and Agricultural activities were minor sources of emissions. Calculation methods, data and data sources are detailed in Appendix A.

Comparisons with the U.S.

Net U.S. emissions in 1990 have been estimated as 5,819,000 TTCDE by the Energy Information Administration (EIA 1994) and as 5,295,000 TTCDE by the Environmental Protection Agency (U.S.E.P.A. 1994). Maine's net emission of 19,610 TTCDE was 0.34% and 0.37% of these estimates, respectively. Results from U.S.E.P.A. are directly comparable to results from Maine because similar methods were used in developing both of these inventories. On a per capita basis, Maine emissions were 16 tons of CO_2 equivalent (TCDE) per person compared to 21 TCDE per person in the U.S. as a whole.

Dividing the emissions into sources reveals some interesting comparisons (Figure 2-2). Energy production as a fraction of total

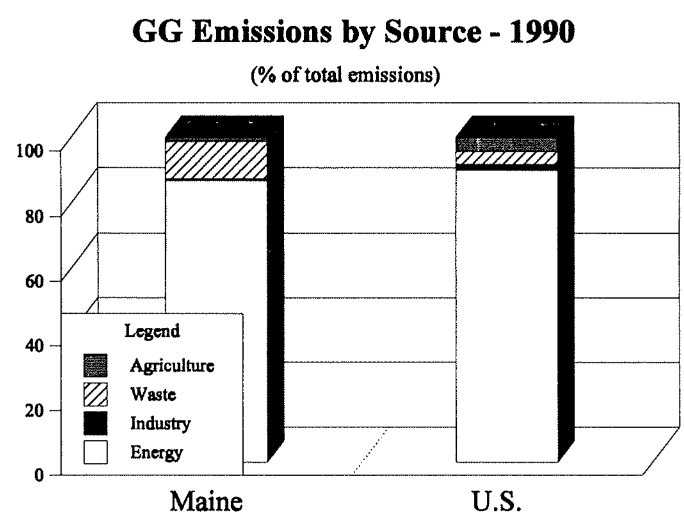


Figure 2-2

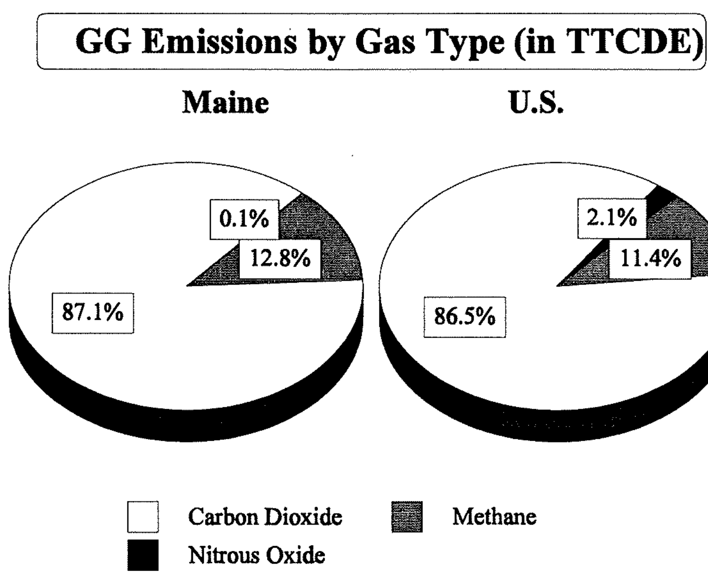


Figure 2-3

emissions (not including Land Use) was similar in Maine and the U.S. (87% vs. 90%, respectively). Emissions from Waste Management in Maine were relatively larger (11%) than in the U.S. (4%). On the other hand, Agriculture emissions made up a smaller fraction of Maine emissions (1%) than in the U.S. (4%). Industry percentages were similar. Land Use was a sink in both Maine and the U.S. and reduced total emissions by 11% and 8%, respectively.

Overall, emissions were dominated by CO_2 (Figure 2-3). It was the largest contributor to emissions in both Maine (87%)

Special Focus 2:
Measuring Amounts of Greenhouse Gases

How do you weigh a gas?

We don't weigh it directly. CO_2, for example, is one part of air along with oxygen and nitrogen gases. Although we can weigh air, we cannot weigh just the CO_2 portion. However, it is easy to determine the weight of gas emissions.

For example, we can weigh a piece of firewood and estimate the weight of carbon in that wood (dry wood is approximately 50.0% C by weight). When the wood is burned, we know that 90% of the C that was in the wood is converted to CO_2. The remaining 10% is converted to methane, carbon monoxide or soot. So if the wood originally weighed 10 lbs, we know that it contained 5 lbs of carbon and that 4.5 lbs of carbon was emitted in the form of CO_2 during combustion. CO_2 weighs 3.67 times as much as C, so the weight of CO_2 emissions from that firewood equals 16.5 lbs.

What is Global Warming Potential?

Our ultimate goal is to determine how much the Greenhouse Effect is being augmented by the emission of anthropogenic greenhouse gases from Maine. However, the ability of greenhouse gases to absorb heat energy varies among gases. Some have a greater ability to absorb heat energy and warm the atmosphere than others; that is, there are strong and weak greenhouse gases. So instead of measuring greenhouse gases by weight, we convert them into units of global warming potential (GWP). Using a common metric (in this case we will be using thousand tons of CO_2 equivalents or TTCDE) allows us to more easily compare the effects of weak and strong greenhouse gases on the Greenhouse Effect.

The amount of heat energy absorbed by a greenhouse gas while it is in the atmosphere depends on (1) its chemical properties, (2) its residence time in the atmosphere and (3) the strength of any indirect effects.

Let's take methane as an example. Because of its chemical properties, one ton of methane absorbs 35 times as much heat energy as one ton of CO_2. However, methane has a shorter residence time in the atmosphere than CO_2 because it is a less stable molecule. So over the next century, one ton of methane emitted now will only absorb 11 times the heat energy as one ton of CO_2. Indirect effects are also important. For example, methane reacts with NO_x and oxygen to form ozone, another greenhouse gas. Thus, in addition to its direct effects on the greenhouse effect, methane may also have indirect effects by influencing the concentrations of other greenhouse gases.

So the actual GWP of one ton of methane is estimated to be 22 times that of one ton of CO_2. Using this conversion factor for methane we can convert tons of methane emissions into carbon dioxide equivalents.

and the U.S. (86%; Figure 2-3). Methane was the next largest component of emissions. It was 13% of the emissions in Maine and 11% of emissions in the U.S. Nitrous oxide made up less than 1% of Maine emissions and 2% of U.S. emissions.

3. Energy Use

Introduction

This chapter describes the CO_2 and methane emissions from fossil fuel combustion and methane emission from biomass burning. CO_2 emission from biomass burning is not included in the calculations because biomass is a renewable source of C (see explanation in Chapter 1).

During combustion, most of the carbon that is contained in fossil fuels is converted into CO_2 and released into the atmosphere. Inefficiencies in the combustion reaction prevent complete oxidation of all carbon into CO_2. A small fraction of the carbon is released as methane. Both of these releases represent an addition of carbon to the global carbon cycle. Other greenhouse gases are also produced and emitted during combustion of fossil fuels including carbon monoxide (CO), various nitrogen oxides (NO_x) and volatile organic carbon (VOC). Although, these trace gases are important contributors to urban smog, they are not included here because either they exert only indirect effects on the global warming potential or there is not enough information on their emission rates. The effect of these trace gases on the greenhouse effect is expected to be much less than that of either CO_2 or methane.

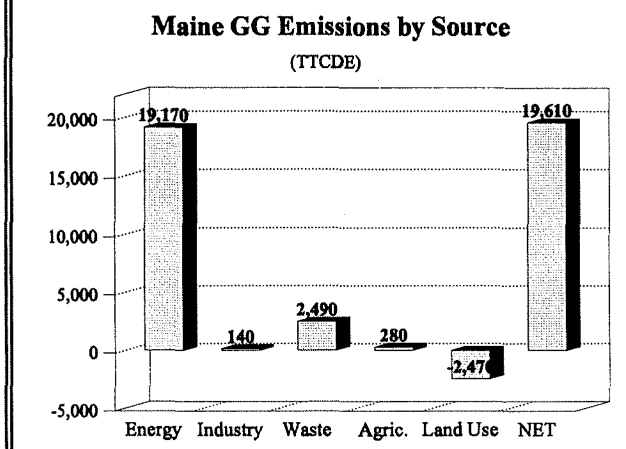


Figure 3-1

CO_2 Emission from Fossil Fuel Combustion

CO_2 emission from fossil fuel combustion was 19,090 TTCDE in 1990 which was 99% of emissions from Energy Use. Emissions were subdivided by sector and fuel type to provide a more complete picture (Figure 3-2 and Table 3-1).

Residential fossil fuel use (2,890 TTCDE) was 15% of total fossil fuel CO_2 emissions and the majority of that (2,340 TTCDE) was in the form of distillate oil (home heating oil). Other minor contributions were made by LPG, kerosene, coal and natural gas consumption.

The Commercial sector accounted for only 8% of the fossil fuel CO_2 emissions - the least of all five sectors (1,490 TTCDE). The fuel type with the highest level of emissions in this category was distillate oil (783 TTCDE). Residual oil was the next highest (468 TTCDE) and other fuel types were of less importance.

Industrial consumption of fossil fuels made up 20% of total fossil fuel CO_2 emissions (3,770 TTCDE). Residual oil was the dominant fuel type used (2,620 TTCDE) but coal and distillate oil contributed significant amounts as well (559 and 327 TTCDE, respectively).

The Transportation sector was the largest contributor, making up 47% of the total fossil fuel CO_2 emissions (9,010 TTCDE). Of the fuel types within Transportation, gasoline had the greatest emissions (5,930 TTCDE). Jet fuel and diesel fuel were also significant sources of emissions (1,110 and 1,830 TTCDE, respectively).

The Utility sector contributed 10% of the total fossil fuel CO_2 emissions (1,930 TTCDE). The only fossil fuel used to a

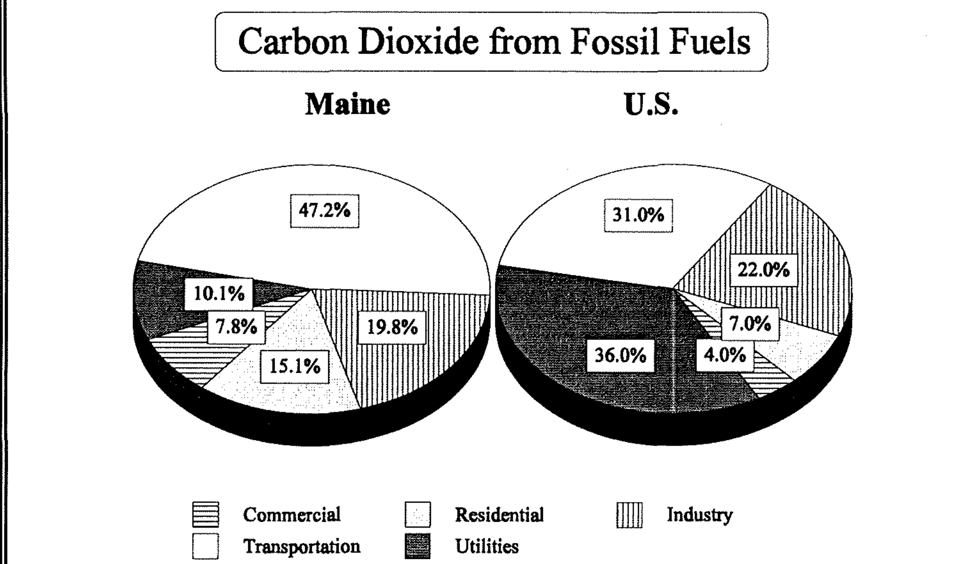


Figure 3-2

significant extent in this sector was residual oil.

When Maine sector emissions are compared with U.S. sector emissions, some interesting differences become apparent (Figure 3-2). The Utility sector comprised 36% of U.S. emissions but only 10% of Maine emissions. One explanation for this is that fossil fuels account for only 9% of Maine's energy mix (Maine State Planning Office, 1992, Table 12). The balance comes from roughly equal percentages of nuclear, hydroelectric and biomass. The latter employs a renewable C source and nuclear and hydroelectric methods produce no emissions. In contrast, the U.S. uses fossil fuels to satisfy 69% of its electricity demand (Resource Data International, 1995)

Percentage Residential emissions were somewhat greater in Maine than in the U.S. (15% compared to 7%, respectively). This may stem from the winter heating requirements of a cold climate. The percentage emissions from the Commercial and Industrial sectors are both similar in Maine and the U.S. Commercial sources are responsible for about one-sixteenth of the emissions and Industry about one-fifth.

The Transportation sector contributions were quite different. Maine's Transportation sector contributed a larger fraction of total emissions (47%) than in the U.S. as a whole (31%). One explanation for this difference is the low density of settlements in Maine that lead to longer travel distances. A second explanation is that the Transportation sector seems relatively larger in Maine simply because the Utility sector is relatively smaller.

<u>Methane Emissions from Fossil Fuel and Biomass Combustion</u>

Methane emission from fossil fuel consumption (85 TTCDE) was less than 1% of total Energy Production emission and 2% of total methane emissions in Maine. The sector with the greatest methane emissions was the Residential sector (32 TTCDE). Wood was the most important fuel type (29 TTCDE) highlighting the inefficiency of combustion in most residential wood stoves and fireplaces. The Transportation sector was the second highest methane emitter (23 TTCDE) and most of that (21 TTCDE) was from gasoline combustion. The next highest methane emission was from the Utility sector (19 TTCDE), specifically the biomass burning power plants. Although these plants have much greater combustion efficiency than residential woodstoves, they consumed substantially more wood than the residential sector (see Table A.3. in Appendix A). The Commercial and Industrial sectors had relatively low methane emission rates mainly because little wood was consumed.

CO_2 Production from Renewable C sources

As stated earlier, CO_2 production from burning of biomass fuels is not included in the inventory because it does not contribute to the Augmented Greenhouse Effect. When a tree is cut and burned, the CO_2 that is released will eventually be reabsorbed by the tree that grows to take its place. Nevertheless, it is useful to document the quantity of CO_2 produced by these processes in case we decide to change these C flow patterns. For instance, if incineration of municipal solid waste (MSW) were discontinued, then that C flow would likely be diverted to landfills. Knowing how much C is currently incinerated, we are better able to predict the consequences of diverting that C flow into landfills.

Biomass fuel consumption produced a total of 6,960 TTCDE of CO_2 emissions, which is equal to about one-third of the total CO_2 produced by fossil fuel combustion (Table 3-2). Wood burning was the largest component of biomass fuel, contributing 6,740 TTCDE. The Utility sector was the largest consumer of wood and produced 60% of the CO_2 from all wood burning (4,060 TTCDE). Incineration of paper mill sludge and MSW produced much smaller amounts of CO_2 (50 and 180 TTCDE, respectively).

Table 3-1. Energy Use Emissions.

Sector/Fuel	CO_2 Emissions (TTCDE)	Methane Emissions (TTCDE)
RESIDENTIAL		
Distillate	2,340	3.5
LPG	213	0.1
Kerosene	253	n.e.
Coal	46	n.e.
Natural Gas	38	0.0
Wood	*	28.8
SUBTOTAL†	**2,890**	**32.4**
COMMERCIAL		
Distillate	783	0.1
Residual	468	0.2
LPG	40	0.0
Gasoline	39	n.e.
Coal	61	0.1
Natural Gas	95	0.0
SUBTOTAL	**1,490**	**1.0**
INDUSTRIAL		
Distillate	327	n.e.
Residual	2,620	2.1
LPG	89	n.e.
Kerosene	16	n.e.
Motor Gasoline	39	n.e.
Coal	559	0.3
Natural Gas	116	0.1
Wood	*	7.2
SUBTOTAL	**3,770**	**9.7**
TRANSPORTATION		
Gasoline	5,930	21.0
Aviation fuel	30	0.6
Jet fuel	1,100	0.7
Diesel fuel	1,830	1.0
Lubricants	32	n.e.
Residual oil	77	n.e.
SUBTOTAL	**9,010**	**23.3**
UTILITIES		
Distillate	9	0.0
Residual	1,920	0.4
Wood	*	18.2
SUBTOTAL	**1,930**	**18.6**
TOTAL	**19,090**	**85**

† subtotals and total have been rounded.
* = not included. See text for explanation.
n.e. = no estimate available

Table 3-2. CO_2 Production from Combustion of Renewable C Sources (Biomass)

Fuel/Sector	CO_2 Production (TTCDE)
WOOD	
Residential	1,260
Industrial	1,420
Utilities	4,060
SUBTOTAL	**6,740**
WASTE INCINERATION	
Paper mill sludge	50
MSW*	180
SUBTOTAL	**220**
TOTAL	**6,960**

* municipal solid waste

Notes

Estimates of emissions from fossil fuel combustion were based upon records of fossil fuel consumption (i.e., sales) in Maine, including fuel that was imported and excluding fuel that was exported. Whether or not the fuel was actually combusted within state boundaries is not pertinent because management of greenhouse gas emissions is most likely to occur at the level of the consumer.

Emissions from biomass fuels (i.e., wood and waste) were estimated from biomass consumption in Maine, including imports and excluding exports. Maine's wood-to-energy plants imported about half of their wood chips (Forest Information Center 1992). Biomass consumption by an industry that was used to produce electricity for sale to utilities (e.g., burning of sawdust at lumber mills for cogeneration of electricity) was included under the Utility sector. Stand-alone biomass power plants were also included in the Utility sector. All other industrial consumption of biomass was placed under the Industrial sector.

4. Industrial Processes

Some industrial processes can lead to emissions of greenhouse gases over and above those generated by fossil fuel use. Some examples of industrial processes that produce significant amounts of emissions in the United States are: aluminum production, CO_2 manufacture, soda ash manufacture and cement production. Cement production was the only industrial process assessed in this inventory, although there may be others in the state.

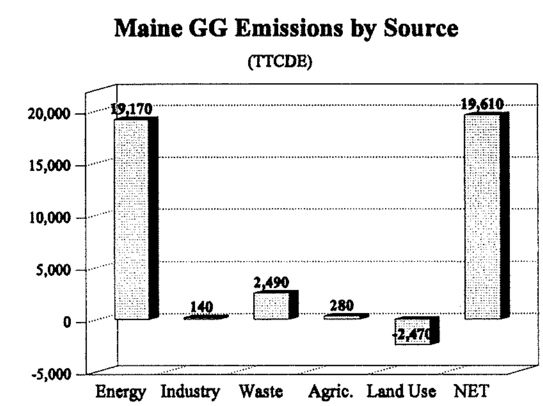


Figure 4-1

Cement Production

CO_2 is generated during the process of making cement clinker. In this process, limestone (calcium carbonate) is heated to form calcium oxide and CO_2. In 1990, the production of 285,900 tons of clinker in Maine led to 140 TTCDE of CO_2 emissions (Figure 4-1). This was less than 1% of net greenhouse gas emissions from the state.

5. Waste Management

This chapter includes estimates of methane emissions from landfilled wastes and sludges. Landfills can be large sources of methane because of the anaerobic conditions that exist. In fact, methane is generated in such large quantities that it can be recovered from landfills and used to generate electricity. The amount of methane generated is difficult to predict because it depends on the quantity of waste, its carbon content, microbial efficiency and environmental factors such as temperature and moisture. Data from 1991 were used because data from 1990 were not available.

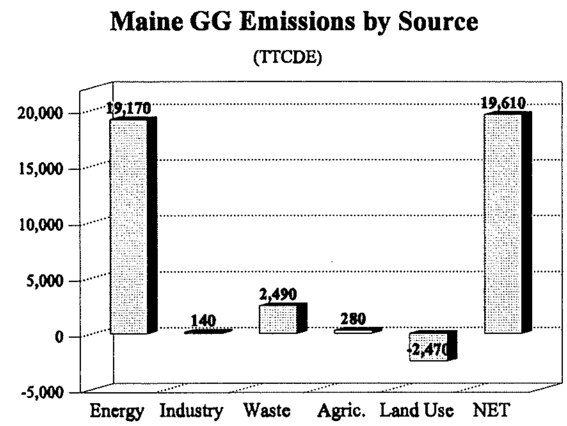


Figure 5-1

Methane from Landfills

Emissions from Waste Management was 2,490 TTCDE or 11% of total greenhouse gas emissions (Figure 5-1). Methane emission from Residential sector waste was 22% of Landfill emissions (Figure 5-2, Table 5-1). Landfilled municipal solid waste (MSW) made up the majority of the Residential emissions (500 TTCDE) compared to landfilled sludge from wastewater treatment plants (30 TTCDE).

The Commercial sector contributed 25% of the Landfill emissions, most of which was from MSW (560 TTCDE) and a smaller amount from wastewater sludge (30 TTCDE).

Waste from the Industry sector, which was represented by pulp and paper mill waste, emitted 53% of the Landfill emissions (1,360 TTCDE). Landfilled sludge was responsible for 810 TTCDE and MSW-like waste for 550 TTCDE.

Table 5-1.
Waste Management Emissions

	Methane Emissions (TTCDE)
LANDFILLS	
Residential	
MSW	500
Wastewater sludge	30
Subtotal	**580**
Commercial	
MSW	560
Wastewater sludge	30
Subtotal	**630**
Industrial*	
MSW-like waste	550
Sludge	810
Subtotal	**1,360**
Landfilled Subtotal	**2,470**
WASTEWATER	
Treatment Systems	20
Subtotal	**20**
TOTAL	**2,490**

*(pulp and paper mills)

Methane from Wastewater Treatment Systems

Wastewater treatment plants, sewers and septic systems all have the potential to

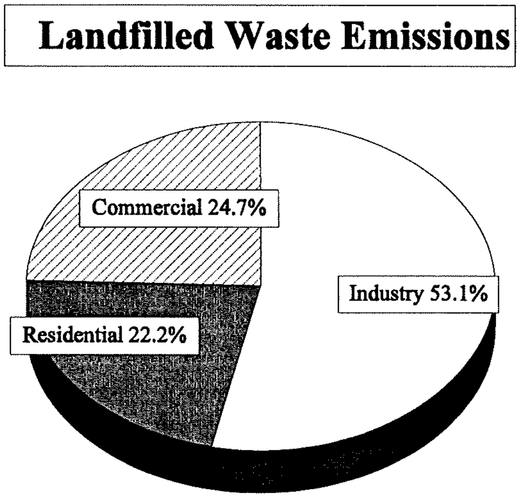


Figure 5-2

Table 5-2.

CO_2 Production from Landfilled Waste

	CO_2 Production (TTCDE)
Residential	760
Commercial	730
Industrial	1,700
TOTAL	**3,190**

generate significant amounts of methane. They contain easily-decomposed carbon sources, nutrients, moisture and active microbial populations. However, under aerobic conditions, methane production is inhibited and these systems are designed to maintain aerobic conditions. Anaerobic conditions occur infrequently, such as during a malfunction of the system or when the system is overloaded. During these anaerobic episodes, methane will be emitted. No state-specific data were available for the amount of C processed in wastewater treatment plants or the fraction that was treated anaerobically. Therefore, national averages were used. Assuming that 15% of the C in wastewater was treated anaerobically, methane emission from wastewater treatment facilities was 20 TTCDE (Table 5-1). This represented less than 1% of total Waste Management emissions.

CO_2 Emissions from Landfilled Waste

Landfilled wastes (wastewater sludge, paper mill sludge and MSW) are considered renewable C sources because most of the material in them ultimately comes from plant material (e.g., food, paper, textiles and wood) CO_2 emissions from decomposition of these organic materials was not included in the inventory of greenhouse gas emissions, but are listed separately in Table 5-2.

6. Agriculture

Methane is produced during various agricultural operations including cattle production, manure handling and crop burning. Nitrous oxide is generated during fertilizer use and crop burning. Agriculture contributed 280 TTCDE or 1.3% of the total emissions from Maine (Figure 6-1).

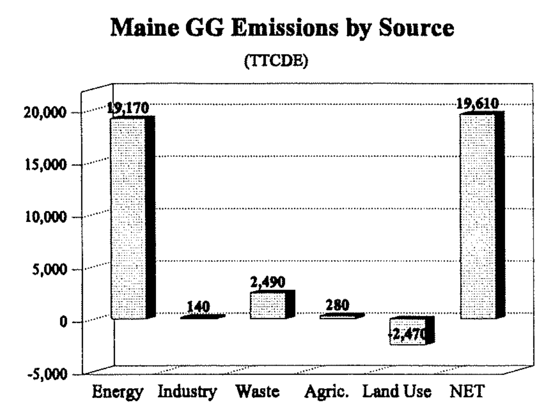


Figure 6-1

Methane from Domesticated Animals

Ruminant animals (animals with a fore-stomach) produce large quantities of methane during their normal digestive process. Anaerobic microorganisms in their digestive tracts convert the coarse plant material they eat into more digestible form. Methane is a by-product of this process. Non-ruminant animals (horses, mules, pigs) also produce methane in their large intestines, but in much smaller quantities.

Methane from domesticated animals was the largest source (217 TTCDE or 78%) of Agriculture emissions (Figure 6-2 and Table 6-1). Of the domesticated animals, dairy cattle accounted for two-thirds of the methane emissions mainly because of their large numbers.

Methane from Manure Management

Methane is produced during decomposition of animal manure under anaerobic (without oxygen) conditions. The type of manure and manure management system will influence the amount of methane produced. For example, lagoon systems are usually anaerobic and produce large quantities of methane. In contrast, field spreading allows manure to remain oxygenated and, therefore, little methane is produced.

Methane emissions from cattle, swine, poultry, sheep, goat, donkey and horse manure was 42 TTCDE or 15% of Agriculture emissions. More than half of these emissions (23 TTCDE) came from cattle manure which was in the greatest quantity. The next greatest was poultry manure (16 TTCDE).

Nitrous Oxide from Fertilizer Use

Nitrogen in soil is transformed by microorganisms into several different forms, including ammonia, nitrate and organically-bound nitrogen. A gaseous form of nitrogen, nitrous oxide, is produced in small amounts as a by-product of some of these transformations under natural conditions. Additions of fertilizer may accelerate these transformations and increase the amount of nitrous oxide produced.

Nitrous oxide emissions from fertilizer use accounted for only 6% of total Agriculture emissions (20 TTCDE). Urea was the most commonly used fertilizer between 1989 and 1991 and was the largest source of nitrous oxide.

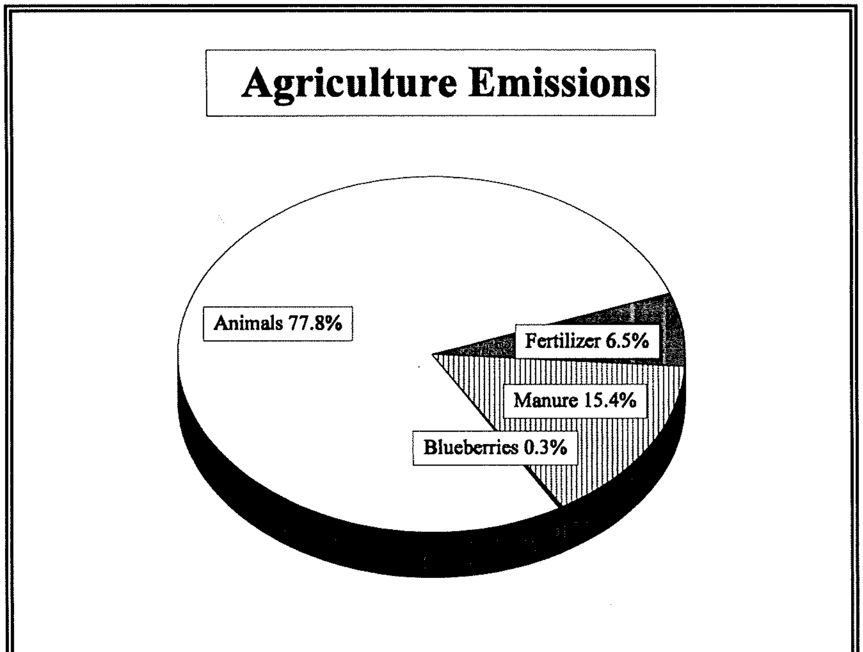


Figure 6-2

Table 6-1.

Methane and Nitrous Oxide Emissions from Agriculture

	Emissions (TTCDE)
Domesticated Animals	
Dairy Cattle	146
Others	71
Subtotal	**217**
Manure Management	
Cattle	23
Poultry	16
Others	3
Subtotal	**42**
Fertilizer Use	
Urea	7
Others	14
Subtotal	**20**
Blueberry Burning	**<1**
TOTAL	**280**

Methane and Nitrous Oxide from Blueberry Field Burning

Residues from many agricultural crops are burned. This is not a common practice in Maine; however, lowbush blueberry fields are typically burned every other year to reduce weed competition, prune the blueberry plants and return nutrients to the soil. Burning releases CO_2, methane and nitrous oxide as well as other greenhouse gases. The CO_2 emitted is not included here because it is a release from a renewable carbon source. However, methane and nitrous oxide emissions are estimated.

The two most commonly used burning methods involve the use of either flame-throwers or straw as combustion fuels. The fuel for the flame-throwers was already counted in Chapter 3 (under Commercial-Residual Oil). So for this burning method only the emissions from burned plant biomass and soil are considered. With the straw method, the emissions from the burned straw are added to those from plant biomass and soil.

A new method that is becoming more popular is the use of mowers to trim the bushes. Because the residue is left to decay naturally, the only emissions would be those from the fuel used to power the mower (these emissions are counted in Chapter 3).

Emissions from blueberry field burning totaled 0.5 TTCDE which was < 1% of Agriculture emissions.

7. Land Use

Growing vegetation acts as a carbon (C) sink by absorbing CO_2 from the atmosphere and converting it into plant biomass during photosynthesis. The huge expanses of forests in Maine (89% of the land area; Seymour and Lemin, 1989) have the potential to sequester large quantities of atmospheric CO_2. Similarly, wetlands in Maine sequester large amounts of C in their deep organic soils.

The net amount of C stored annually in a forest ecosystem is equal to the rate of gross C storage minus the rate of C release to the atmosphere. If the rate of storage in trees is greater, then the forest will act as a net sink for CO_2. If the rate of C release is greater, then the forest will act as a net source of CO_2.

Human activity can greatly affect the balance between C storage and C release. Forestry operations have a direct effect on the growth rate of trees and, therefore, the rate of C storage. In addition, humans harvest forest products, which is the primary mode of C release. Furthermore, changes in forested area, such as forest clearing for development, will result in permanent changes in the carbon storage capacity of Maine's forests. Reductions in the area of wetlands will have an impact on methane emissions as wetlands are large sources of this greenhouse gas.

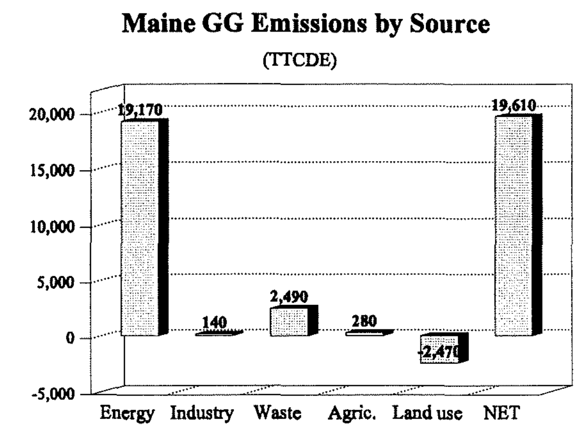


Figure 7-1

Storage by Forests

Storage of carbon in forested ecosystems equals the amount of carbon accumulated by growing vegetation (primarily trees) minus the amount of C released by forestry operations. For simplicity it was assumed that all C removed from forests was instantaneously released to the atmosphere as CO_2. In reality, some forest products, such as lumber, will continue to sequester carbon for years or decades. We need better information on the fate of forest products and their lifetimes before we can accurately predict the rate of release of CO_2.

Storage of C by trees was 29,490 TTCDE (Figure 7-2). Carbon released from forests by harvesting operations was 27,020 TTCDE. Therefore, Maine's forests acted as a net sink for CO_2 in 1990 by accumulating 2,470 TTCDE. It is interesting to note that these internal fluxes of C storage and release in 1990 were larger than the total greenhouse gas emissions from all the other sectors combined (compare Figure 7-2 to Figure 7-1).

Net C storage by forests in 1990 is a point estimate using the best available data. It is not likely that Maine forests will continue to accumulate C indefinitely for two reasons. First, the forested area in Maine can not increase much above the current 89% without sacrificing essential agricultural land. Second, C release by the forest products industry varies from year to year and is influenced in part by economic trends. If C removal was increased by just 10%, Maine forests would become a net source of CO_2 instead of a net sink.

Considering all of these factors and

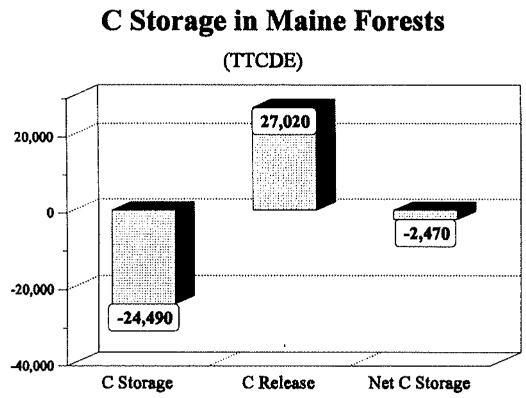


Figure 7-2

assuming no drastic changes in forestry practices or forested land area, it is likely that during the next several decades Maine forests will fluctuate between being a net sink and a net source of atmospheric CO_2.

Forest Conversion

Permanent changes in forest area (or forest conversion) will affect the maximum amount of C that can be sequestered in Maine forests. Forested area in Maine decreased slightly from 17.58 million acres in 1987 to 17.56 million acres in 1992 (Soil Conservation Service 1994). This is a decrease of less than one-tenth of one percent of the total forested area annually (5,440 acres per year). The amount of stored carbon removed during forest conversion in 1990 was 623 TTCDE. This value makes up a part of the 27,020 TTCDE of C release in Figure 7-2.

It is important to maintain a longer-term perspective of forest dynamics and their trends through time. Circa 1900, agriculture in New England was at its peak. It has been estimated that 50 to 80% of the land area was cleared for crops or pasture at that time (Cronon 1983). We do not have accurate records from that period but it is safe to

Table 7-1.
Natural Methane Production in Wetlands

	Annual Methane Production (TTCDE)
CO_2 Absorption	-2,070
Methane Production	4,330
Net Production	**2,260**

assume that forested area was at its lowest point around this time (20 to 50%). Since that time, most of the agricultural land has been abandoned and forests have been allowed to regenerate. Forested area increased to 89% in 1982 and has remained at that level or declined slightly since then.

Wetland Conversion

Wetlands perform two functions that affect greenhouse gas concentrations in the atmosphere. Atmospheric CO_2 is fixed by plants and sequestered in deep organic soils at a rate of 2,070 TTCDE annually in Maine's wetlands (Figure 7-3). At the same time, a portion of the sequestered C is converted to methane by soil microorganisms and released to the atmosphere (4,330 TTCDE per year). Thus, wetlands act as a net source of greenhouse gases in terms of global warming potential (2,260 TTCDE net greenhouse gas emission). These are the natural rates of greenhouse gas emissions that have been occurring for centuries and, therefore, are part of the natural Greenhouse Effect. They are not included in this inventory because they do not contribute to the Augmented

Greenhouse Effect. However, loss of wetland area in Maine by draining or filling may cause a permanent change in these fluxes that may affect the Augmented Greenhouse Effect.

We were not able to include the effects of permanent change in wetland area in this inventory because no standard methodology exists. Wetland destruction by draining or filling will affect both CO_2 absorption and methane emission processes. The nature and extent of these changes are not well understood and require further research.

8. References

American Horse Council. 1987. New England Farm Bulletin.

Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. U.S.D.A. Forest Service General Technical Report WO-59.

Bogner, J. and K. Spokas. 1995. Carbon Storage in Landfills In Lal, R., J. Kimble, E. Levine and B.A. Stewart (eds.), Soils and Global Change. CRC Press, Boca Raton.

Bolin, B. (1986) How much CO_2 will remain in the atmosphere? The carbon cycle and projections for the future. *In* Bolin, B., B.R. Doos, J. Jager and R.A. Warric (eds.), The greenhouse effect, climate change and ecosystems. SCOPE 29. Wiley and Sons, NY. (pp 93-156)

Bureau of Census. 1992. Census of Agriculture. Vol. 1, Pt. 19. U.S. Dept. of Commerce, U.S. Government Printing Office., Washington, DC.

Cicerone, R.J. and R.S. Oremland (1988) Biogeochemical aspects of atmospheric methane. Global Biogeochemical Cycles 2:299-327.

Clinton, W.J. and A. Gore, Jr. 1993. The Climate Change Action Plan. Washington, DC.

Cronon, W. 1983. Changes in the Land. Hill and Wang, New York.

Forest Information Center. 1992. 1990 Woodprocessor Report. Maine Forest Service, Maine Dept. of Environmental Protection, Augusta, ME.

IPCC 1994. IPCC guidelines for national greenhouse gas inventories. Vols. 1-3. Intergovernmental Panel on Climate Change, Organization for Economic Cooperation and Development. Paris, France.

Kroeze, C. 1994. Nitrous oxide and global warming. The Science of the Total Environment 143:193-209.

Maine Department of Environmental Protection. 1992. Industrial Boiler Inventory: 1989 -1992. Augusta, ME.

Maine State Planning Office. 1992. The Comprehensive Energy Report from Maine. Augusta, ME.

Maine State Planning Office. 1994. The Comprehensive Energy Report from Maine. (Draft). Augusta, ME.

Maine Waste Management Agency. 1993. State of Maine Waste Management and Recycling

Plan. Augusta, ME.

Overpeck, J.T., D. Rind and R. Goldberg (1990) Climate-induced changes in forest disturbance and vegetation. Nature 343:51-53.

Overpeck, J.T., P.J. Bartlein and T. Webb III. 1991. Potential magnitude of future vegetation change in eastern North America: Comparisons with the past. Science 254:692-695.

Pastor, J. and W.M. Post. 1988. Response of northern forests to CO_2-induced climate change. Nature 334:55-58.

Powell, D.S. and D.R. Dickson. 1984. Forest Statistics for Maine: 1971 and 1982. U.S.D.A. Forest Service, Northeastern Station, Resource Bulletin NE-81.

Radian Corp. 1990. Emissions and cost estimates of globally significant anthropogenic combustion sources of NO_x, N_2O, CH_4, CO and CO_2. Office of Research and Development, U.S.E.P.A. Washington, DC.

Resource Data International, Inc. 1995. Energy choices in a competitive era: The role of renewable and traditional resources in America's electric generation mix. Center for Energy and Economic Development, Alexandria, VA.

Rock, C.A., J.A. Alexander and B.S. Beyer. 1983. Pulp and paper sludge disposal: The problem, current practice and future directions. Land and Water Resources Center, University of Maine, Orono, ME. (35 pp.)

Seymour, R.S. and R.C. Lemin, Jr. 1989. Timber supply projections for Maine, 1980-2000. CFRU Research Bulletin No. 7. Maine Agricultural Experiment Station, Orono, ME.

Seymour, R.S. and R.C. Lemin, Jr. 1991. Empirical yields of commercial tree species in Maine. CFRU Research Bulletin No. 8. Maine Agricultural Experiment Station, Orono, ME.

Smith, D.W. and R.J. Hilton. 1972. The comparative effects of pruning by burning or clipping n lowbush blueberries in north-eastern Ontario. Journal of Applied Ecology. Vol. 8:781-789.

Soil Conservation Service. 1994. Summary Report: 1992 National Resources Inventory. U.S.D.A., Washington, DC.

Tabasaran, O. 1981. Gas production from landfills. In (Bridgewater, A.V. and K. Lidgren, eds.) Household Waste Management in Europe: Economics and Techniques. Van Nostrand Reinhold Co., New York. (pp. 159-175)

Tennessee Valley Authority. 1989. Commercial Fertilizers. National Fertilizer and Environmental Research Center, Muscle Shoals, Alabama.

Tennessee Valley Authority. 1991. Commercial Fertilizers. National Fertilizer and Environmental Research Center, Muscle Shoals, Alabama.

U.S.D.A. 1991. Agricultural Statistics. U.S. Government Printing Office, Washington, DC.

U.S.D.A. 1992. Agricultural Statistics. U.S. Government Printing Office, Washington, DC.

U.S.D.O.E. 1992. The State Energy Data Report. Washington, DC.

U.S.E.P.A. 1979. Process Design Manual for Sludge Treatment and Disposal. MERL-ORD, EPA 625/1-79-011. Washington, DC.

U.S.E.P.A. 1995. State Workbook: Methodologies for estimating greenhouse gas emissions. 2nd ed. U.S. Environmental Protection Agency. Washington, DC.

Wardwell, R.E. 1982. Bioconversion of papermill sludge. In proceedings of the symposium on Long range disposal alternatives for pulp and paper sludges. Oct. 13-14, 1982. University of Maine, Orono, ME. (pp. 130-152).

Zibilske, L. 1991. Soil responses to sludge applications. In Proceedings from the Papermill Sludges: Disposal Options and Environmental Impacts Seminar. March 28, University of Maine, Orono, ME.

9. Glossary of Terms

Aerobic - with oxygen present. With regard to decomposition processes, aerobic conditions indicate that organic matter will be completely degraded into its components (mainly CO_2 and water). Little methane is emitted in aerobic decomposition.

Anaerobic - without oxygen. Without oxygen decomposers are not able to degrade organic matter completely to CO_2 and water. Intermediate products accumulate such as methane and alcohols. These products often create a bad odor.

Augmented Greenhouse Effect - When greenhouse gas concentrations in the atmosphere are raised above natural levels, the Greenhouse Effect is magnified resulting in global warming and other global climate changes. Human activity in the past 200 years has caused this Augmented Greenhouse Effect.

Biomass - in this report, biomass refers to living organic matter. Organic matter always contains carbon.

Bituminous Coal - anthracite, or black coal.

B.O.D. - Biological oxygen demand (BOD) is an indicator of the amount of C in water. Technically, it is the amount of oxygen required to decompose an organic pollutant.

Btu - British Thermal Unit. It is a measure of energy. 1 Btu = 252 calories or 1055 joules.

Distillate Oil - light oils, these are the oils that are distilled from crude oil. Used for home heating oil, water heaters. Gasoline is also a type of distillate oil but is considered separately in this inventory.

Emission - in this report the production and transfer of a greenhouse gas to the atmosphere over and above natural greenhouse gas fluxes. Emissions contribute to the Augmented Greenhouse Effect.

Fossil fuel - namely oil, coal, tar sands, oil shales and natural gas. These fuels are the remains of living organisms that have been transformed by the high temperatures and pressures in the earth's crust.

Greenhouse Effect - The natural mechanism in the Earth's atmosphere that slows down the loss of heat from the surface of the Earth to outer space. The Greenhouse Effect is essential to life of earth. It is caused by low concentrations of greenhouse gases in the atmosphere that absorb heat energy.

Greenhouse gas - any of several gases that absorb heat energy. Naturally occurring greenhouse gases are water vapor, CO_2, methane, nitrous oxide and ozone. Human-made greenhouse gases are chlorofluorocarbons (CFCs).

LPG - liquefied petroleum gas. Gaseous petroleum by-products, mainly propane and butane, that are held under pressure in liquid form.

Production - In this report, production of a greenhouse gas (in contrast to emission) does not contribute to the Augmented Greenhouse Effect because it is generated by a natural source or is generated from renewable C sources.

Residual Oil - heavy oils, these are the oils remaining after the distillation process. These are used as fuels in larger Industrial and Commercial operations.

Ruminant - namely cattle, deer and camels. These animals have a four-chambered stomach that allows them to digest extremely coarse and low nutrient forages such as grass and straw. Their unique digestive pathway produces large amounts of methane.

Sink - in biogeochemical terms, a sink is something that stores or sequesters an element. It removes it from circulation.

Source - in biogeochemical terms, a source is something that releases or produces an element. It adds it to the circulating flux.

TTCDE - thousand tons carbon dioxide equivalent. Common units for global warming potential of greenhouse gases.

Appendix A

Data from Chapter 2. Maine Emissions

Table A.1. Summary of Maine Emissions

The values in Table A.1. are derived from the subsequent tables in this Appendix. They are summarized here for convenience.

Table A.1. Summary of Maine Emissions

Source	GG Emissions (TTCDE)
Energy Production	
Residential	2,920
Commercial	1,490
Industrial	3,780
Transportation	9,030
Utilities	1,950
Subtotal	**19,170**
Industry	
Cement Production	140
Subtotal	**140**
Waste Management	
Landfills	2,470
Wastewater Treatment	20
Subtotal	**2,490**
Agriculture	
Domesticated Animals	217
Animal Manure	42
Fertilizer Use	20
Blueberry Cultivation	1
Subtotal	**280**
TOTAL EMISSIONS	**22,080**
Land Use	
Storage by Forests	(2,470)
Subtotal	**(2,470)**
NET EMISSIONS	**19,610**

Data from Chapter 3. Energy Use

Estimates were made of CO_2 and methane emissions from energy production processes. Fuel sources included various fossil fuels, wood, MSW (in waste-to-energy plants) and paper mill sludge. The basic procedure was to first obtain data on amount of each fuel type consumed. The amount of carbon in the fuel was then calculated. An emissions factor (EF) was estimated. The amount of C or fuel consumption was then multiplied by the EF to obtain an estimate of greenhouse gas emissions.

Data and calculations for fossil fuels are presented in Table A.2. Data and calculations for biomass fuels are presented in Table A.3. The list following each table describes the calculation procedures column by column.

Data from Chapter 3. Energy Use
Table A.2. Fossil Fuels

	A	B	C	D	E	F	G	H	I	J
Sector/Fuel	Consumption	C Content Coefficient	Total Carbon	Stored Carbon	Net Carbon	Total CO2 Emissions	Methane EF	Methane Emissions	CO2 Emissions	Methane Emissions
	(MBtu)	(lbs C/MBtu)	(tons C)	(tons C)	(tons C)	(tons C)	(lbs/MBtu)	(tons CH4)	(TTCDE)	(TTCDE)
RESIDENTIAL										
Distillate	29,300,000	44.0	644,600	0	644,600	638,154	0.0110	161.2	2,340	3.55
LPG	3,100,000	37.8	58,590	0	58,590	58,004	0.0024	3.7	213	0.08
Kerosene	3,200,000	43.5	69,600	0	69,600	68,904	n.e.	n.e.	253	n.e.
Bituminous Coal	450,000	56.0	12,600	0	12,600	12,474	n.e.	n.e.	46	n.e.
Natural Gas	660,000	31.9	10,527	0	10,527	10,474	0.0021	0.7	38	0.02
Subtotal	**36,710,000**		**795,917**	**0**		**788,010**		**165.6**	**2,889**	**3.64**
COMMERCIAL										
Distillate	9,800,000	44.0	215,600	0	215,600	213,444	0.0013	6.4	783	0.14
Residual	5,445,000	47.4	129,047	0	129,047	127,756	0.0035	9.5	468	0.21
LPG	584,100	37.8	11,039	0	11,039	10,929	0.0020	0.6	40	0.01
Kerosene	400,000	43.5	8,700	0	8,700	8,613	n.e.	n.e.	32	n.e.
Gasoline	500,000	42.8	10,700	0	10,700	10,593	n.e.	n.e.	39	n.e.
Bituminous Coal	600,000	56.0	16,800	0	16,800	16,632	0.0221	6.6	61	0.15
Natural Gas	1,640,000	31.9	26,158	0	26,158	26,027	0.0225	2.1	95	0.05
Subtotal	**18,969,100**		**418,044**	**0**		**413,994**		**25.2**	**1,518**	**0.55**
INDUSTRY										
Asphalt	4,300,000	45.5	97,825	97,825	0	0	n.e.	0.0	0	0.00
Distillate	4,100,000	44.0	90,200	0	90,200	89,298	n.e.	n.e.	327	n.e.
Residual	30,500,000	47.4	722,850	0	722,850	715,622	0.0064	97.6	2,624	2.15
LPG	1,300,000	37.8	24,570	0	24,570	24,324	n.e.	n.e.	89	n.e.
Lubricants	400,000	44.6	8,920	4,460	4,460	4,415	n.e.	n.e.	16	n.e.
Kerosene	200,000	43.5	4,350	0	4,350	4,307	n.e.	n.e.	16	n.e.
Motor Gasoline	500,000	42.8	10,700	0	10,700	10,593	n.e.	n.e.	39	n.e.
Bituminous Coal	5,500,000	56.0	154,000	0	154,000	152,460	0.0053	14.6	559	0.32
Natural Gas	2,000,000	31.9	31,900	0	31,900	31,741	0.0029	2.9	116	0.06
Subtotal	**48,800,000**		**1,145,315**	**102,285**		**1,032,759**		**115.1**	**3,787**	**2.53**

Data from Chapter 3. Energy Use
Table A.2. Fossil Fuels

	A	B	C	D	E	F	G	H	I	J
Sector/Fuel	Consumption	C Content Coefficient	Total Carbon	Stored Carbon	Net Carbon	Total CO2 Emissions	Methane EF	Methane Emissions	CO2 Emissions	Methane Emissions
	(MBtu)	(lbs C/MBtu)	(tons C)	(tons C)	(tons C)	(tons C)	(lbs/MBtu)	(tons CH4)	(TTCDE)	(TTCDE)
TRANSPORTATION										
Gasoline	76,422,050	42.8	1,635,432	0	1,635,432	1,619,078	0.0250	955.3	5,937	21.02
Aviation fuel	392,500	41.6	8,164	0	8,164	8,082	0.1330	26.1	30	0.57
Jet fuel	14,000,000	43.5	304,500	0	304,500	301,455	0.0044	30.8	1,105	0.68
Diesel	23,612,200	42.8	505,301	0	505,301	500,248	0.0040	47.2	1,834	1.04
LPG	100,000	37.8	1,890	0	1,890	1,871	n.e.	n.e.	7	n.e.
Lubricants	800,000	44.6	17,840	8,920	8,920	8,831	n.e.	n.e.	32	n.e.
Residual Fuel Oil	900,000	47.4	21,330	0	21,330	21,117	n.e.	n.e.	77	n.e.
Subtotal	**116,226,750**		**2,494,457**	**8,920**		**2,460,682**		**1,059.4**	**9,022**	**23.31**
UTILITIES										
Distillate	110,675	44.0	2,435	0	2,435	2,410	0.00007	0.0	9	0.00
Residual	22,283,100	47.4	528,109	0	528,109	522,828	0.0015	16.7	1,917	0.37
Subtotal	**22,393,775**		**530,544**	**0**		**525,239**		**16.7**	**1,926**	**0.37**
TOTAL						**5,220,684**		**1,382**	**19,143**	**30.40**

n.e. = no estimate available

Table A.2. Fossil Fuels

Column: **A: Fuel Consumption (million Btu)**
Source(s): Maine State Planning Office. 1994. The Comprehensive Energy Report from Maine, Draft. Augusta, ME.
U.S. Department of Energy. 1992. The State Energy Data Report.
Notes: This is fuel consumed by (sold to) individuals in Maine in 1990. Some of the purchased fuel will be exported before combustion (by people driving to other states, for example) and some fuel will be imported from out of state to be combusted in Maine. These imports and exports were not estimated.

Diesel and motor gasoline values are from Maine Department of Transportation because the U.S.D.O.E. source did not distinguish between the two. All coal was assumed to be bituminous. The electric utility data is based on utility reports to the Federal Energy Regulatory Commission (specifically, FERC Form 1's) reports, and SPO research. It is based on electricity generated, some of which is exported.

Primary Maine sources were used whenever possible in the MSPO to corroborate accuracy or fill in gaps. Recent year transportation fuel data is from the Maine Dept. of Transportation and is based on fuel tax revenues. Recent year data on industrial wood and residual oil use is from the Maine Dept. of Environmental Protection and is based on survey data. Jet fuel consumption has probably decreased since 1990 because of the closure of Loring Air Force Base and the decrease in commercial airline service.

Column: **B: Carbon Content Coefficient (lbs C/million Btu)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (Table D1-2).
Notes: Different fuels contain different amounts of carbon per unit energy produced. For example, coal is a relatively inefficient energy source, so it has a high carbon content coefficient. Natural gas is more efficient and has a lower carbon content coefficient.

Column: **C: Total Carbon in fuel consumed (tons C)**
Source(s): (calculated)
Notes: Amount of total carbon in the fuel that was consumed.
column A * column B / 2000 (lbs/ton)

Column: **D: Stored Carbon (tons C)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (Table D1-3).
U.S. Department of Energy. 1992. The State Energy Data Report.
Notes: Some petrochemicals may be used to form stable products that are not burned (such as asphalt and lubricants). These products sequester carbon for long periods of time and should not be included in emissions estimates. All the carbon in asphalt and 50% of the carbon in lubricants is assumed to be sequestered.

Column: **E: Net Carbon (tons C)**
Source(s): (calculated)

Notes: Net Carbon is total carbon consumed minus stored C.
column E = column C - column D.

Column: **F: Total CO_2 Emissions (tons C)**
Source(s): (calculated)
Notes: The fraction of carbon that is combusted and oxidized completely to carbon dioxide, the combustion factor (CF), is multiplied by the Net Carbon to obtain the Total Carbon Dioxide Emissions. CF = 0.995 for natural gas and 0.990 for everything else.
column F = column E * CF.

Column: **G: Methane Emission Factor (lbs CH_4/MBtu)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (Tables D14-2 to D14-6).
Radian Corporation. 1990. Emissions and cost estimates for globally significant anthropogenic combustion sources of NO_X, N_2O, CH_4, CO and CO_2. Office of Research and Development, U.S.E.P.A.
Notes: Methane emissions from fossil fuel combustion depends on the carbon content of the fuel type, but also the efficiency of combustion. Different types of boilers produce different amounts of methane per unit energy. (n.e. indicates that no estimate was available.)

Column: **H: Methane Emissions (tons methane)**
Source(s): (calculated)
Notes: column H = column A * column G / 2000 (lbs/ton)

Column: **I: CO_2 Emissions (TTCDE)**
Source(s): (calculated)
Notes: CO_2 emissions in tons is converted into TTCDE.
column I = column F * 44 / 12 / 1000

Column: **J: Methane Emission (TTCDE)**
Source(s): (calculated)
Notes: The methane emissions in tons is converted to thousand tons of carbon dioxide equivalents (TTCDE) by multiplying by the global warming potential (GWP). Note that estimates were not available for some fuel types. Therefore, the Total for this column is an underestimate of the actual methane emissions.
column J = column H * 22 (GWP) / 1000

Data from Chapter 3. Energy Use

Table A.3. Biomass Fuels

	A	B	C	D	E	F	G	H
Fuel/Sector	Consumption	Carbon Fraction	Total Carbon	Total CO2 Emissions	Methane EF	Methane Emissions	CO2 Emissions	Methane Emissions
	(wet tons)	(t C / t dm)	(tons C)	(tons C)	(lbs/MBtu)	(tons CH4)	(TTCDE)	(TTCDE)
WOOD								
Residential	1,533,600	0.498	381,866	343,680	0.1640	1,308	**1,260**	28.8
Industrial	1,686,000	0.510	429,930	386,937	0.0331	290	**1,419**	6.4
Utilities	4,820,000	0.510	1,229,100	1,106,190	0.0398	998	**4,056**	21.9
Subtotal	**8,039,600**		**2,040,896**	**1,836,807**		**2,596**	**6,735**	**57.1**
WASTE INCINERATION								
Paper Mill Sludge	292,820	0.120	14,055	12,650	0.0015	2.2	**46**	0.049
MSW	487,400	0.220	53,614	48,253	0.0015	3.7	**177**	0.082
Subtotal	**780,220**		**67,669**	**60,902**		**6**	**223**	**0.13**
TOTAL							**6,958**	**57.2**

Table A.3. Biomass Fuels

Column: **A: Fuel Consumption (wet tons)**

Source(s): (1) Maine State Planning Office, 1994.The Comprehensive Energy Report for Maine, Draft. Augusta, ME.
(2) Maine Department of Environmental Protection. 1993. Industrial Boiler Inventory: 1989 through 1992. Augusta, ME.
(3) Maine Waste Management Agency. 1993. State of Maine Waste Management and Recycling Plan. Augusta, ME.

Notes: This is fuel consumed in Maine in 1990 including wood imports minus wood exports. Residential wood use data is based on surveys performed by the OER. Industry and Utility wood use estimates are from source #1 and modified using source #2. Wood use under Utilities includes wood burned by Industry to generate electricity for sale to utilities. MSW and papermill sludge estimates are from source #3. Waste-to-energy incinerators are included in this chapter, but other waste incinerators are not included.

Column: **B: Carbon Fraction of Dry Matter (t C/t dm)**

Source(s): (1) U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed.
(2) R.A. Birdsey. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. U.S. Forest Service, U.S.D.A. General Technical Report WO-59. (Table 1.2)
(3) Fernandez, I.J. 1995. Professor, Dept. of Applied Ecology and Environmental Science, University of Maine, Orono, ME. Personal interview.
(4) Zibilske, L.M. 1995. Associate Professor, Dept. of Applied Ecology and Environmental Science, University of Maine, Orono, ME. Personal interview.

Notes: Wood from hardwood trees contains 49.8% carbon on average. This value was used for Residential wood because the majority of wood burned in this sector is hardwood. Industrial and utility sectors use an unknown mix of softwood and hardwood so a median value of 51% carbon was used. Paper mill sludge is typically 30% carbon (I.J. Fernandez, personal communication; L.M. Zibilske, personal communication).

Column: **C: Total Carbon in fuel consumed**

Source(s): (calculated)

Notes: Total carbon in the fuel that was consumed is calculated by first converting the wet mass of fuel to dry weight. For wood, the dry fraction (DF) is 0.50 (R.S. Seymour, personal communication). For Sludge the dry fraction is 0.4 (I.J. Fernandez, personal communication). The dry fraction of MSW was assumed to be the same as wood. The dry weight of the fuel is then multiplied by the carbon fraction to obtain Total Carbon.
column C = column A * DF (tons dm/wet ton) * Column B

Column: **D: Total Carbon Dioxide Emissions (tons C)**

Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (Table D1-4).

Notes: The fraction of carbon that is combusted and oxidized completely to carbon dioxide, the combustion factor (CF), is multiplied by the Total Carbon to obtain the Total

Carbon Dioxide Emissions. CF = 0.90 for wood, MSW and sludge.
column D = column C * CF.

Column: **E: Methane Emission Factor (lbs CH_4/MBtu)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (Tables D14-2 to D14-6).
Radian Corporation. 1990. Emissions and cost estimates for globally significant anthropogenic combustion sources of No_x, N_2O, CH_4, CO and CO_2. Office of Research and Development, U.S.E.P.A.
Notes: Methane emissions from biomass fuel combustion depends on the carbon content of the fuel type, but also the efficiency of combustion. Different types of boilers produce different amounts of methane per unit energy. No emission factors were available for sludge or MSW so minimum values of 0.0015 were assigned. These are comparable to highly-efficient oil boilers and, therefore, probably underestimate the actual emission factors.

Column: **F: Methane Emissions (tons CH_4)**
Source(s): Maine State Planning Office, 1994. The Comprehensive Energy Report for Maine, Draft. Augusta, ME.
Notes: The wet tonnage of fuel must first be converted into energy units. So fuel consumption in wet tons is multiplied by 10.4 MBtu /ton for wood or 10.16 MBtu/ton for MSW and Sludge. That energy value is then multiplied by the EF from column E.
Column F = column A * 10.4 (MBtu/ton) * column E / 2000 (lbs/ton).

Column: **G: CO_2 Emission (TTCDE)**
Source(s): (calculated)
Notes: These values represent CO_2 emissions from a renewable source. Therefore, they are not included in the calculation for greenhouse gas emissions.
Column G = column D * 44 / 12 / 1000

Column: **H: Methane Emission (TTCDE)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (Box I-2, p. viii).
Notes: The methane emissions in tons is converted to thousand tons of carbon dioxide equivalents (TTCDE) by multiplying by the global warming potential (GWP).
column H = column F * 22 (GWP) / 1000

Data from Chapter 4. Industrial Processes

The State Workbook: Methodologies for estimating greenhouse gas emission lists six industrial processes that are potential sources of greenhouse gas emissions: cement production, nitric acid production, adipic acid production, lime manufacture and use, soda ash manufacture and consumption and CO_2 production. Cement production was the only one of these industries that was identified for this report, although it is likely that other industries contribute emissions. Masonry cement production was a small fraction of total cement production and was not calculated.

The total amount of cement clinker produced in 1990 was obtained and multiplied by an emissions factor.

Table A.4. Cement Production

	A	B	C	D
Source	Clinker Produced (tons)	t CO2 per t Clinker	Total CO2 Emissions (tons)	Total CO2 Emissions (TTCDE)
Cement Production	285,911	0.5071	144,985	**145**

Table A.4.

Column: **A: Clinker Produced (tons)**
Source(s): Dragon Products, Co. P.O. Box 191, Thomaston, ME 04861 (Steve Wallace, contact).
Notes: Dragon Products is the only cement manufacturer in Maine. CO_2 is produced during the making of cement clinker. In this process, limestone (calcium carbonate) is heated to form calcium oxide and CO_2.

Column: **B: tons CO_2 per ton Clinker (ton/ton)**
Source(s): U.S.E.P.A., 1995. <u>State Workbook: Methodologies for estimating greenhouse gas emission</u>, 2nd ed. (pg. D2-2).
Notes: This emissions factor represents the amount of CO_2 generated per ton clinker produced.

Column: **C: Total CO_2 Emissions (tons)**
Source(s): (calculated)
Notes: Total CO_2 emissions equal the clinker produced times the emissions factor.
column C = column A * column B

Column: **D: Total CO_2 Emissions (TTCDE)**
Source(s): (calculated)
Notes: The CO_2 emissions in tons is converted to thousand tons of carbon dioxide equivalents (TCDE) by dividing by 1000.
column D = column C / 1000

Data from Chapter 5. Waste Management

Methane and CO_2 are produced during the anaerobic decomposition of landfilled wastes. This release of CO_2 can be considered a release from a renewable source (e.g., paper and food) and so is not included in the calculation of greenhouse gas emissions. Methane may also be released from wastewater treatment systems under anaerobic conditions.

The methodology for estimating methane emissions from landfills is based on a mass balance approach, where an instantaneous release of methane is assumed to enter the atmosphere during the same year that refuse is placed in the landfill. The methodology only requires states to determine pounds of municipal solid waste landfilled because default values are used for the other parameters. The alternative method No. 1 was used because there was no information available on the size of landfills in Maine. The calculations assume sanitary landfills, where compacted waste is spread evenly over the active area of the landfill and covered with some type of nonporous soil. In 1990, out of the 200 municipal landfills, only 19 may have been lined. The DEP did not begin to require lined landfills until 1989. It is not known how landfill construction would affect the anaerobic conditions.

The landfilling of papermill sludge also results in methane emissions. However, determining methane emissions is difficult as the composition of the sludge varies (Rock et al. 1983). It is composed of varying blends of primary and secondary sludge, but usually in a three-to-one ratio (Zibilske 1991). Primary sludge is mainly wood fiber, whereas secondary sludge results from the biological treatment of wastewater.

The extent of venting and flaring of methane in landfills in Maine is not known, but was uncommon if practiced at all (D. Lord, personal communication).

Data from Chapter 5. Waste Management

Table A.5. Methane and CO2 Emissions from Landfilled Waste

	A	B	C	D	E	F	G	H
Source	Waste Generated	Fraction Landfilled	Degradable C Fraction	Dissimilated C	Methane Fraction	Methane Emission	Methane Emission	CO2 Emission
	tons	%	%	%		(tons CH4)	(TTCDE)	(TTCDE)
Residential								
MSW*	585,503	0.340	0.22	0.77	0.5	22,482	495	618
Wastewater sludge	104,000	0.213	0.12	0.77	0.5	1,365	30	38
Subtotal	**689,503**					**23,846**	**525**	**656**
Commercial								
MSW	660,248	0.340	0.22	0.77	0.5	25,352	558	697
Wastewater sludge	104,000	0.213	0.12	0.77	0.5	1,365	30	38
Subtotal	**764,248**					**26,716**	**588**	**735**
Industrial**								
MSW-like waste	276,527	0.807	0.22	0.77	0.5	25,202	554	693
Sludge	958,466	0.622	0.12	0.77	0.5	36,724	808	1,010
Subtotal	**1,234,993**					**61,926**	**1,362**	**1,703**
TOTAL							**2,475**	**3,093**

*MSW = municipal solid waste

** pulp and paper mills

Table A.5. Methane and CO_2 Emissions from Landfilled Waste

Column: **A: Waste Generated (tons)**

Source(s): Maine Waste Management Agency. 1993. State of Maine Waste Management and Recycling Plan. (Tables 4-2, 5-1, 7-2).

Notes: Data are from 1991 because this information was not gathered in 1990. The amounts of MSW generated by Residential and Commercial sectors were obtained by multiplying total MSW produced by 47% and 53%, respectively (Table 4-2 in the source). Total wastewater sludge production (from publicly-owned waste water treatment plants) was 208,000 tons. We assumed that contributions from the Residential and Commercial sectors were equal. Industrial sources are represented solely by pulp and paper mills. The sludge is a by-product of their production processes and is usually landfilled on paper company land.

Column: **B: Fraction Landfilled**

Source(s): Maine Waste Management Agency. 1993. State of Maine Waste Management and Recycling Plan. (Tables 4-1, 7-2).

Notes: This is the fraction of waste generated that is landfilled. Other disposal options include recycling and reuse, incineration, landspreading and composting. Up until about 1985, virtually all waste generated was landfilled. Since then, incineration and recycling options have become more common. The Maine Waste Management Agency predicts that the fraction of waste that is recycled will continue to increase at the expense of landfilling and incineration.

Column: **C: Degradable C Fraction (%)**

Source(s): (1) U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. D5-7).

(2) U.S. EP.A. 1979. Process Design Manual for Sludge Treatment and Disposal. MERL-ORD, EPA 625/1-79-011.

(3) Fernandez, I.J. 1995. Professor, Dept. of Applied Ecology and Environmental Science, University of Maine, Orono, ME. Personal interview.

(4) Zibilske, L.M. 1991. Soil Responses to Sludge Applications. Papermill sludges: Disposal options and environmental impacts seminar, University of Maine, Orono, ME. March 28.

Notes: Landfill waste is approximately 22% degradable carbon by weight. This is an average value and the actual values depend on the type of waste and its water content. Not all C in landfilled waste is degradable within the time period considered (about 50 years). Some is physically inaccessible to microorganisms and some is chemically resistant to decay. After sludge has been processed, which includes dewatering, it is composed of approximately 60 (+ 15%) water and the dry matter is 30 ($\pm$ 10) % carbon (Fernandez, pers. comm.). Other published values exhibit a range from 14 to 44% carbon by dry weight (U.S.E.P.A. 1979). So the C fraction of sludge is (0.3 x 0.4 =) 12%.

Column: **D: Dissimilated C (%)**

Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas

emission, 2nd ed. (pg. D5-3).
Tabasaran, O. 1981. Gas production from landfills. In (Bridgewater, A.V. and K Lidgren, eds.) Household Waste management in Europe: Economics and Techniques. Van Nostrand Reinhold Co., New York. pp 159-175.

Notes: During decomposition the end products can be classified as either dissimilated or assimilated C products. Dissimilated C, like CO_2 or methane, is released from microorganisms. Assimilated C is used to produce new microorganisms and is thereby stored in the landfill.

Column: **E: Methane fraction of Biogas (ton/ton)**

Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. D5-6).

Notes: This emissions factor represents the fraction of all biogas produced that is methane. The workbook states that approximately half the gas produced in landfills is methane and the remaining half is CO_2.

Column: **F: Methane Emission (tons)**

Source(s): (calculated)

Notes: Emissions of methane are estimated by calculating the amount of C degraded and multiplying that by the fraction dissimilated and the emissions factor.
column F = column A * column B * column C * column D * column E

Column: **G: Methane Emission (TTCDE)**

Source(s): (calculated)

Notes: The methane emissions in tons is converted to thousand tons of carbon dioxide equivalents (TTCDE) by multiplying by the GWP and dividing by 1000.
column G = column F * 22 / 1000

Column: **H: CO_2 Emissions (TTCDE)**

Source(s): (calculated)

Notes: This represents the amount of CO_2 generated during decomposition of landfilled carbon. Because this CO_2 comes from a renewable resource it will not be included in calculations of greenhouse gas emissions. The workbook states that equal volumes of methane and CO_2 are produced. So, the tons of methane emissions are used to calculate the tons of CO_2 produced concurrently. Then, the CO_2 emission in tons is converted to thousand tons of carbon dioxide equivalents (TTCDE) by dividing by 1000.
column H = column F * 44 / 16 / 1000

Data from Chapter 5. Waste Management

Table A.6. Methane Emissions from Wastewater Treatment

A	B	C	D	E	F	G	H	I
Population	BOD Generation Rate	BOD Generated	Anaerobic Fraction	Anaerobic BOD	Methane Emissions Factor	Methane Emission	Methane Recovered	Net Methane Emission
	(lbs/ cap/day)	(lbs/day)		(lbs/yr)	(lb/lb BOD)	(tons)	(tons)	(TTCDE)
1,241,928	0.1356	168,405	0.15	9,220,198	0.22	1,014	0	**22**

Table A.6. Methane Emissions from Wastewater Treatment

Column: **A: Population**
Source(s): Maine State Planning Office. 1994. The Comprehensive Energy Report for Maine, Draft. Augusta, ME.
Notes: This is the population of Maine in 1990.

Column: **B: BOD Generation Rate (lbs BOD / capita / day)**
Source(s): U.S.E.P.A. 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 12-2).
Notes: This is the national average amount of BOD generated each day per person in the U.S. No state specific data were available.

Column: **C: BOD Generated (lbs BOD / day)**
Source(s): (calculated)
Notes: Multiply the BOD Generation Rate by the population to get total BOD generated each day.
column C = column A * column B

Column: **D: Anaerobic Fraction**
Source(s): U.S.E.P.A. 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 12-2).
Notes: This represents the fraction of wastewater C that is treated anaerobically. The default value was chosen because no state-specific data were available. Because wastewater treatment systems are designed to be aerobic, the value of 0.15 is probably an overestimate. Only under anaerobic conditions will methane be generated.

Column: **E: Anaerobic BOD (lbs / year)**
Source(s): (calculated)
Notes: This is the amount of BOD that is treated anaerobically each year.
column E = column C * 365 * column D

Column: **F: Methane Emissions Factor (lbs methane / lb BOD)**
Source(s): U.S.E.P.A. 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 12-2).
Notes: The average amount of methane produced per pound of BOD treated anaerobically equals 0.22.

Column: **G: Methane Emission (tons)**
Source(s): (calculated)
Notes: The methane emissions in tons is calculated by multiplying the anaerobic BOD by the emissions factor.
column G = column E * column F / 2000

Column: **H: Methane Recovered (tons)**

Source(s): none
Notes: This represents the amount of methane recovered and burned by wastewater treatment facilities. To our knowledge this is not done in Maine.

Column: **I: Net Methane Emission (TTCDE)**
Source(s): (calculated)
Notes: The methane emissions in tons is converted to global warming potential by multiplying by the conversion factor.

column I = column G * 44 / 12 / 1000

Data from Chapter 6. Agriculture

Some agricultural operations lead to production of greenhouse gases or to net conversion of CO_2 to methane. Four sources of emissions were investigated in this inventory: domesticated animals, manure management, fertilizer use and blueberry field burning.

Methane is formed during the natural digestive process of all animals. Ruminant animals produce much greater quantities of methane than other animals. The amount of methane produced depends on the type of animal, its size and its food type. The Workbook specifies emission factors for each of the main animal types. These values are national means based on common animal raising practices. It is possible that these values will vary systematically among regions or within states in the U.S. The method requires data on the number of each type of animal in the state in 1990.

Decomposition of manure leads to production of CO_2 and methane. The relative amounts of these two C fractions depends on the availability of oxygen. CO_2 will dominate under aerobic conditions (when oxygen is plentiful), whereas methane will dominate under anaerobic conditions. The chosen method of manure management will determine whether decomposition is aerobic or anaerobic. For example, Daily Spread refers to collecting manure and bedding and applying it to fields on a regular basis. Manure spread over a large area in this manner will decompose aerobically. In contrast, Pit Storage is the practice of storing manure in a slurry form in a cement pit for periods of a few weeks to a few months. Manure in these systems will decompose anaerobically and generate mostly methane. Emissions from manure depend on the management system, the animal type and the quantity of manure produced. Environmental factors, such as temperature and rainfall, will also influence the emissions rate, but insufficient information is available to be able to include those factors.

Nitrous oxide (N_2O) is produced naturally in soils as a by-product of nitrogen transformations in soil (such as nitrification and denitrification). Fertilizing with N increases the rate of N transformations and thereby increases nitrous oxide production. The emissions factor for nitrous oxide depends on the type of fertilizer added. However, there has not been enough research on the effects of different fertilizer types, so for simplicity the Workbook recommends that a single emissions factor is used for all fertilizer types.

Burning of crop residues is a common practice in some parts of the world, but is uncommon in Maine. This potential source of emissions was omitted. However, blueberry fields in Maine are burned regularly. Burning is used to reduce weed competition, prune the plants and return nutrients to the soil. During burning, vegetative matter and soil organic matter are combusted releasing CO_2, methane and nitrous oxide. The CO_2 is released from a renewable C source and so is excluded from the inventory. Maine is one of the few states with large-scale blueberry production, so this is a state-specific emissions source. As a result we had to devise our own methodology. There is a trend of increasing reliance on flail mowers for pruning blueberry fields (D. Yarborough, pers. comm.). The mowing procedure does not involve burning and the crop residue is allowed to decompose on the soil surface. Thus, the only emissions from this procedure is from the fuel used to power the mower (this would be accounted for in Chapter 3).

There are two main methods of blueberry field burning. One involves the use of a flamethrower to ignite the field using 50 gallons of #2 fuel (Residual Oil) per acre. Using this method, the inventory must account for emissions from the organic matter burned as well as emissions from combustion of the fuel oil. Emissions from the fuel oil were counted in Chapter

3 (Commercial Sector - residual oil) when the fuel was sold to the farmer. The second method makes use of one ton of straw per acre (D. Yarborough, pers. comm.) as a fuel source. Emissions from fields employing this method come from vegetative matter, soil organic matter and straw.

Our estimation procedure was adapted from the methods used to calculate emissions from crop burning. First we had to determine the total quantity of C and N that was combusted in 1990. For that calculation we needed (1) acreage of blueberry fields, (2) mean biomass per acre of blueberries, and (3) C and N content of blueberry plants. Then we applied an emissions factor to that quantity. We used the open-burning emissions factors from the Workbook chapter on crop burning. Data were available for only a limited number of low-bush blueberry fields, so the appropriateness of applying these data to all Maine fields requires further research.

Table A.7. Methane Emissions from Domesticated Animals

	A	B	C	D
Animal Type	No. of Animals	Emission Factor	Methane Emission	Methane Emission
	(head)	(lbs/head/yr)	(tons)	(TTCDE)
Dairy Cattle				
Mature Cows	43,000	258.5	5,558	122.3
Replacements	17,000	128.5	1,092	24.0
Beef Cattle				
Mature Cows	16,000	135.3	1,082	23.8
Replacements	5,000	140	350	7.7
Bulls	2,000	220	220	4.8
Steers	5,000	76	190	4.2
Calves	26,000	46	598	13.2
Horses	28,000	39.6	554	12.2
Mules/Asses	105	48.5	3	0.1
Sheep	20,000	17.6	176	3.9
Goat	1,220	11	7	0.1
Swine	9,900	3.3	16	0.4
TOTAL			**9,846**	**217**

Table A.7. Methane Emissions from Domesticated Animals

Column: **A: No. of Animals (head)**

Source(s): (1) Bureau of Census. 1992. Census of Agriculture, U.S. Dept. of Commerce, U.S. Government Printing Office, Washington DC Vol. 1, Pt. 19.

(2) U.S. Dept. of Agriculture. 1991. Agricultural Statistics. U.S. Government Printing Office.

(3) U.S. Dept. of Agriculture. 1992. Agricultural Statistics. U.S. Government Printing Office.

(4) Libby, Russell, Research Director, Maine Dept. of Agriculture. 1994. Personal Interview.

(5) American Horse Council. 1987. New England Farm Bulletin

Notes: Cattle numbers are from source #2, Table 388. Swine and sheep number are from source #3, Tables 401 and 420. Mules and goats are from source #1, Table 40. Number of horses was estimated by R. Libby because the Census of Agriculture does not include horse farms or horses not on farms. His estimate was derived from source #5.

Column: **B: Emissions Factor (lbs methane/head/year)**

Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. D6-3).

Notes: This emissions factor represents the amount of methane generated per animal each year. These are national averages for each animal type.

Column: **C: Methane Emissions (tons)**

Source(s): (calculated)

Notes: Methane emissions equal the number of animals times the emission factor and converted into tons.

column C = column A * column B / 2000

Column: **D: Methane Emissions (TTCDE)**

Source(s): (calculated)

Notes: Methane emissions in tons are converted into TTCDE by multiplying by the GWP and dividing by 1000.

column D = column C * 22 / 1000.

Table A.8. Methane Emissions from Animal Manure

	A	B	C	D	E	F	G	H	I	J	K
Animal Type	No. of Animals	Animal Mass	VS* per mass	Total VS	Max. CH4 Prod.	Potential Emissions	Mgmt.# Type	Mgmt. Usage	Emissions Factor	Methane Emissions	Methane Emissions
	(head)	(lbs/head)	(lbs/lbs/yr)	lbs	(ft3/lbs VS)	(ft3)				(tons)	(TTCDE)
Beef Cattle											
Calves	26,000	397	2.6	26,837,200	2.72	72,997,184	PA	1	0.008	12.1	0.3
Heifers	5,000	794	2.6	10,322,000	2.72	28,075,840	PA	1	0.008	4.6	0.1
Steers	5,000	794	2.6	10,322,000	2.72	28,075,840	PA	1	0.008	4.6	0.1
Cows	16,000	1102	2.6	45,843,200	2.72	124,693,504	PA	1	0.008	20.6	0.5
Bulls	2,000	1587	2.6	8,252,400	2.72	22,446,528	PA	1	0.008	3.7	0.1
										45.6	**1.0**
Dairy Cattle											
Heifers	17,000	903	3.65	56,031,150	3.84	215,159,616	LS	0.29	0.155	199.7	4.4
							DS	0.58	0.002	5.2	0.1
							SS	0.13	0.008	4.6	0.1
Cows	43,000	1,345	3.65	211,097,750	3.84	810,615,360	LS	0.29	0.155	752.4	16.6
							DS	0.58	0.002	19.4	0.4
							SS	0.13	0.008	17.4	0.4
										998.7	**22.0**
Swine											
Market	8,700	101	3.1	2,723,970	7.53	20,511,494	AL	0.03	0.9	11.4	0.3
							DL	0.53	0.008	1.8	0.0
							P<1	0.02	0.075	0.6	0.0
							P>1	0.42	0.155	27.6	0.6
Breeding	1,200	399	3.1	1,484,280	5.77	8,564,296	AL	0.03	0.9	4.8	0.1
							DL	0.53	0.008	0.7	0.0
							P<1	0.02	0.075	0.3	0.0
							P>1	0.42	0.155	11.5	0.3
										58.7	**1.3**

*VS = volatile solids

#Management Types: PA = pasture; LS=Liquid slurry; DS=Daily spread; SS=Solid storage; AL= Anaerobic Lagoon; DL=Drylot; P>1=pit storage > 1 month; P<1=pit storage< 1 month; DP=Deep pit stacks; L=litter; PD=Paddock.

Table A.8. Methane Emissions from Animal Manure (cont'd)

	A	B	C	D	E	F	G	H	I	J	K
Animal Type	No. of Animals	Animal Mass	VS* per mass	Total VS	Max. CH4 Prod.	Potential Emissions	Mgmt.# Type	Mgmt. Usage	Emissions Factor	Methane Emissions	Methane Emissions
	(head)	(lbs/head)	(lbs/lbs/yr)	lbs	(ft3/lbs VS)	(ft3)				(tons)	(TTCDE)
Poultry											
Layers	4,013,000	3.5	4.4	61,800,200	5.45	336,811,090	DP	0.81	0.1	563.4	12.4
							LS	0.09	0.155	97.0	2.1
							O	0.1	0.07	48.7	1.1
Broilers	52,576	1.5	6.2	488,957	4.81	2,351,882	L	1	0.1	4.9	0.1
Turkeys	2,530	7.5	3.32	62,997	4.81	303,016	L	1	0.1	0.6	0.0
										714.6	**15.7**
Other											
Sheep	20,000	154	3.36	10,348,800	3.04	31,460,352	PA	0.66	0.008	3.4	0.1
							O	0.34	0.07	15.5	0.3
Goats	1,220	141	3.48	598,630	2.72	1,628,273	PA	1	0.008	0.3	0.0
Donkeys	105	661	3.65	253,328	5.29	1,340,106	PA	1	0.008	0.2	0.0
Horses	28,000	992	3.65	101,382,400	5.29	536,312,896	PD	0.35	0.008	31.0	0.7
							PA	0.65	0.008	57.6	1.3
										108.0	**2.4**
TOTAL										**1,926**	**42.4**

*VS = volatile solids

#Management Types: PA = pasture; LS=Liquid slurry; DS=Daily spread; SS=Solid storage; AL= Anaerobic Lagoon; DL=Drylot; P>1=pit storage > 1 month; P<1=pit storage< 1 month; DP=Deep pit stacks; L=litter; PD=Paddock.

Table A.8. Methane Emissions from Animal Manure

Column: **A: No. of Animals (head)**
Source(s): (1) Bureau of Census. 1992. Census of Agriculture, U.S. Dept. of Commerce, U.S. Government Printing Office, Washington DC Vol. 1, Pt. 19.
(2) U.S. Dept. of Agriculture. 1991. Agricultural Statistics. U.S. Government Printing Office.
(3) U.S. Dept. of Agriculture. 1992. Agricultural Statistics. U.S. Government Printing Office.
(4) Libby, Russell, Research Director, Maine Dept. of Agriculture. 1994. Personal Interview.
(5) American Horse Council. 1987. New England Farm Bulletin
Notes: Cattle numbers are from source #2, Table 388. Swine and sheep number are from source #3, Tables 401 and 420. Mules, poultry, turkeys and goats are from source #1, Tables 20 and 40. Number of horses was estimated by R. Libby because the Census of Agriculture does not include horse farms or horses not on farms. His estimate was derived from source #5.

Column: **B: Animal Mass (lbs/head)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 7-12).
Notes: Typical animal mass for each animal type was obtained from the Workbook.

Column: **C: Volatile Solids per mass (lbs VS / lbs animal mass / yr)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 7-12).
Notes: Volatile solids is the portion of manure that is potentially biodegradable (i.e., organic). Average values for each animal type were obtained from the Workbook.

Column: **D: Total Volatile Solids (lbs)**
Source(s): (calculated).
Notes: Total volatile solids produced in 1990 by each animal type is calculated by multiplying the number of animals, animal mass and VS/mass.
column D = column A * column B * column C

Column: **E: Maximum Methane Production (ft^3 methane / lb volatile solids)**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 7-12).
Notes: These values were obtained from the Workbook and represent the average methane production potential of different types of manure under ideal conditions.

Column: **F: Potential Emissions (ft^3 methane)**
Source(s): (calculated)
Notes: This is the product of methane production potential and total VS. It represents the maximum amount of methane that could be produced if all C in the manure was converted to methane.

column F = column D * column E

Column: **G: Management Type**

Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. D7-6).

Notes: For each animal type all the manure management systems employed are listed. For some animals only one type of system is used. For other animals, several management systems are in use in Maine.

Column: **H: Management Usage (fraction)**

Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pp. 7-5 to 7-10).

Notes: This number is the relative frequency of use of each management type. For example, only one type of management system is used for beef cows (Pasture), so the value is 1.0 (100%). For horses, 35% of farms use the Paddock system and 65% use the Pasture system, so the values are 0.35 and 0.65, respectively. Values for each state and animal type are given in the Workbook.

Column: **I: Emissions factor**

Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 7-13).

Notes: This emissions factor represents the fraction of potential methane production that is actually produced. Under extreme anaerobic conditions (anaerobic lagoons), the emission factor is high (0.90). Under aerobic conditions, such as pasture, the emission factor is quite low (0.008). Values were obtained from the Workbook.

Column: **J: Methane Emissions (tons)**

Source(s): (calculated)

Notes: Methane emissions were calculated by dividing up the potential methane production by management type and its frequency. Then the emissions factor for that management type was applied to the corresponding fraction of potential methane production.

column J = column F * column H * column I * 0.0413 lb/ft^3 / 2000

Column: **K: Methane Emissions (TTCDE)**

Source(s): (calculated)

Notes: Methane emissions in tons are converted into TTCDE by multiplying by the GWP and dividing by 1000.

column K = column J * 22 / 1000

Data from Chapter 6. Agriculture

Table A.9. Nitrous Oxide Emissions From Fertilizer Use

				A	B	C	D	E
	Fertilizer Consumption							
Fertilizer	1989	1990	1991	3-yr. Mean	Emissions Factor	N2O-N Emissions	N2O Emissions	N2O Emissions
	(tons N)	(tons N)	(tons N)	(tons N)		(tons N)	(tons)	(TTCDE)
Ammonium Sulfate	50	50	50	50	0.0117	0.58	0.92	0.25
Ammonium Nitrate	1,891	595	615	1,033	0.0117	12.09	19.00	5.13
Sodium Nitrate	0	0	0	0	0.0117	0.00	0.00	0.00
Urea	1,365	1,492	1,305	1,387	0.0117	16.23	25.50	6.89
Ammonium Phosphate		938	1,285	1,112	0.0117	13.01	20.44	5.52
Anhydrous Ammonia	0	0	21	7	0.0117	0.08	0.13	0.04
Aqua Ammonia	0	0	0	0	0.0117	0.00	0.00	0.00
Nitrogen solutions	277	253	268	266	0.0117	3.11	4.89	1.32
Calcium Nitrate	0	0	0	0	0.0117	0.00	0.00	0.00
Potassium Nitrate		10	115	62	0.0117	0.73	1.15	0.31
Other N	45	30	121	65	0.0117	0.76	1.20	0.32
TOTAL							**73.22**	**19.77**

Table A.9. Nitrous Oxide Emissions from Fertilizer use

Column: **A: Mean Fertilizer Consumption (tons N)**
Source(s): (1) Tennessee Valley Authority. 1989. Commercial Fertilizers. National Fertilizer and Environmental Research Center, Muscle Shoals, Alabama. (pp. 6-7)
(2) Tennessee Valley Authority. 1991. Commercial Fertilizers. National Fertilizer and Environmental Research Center, Muscle Shoals, Alabama. (pp. 10-11)
Notes: A three year mean was required because fertilizer use varies considerably from year to year. Values were obtained from the sources and converted into tons of N using conversion factors in the same sources.

Column: **B: Emissions Factor**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. 9-4).
Notes: This emissions factor represents the fraction of applied fertilizer that is converted into nitrous oxide. For simplicity the same factor is used for all fertilizer types.

Column: **C: Nitrous Oxide-N Emissions (tons N)**
Source(s): (calculated)
Notes: N emissions in tons of N are calculated by multiplying the fertilizer used by the emissions factor.
column C = column A * column B

Column: **D: Nitrous oxide Emissions (tons)**
Source(s): (calculated)
Notes: N emissions in tons are calculated by converting tons of N into tons of N_2O.
column D = column C * 44/28

Column: **E: Nitrous Oxide Emissions (TTCDE)**
Source(s): (calculated)
Notes: Nitrous oxide emissions in tons are converted into TTCDE by multiplying by the GWP and dividing by 1000.
column E = column D * 270 / 1000

Data from Chapter 6. Agriculture

Table A.10. Emissions from Blueberry Field Burning

	A	B	C	D	E	F	G	H	I	J	K
Method	Area	O.M. Burned	C Content	Total C Burned	CO2 Emissions	Methane Emissions	Methane Emissions	C:N ratio	Total N Burned	N2O Emissions	N2O Emissions
	(acre)	(lbs/ac)		(tons)	(TTCDE)	(tons)	(TTCDE)		(tons)	(tons)	(TTCDE)
Straw	2,610	4,166	0.47	2,555	8.24	10.22	0.22	70	36	0.40	0.11
Flamethrower	17,550	785	0.45	3,100	10.00	0.99	0.02	70	44	0.49	0.13
Flail Mower	9,840	785	0.45	1,738	6.37						
TOTAL	**30,000**				**24.62**		**0.25**				**0.24**

Table A.10. Emissions from Blueberry Field Burning

Column: **A: Area (acres)**
Source(s): Yarborough, David. 1994. Blueberry Extension Specialist, Cooperative Extension, University of Maine, Orono. Personal Interview.
Notes: There are approximately 60,000 acres in production, we assumed that 30,000 acres were burned each year (two-year cycle). A survey of Maine blueberry growers revealed that 58.5% used flame throwers, 8.7% used straw and 32.7% used flail mowers. These percentages were applied to the 30,000 acres to obtain the acreage.

Column: **B: Organic matter burned (lbs O.M. / acre)**
Source(s): Smith, D.W. and R.J. Hilton. 1972. The comparative effects of pruning by burning or clipping on lowbush blueberries in north-eastern Ontario. Journal of Applied Ecology, Vol. 8. (pp. 781-789)
Notes: The amount of organic matter burned was taken from the source in which all three types of pruning were attempted. The value under the straw burn includes one ton of straw per acre.

Column: **C: Carbon Content**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. D11-3).
Notes: Carbon content of the vegetation was estimated from values listed in the workbook. An average value of 0.45 was selected for blueberry plants. A slightly higher value was used in the straw-burn method because oat straw has a higher than average C content.

Column: **D: Total Carbon Burned**
Source(s): (calculated)
Notes: Total C burned (or clipped in the case of the flail mower) is the product of area, O.M. burned and C content.
column D = column A * column B * column C / 2000

Column: **E: CO_2 Emissions (TTCDE)**
Source(s): (calculated)
Notes: CO_2 emissions in tons C were calculated by multiplying the total C burned by an emissions factor for burning of crop residues. For CO_2 this value is 0.88 (Workbook page D11-2). Emissions are then converted to TTCDE.
column E = column D * 0.88 * 44 / 12 / 1000

Column: **F: Methane Emissions (tons)**
Source(s): (calculated)
Notes: Methane emissions in tons were calculated by multiplying the total C burned by an emissions factor for burning of crop residues. For methane this value is 0.003. (Workbook page D11-4).
column F = column D * 0.003 * 16 / 12

Column: **G: Methane Emissions (TTCDE)**
Source(s): (calculated)
Notes: Emissions are then converted to TTCDE.
column G = column F * 22 / 1000

Column: **H: Carbon to Nitrogen Ratio**
Source(s): U.S.E.P.A., 1995. State Workbook: Methodologies for estimating greenhouse gas emission, 2nd ed. (pg. D11-3).
Notes: This is the ratio of carbon to nitrogen in plant tissue.

Column: **I: Total N burned (tons N)**
Source(s): (calculated)
Notes: The total C burned was divided by the C:N ratio to obtain the amount of N in plant tissue that was burned.
column I = column D / column H

Column: **J: Nitrous Oxide Emissions (tons)**
Source(s): (calculated)
Notes: Nitrous oxide emissions in tons were calculated by multiplying the total N burned by an emissions factor for burning of crop residues. For nitrous oxide this value is 0.007 (Workbook page D11-4).
column J = column I * 0.007 * 44 / 28

Column: **K: Nitrous Oxide Emissions (TTCDE)**
Source(s): (calculated)
Notes: Emissions are then converted to TTCDE.
column K = column J * 270 / 1000

Data from Chapter 7. Land Use

Many land use practices affect the production or storage of greenhouse gases. Most of these, however, are either natural fluxes of the C cycle or temporary changes. A few land management practices, however, may have significant, permanent impacts on the C cycle or greenhouse gas emissions. Permanent (or at least long-term) changes in land use may affect the C storage capacity of a state. For example, clearing of a large area of forest for conversion into housing developments will reduce the C storage capacity of that area. That means that less CO_2 will be absorbed in that area each year leaving more CO_2 in the atmosphere. Information that is crucial for assessing the effects of forest conversion on greenhouse gases is knowing into what the forests are converted. Or if forest area is increasing, from what is it being converted? This information is lacking in Maine and probably most of the U.S. Nevertheless, forest conversion into other land uses is one land use practice that should be considered.

Loss of wetlands by draining or filling is another land use practice that may affect greenhouse gas emissions. In essence, wetlands convert atmospheric CO_2 to soil organic carbon and methane gas. Some of the soil carbon is stored and effectively removed from the global carbon cycle (unless the wetland is drained). The methane is released into the atmosphere. Because methane has a greater GWP than CO_2, temperate wetlands are a net source of global warming. Therefore, one would assume that loss of wetlands would tend to reduce greenhouse gas emissions. This may or may not be true because of other complicating factors. For example, draining a wetland will cause methane emissions to cease, but the soil organic carbon that was stored will begin to decompose rapidly, releasing the carbon that was accumulated over hundreds or thousands of years. This release of fossil carbon may cancel out any benefit of reduced methane emissions. All of these factors further depend on wetland type, water depth, vegetation type and hydrology. More research is needed before we can accurately predict C dynamics in an altered wetland.

Carbon stored in forest biomass is still an active part of the global carbon cycle and should not be considered permanent storage or C removal from the cycle. Wildfires are vivid reminders that forest carbon can be reintroduced into the global C cycle at any time. However, in most cases the period of storage is long enough (years to decades), that it warrants inclusion in this inventory.

Another reason why carbon storage by forests is included in this inventory is that forestry practices can have a significant impact on net greenhouse gas emissions. Information in Chapter 7 revealed that a small change in harvesting practices would have a much larger relative effect on greenhouse gas emissions. Carbon storage by forests equals the C accumulated during tree growth minus the C removed by harvesting. Both of these factors vary each year. C accumulation depends on climate, age of the trees and available nutrients. Harvesting depends on climate and the economics of the forest products industry.

Data from Chapter 7. Land Use

Table A.11. Carbon Accumulation in Forests

	A	B	C	D	E	F	G	H
Forest Type	Forest Area	Stemwood Growth Rate	Expansion Factor	Conv. Factor	Annual Biomass Increment	Dry matter C Content	Total C Storage	Total C Storage
	(1000 ac)	(ft3/ac/yr)	(ft3/ft3)	lbs dm/ft3	(1000 t /yr)	(t C/t dm)	(1000 t C/yr)	(TTCDE)
Spruce-Fir	5,938	35.47	2.19	24.7	5,706	0.521	2,973	10,900
White Pine	1,527	29.08	2.19	24.7	1,203	0.521	627	2,298
Hemlock	654	21.86	2.19	24.7	387	0.521	202	740
Cedar-Larch	1,708	28.29	2.19	24.7	1,309	0.521	682	2,501
N. Hardwood	5,049	30.86	2.14	31.3	5,210	0.498	2,595	9,514
Aspen-Birch	1,431	29.12	2.14	31.3	1,393	0.498	694	2,544
Oak	263	32.88	2.14	31.3	289	0.498	144	527
Old-Field Hdwd.	245	30.86	2.14	31.3	253	0.498	126	462
TOTAL	**16,816**				**15,751**		**8,042**	**29,487**

Table A.11. Carbon Accumulation in Forests

Column: **A: Forest Area (1000 acres)**

Source(s): Seymour, R.S. and R.C. Lemin, Jr. 1989. Timber supply projections for Maine, 1980-2000. CFRU Research Bulletin No. 7., Maine Agricultural Experiment Station, Orono, ME. (Table 1).

Notes: Forest area data was from 1980-82, but this is the most recent comprehensive survey of Maine's forests. Other sources reveal that forested area in Maine has changed very little between 1982 and 1992, so we expect these values to be reasonable estimates of forested area in 1990. The Forest Inventory will be repeated in the mid-1990's using the same methods.

Column: **B: Stemwood Growth Rate (ft^3 wood / acre / year)**

Source(s): Seymour, R.S. and R.C. Lemin, Jr. 1991. Empirical yields of commercial tree species in Maine. CFRU Research Bulletin No. 8, Maine Agricultural Experiment Station, Orono, ME.

Notes: Growth rate varies with the age of trees, so growth rates were estimated between tree ages of 15 and 70 years of age. The source provides tables containing average stemwood volume at different ages for each of the forest types. Stemwood Growth rate was taken as the slope of the best-fit (by least squares) line to these data.

Column: **C: Expansion Factor (ft^3/ft^3)**

Source(s): Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. U.S.D.A. Forest Service, General Technical Report WO-59. (Table 1.1)

Notes: The growth rate in column B refers only to stemwood growth. The expansion factor converts merchantable volume into total volume, which includes branches and foliage.

Column: **D: Conversion Factor (lbs dry matter / ft^3)**

Source(s): Seymour, R.S. and R.C. Lemin, Jr. 1989. Timber supply projections for Maine, 1980-2000. CFRU Research Bulletin No. 7., Maine Agricultural Experiment Station, Orono, ME. (pg. 36).

Notes: This factor converts ft^3 of wood to lbs dry matter. The equations are listed below for softwoods and hardwoods. The first number represents the lbs of dry matter per cord. The second number represents the ft^3 of wood per cord and the last number is the ratio of dry weight to wet weight.
Conversion Factor (softwoods) = 4200 / 85 * 0.5
Conversion Factor (hardwoods) = 5000 / 80 * 0.5

Column: **E: Annual Biomass Increment (1000 tons dry matter / year)**

Source(s): (calculated)

Notes: This number represents the total accumulation of biomass in Maine forests in a year.
column E = column A * column B * column C * column D / 2000

Column: **F: Carbon Content of Dry Matter (tons C / ton dry matter)**

Source(s): Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. U.S.D.A. Forest Service, General Technical Report WO-59. (Table 1.2)

Notes: This is the average carbon content of dry wood.

Column: **G: Total C Uptake by Trees (1000 tons C / year)**
Source(s): (calculated)
Notes: The C content of wood is multiplied by the wood (dry matter) production to obtain C uptake and storage by trees.
column G = column E * column F

Column: **H: CO_2 Removal from the atmosphere by Accumulation (TTCDE)**
Source(s): (calculated)
Notes: Atmospheric CO_2 removal in TTCDE was calculated by converting from 1000 tons C to 1000 tons CO_2.
column H = column G* 44 / 12

Data from Chapter 7. Land Use

Table A.12. Carbon Removal from Forests

	A	B	C	D	E	F	G
Harvest Categories	Commercial Timber Harvested	Conversion Factor	Commercial Timber Harvested	Expansion Factor	Total Biomass Harvested	Carbon Content	Carbon Harvested
	(cords)	(gr. ton/cord)	(1000 tons)		(1000 tons)	(t C/t)	(1000 t C)
Sawlog							
softwd	1,508,780	2.1	1,584	2.19	3,474	0.521	1,810
hdwd	509,532	2.5	637	2.14	1,363	0.498	679
Pulp and Paper							
softwd	1,868,022	2.1	1,961	2.19	4,301	0.521	2,241
hdwd	1,366,476	2.5	1,708	2.14	3,655	0.498	1,820
Biomass Chips							
all	683,497	2.5	854	1.00	854	0.510	436
TOTAL					**13,648**		**6,986**

H	I	J	K	L	M	N
Commercial Carbon Harvested	Residential Fuelwood Consumed	Total Carbon Released	Potential CO2 Released	Total C Stored	Net C Storage	Net CO2 Storage
(1000 t C)	(1000 t C)	(1000 t C)	(TTCDE)	(1000 t C)	(1000 t C)	(TTCDE)
6,986	382	7,368	27,016	8,042	674	**2,472**

Table A.12. Carbon Removal from Forests and Net C Storage by Forests

Column: **A: Commercial Timber Harvested**
Source(s): Forest Information Center. 1992. 1990 Woodprocessor Report. Maine Department of Environmental Protection - Forest Service, Augusta, ME.
Notes: This data represents all wood processed by mills in Maine and whole-tree chippers plus wood harvested from Maine's forests and exported before processing.

Column: **B: Conversion Factor (green ton / cord)**
Source(s): Seymour, R.S. and R.C. Lemin, Jr. 1989. Timber supply projections for Maine, 1980-2000. CFRU Research Bulletin No. 7., Maine Agricultural Experiment Station, Orono, ME. (pg. 36).
Notes: These factors were used to convert cords into green (wet) tons.

Column: **C: Commercial Timber Harvested (1000 tons dry matter)**
Source(s): (calculated)
Notes: This is calculated by converting timber harvested in cords to tons dry matter. The last factor in the following equation is the ratio of dry weight to wet (green) weight.
column C = column A * column B * 0.5 / 1000

Column: **D: Expansion Factor**
Source(s): Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. U.S.D.A. Forest Service, General Technical Report WO-59. (Table 1.1)
Notes: The expansion factor converts merchantable volume into total volume, which includes branches and foliage.

Column: **E: Total Biomass Harvested (1000 tons dry matter)**
Source(s): (calculated)
Notes: The commercial timber harvested is multiplied by the Expansion Factor to account for branches and foliage that are left in the forest.
column E = column C * column D

Column: **F: Carbon Content of Dry Matter (tons C / ton dry matter)**
Source(s): Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. U.S.D.A. Forest Service, General Technical Report WO-59. (Table 1.2)
Notes: This is the average carbon content of dry wood.

Column: **G: Carbon Harvested Commercially (1000 tons C)**
Source(s): (calculated)
Notes: C harvested commercially from Maine forests is the biomass harvested times the C content of biomass.
column G = column E * column F

Column: **H: Carbon Harvested Commercially (1000 tons C)**
Source(s): (calculated)
Notes: This number is simply carried over from column G.

Column: **I: Residential Fuelwood Consumed (1000 tons C)**
Source(s): Table A.3, this document.
Notes: This value is taken from Table A.3. - Biomass Fuels and represents wood harvest over and above that processed by mills. We assumed that most residential fuelwood consumers either cut their own wood or bought if from a private source and for those reasons we assumed it was not included in the commercial harvest figures.

Column: **J: Total Carbon Released**
Source(s): (calculated)
Notes: Total C harvested from Maine forests (and assumed to be released to the atmosphere) is the C harvested commercially plus the residential fuelwood consumed.
column J = column H + column I

Column: **K: Potential CO_2 Released (TTCDE)**
Source(s): (calculated)
Notes: This is the global warming potential of C released from forest harvesting assuming it is all converted to CO_2..
column K = column J * 44 / 12

Column: **L: Total C Stored (1000 tons C)**
Source(s): Table A.11, this document.
Notes: This number is carried over from Table A.11. - Carbon Accumulation in Forests, column G.

Column: **M: Net C Storage (1000 tons C)**
Source(s): (calculated)
Notes: Net C storage is the C Released minus the C Stored.
column M = column J - column L

Column: **N: Net CO_2 Storage (TTCDE)**
Source(s): (calculated)
Notes: Net CO_2 storage is calculated from the tons of C stored.
column N = column M * 44 / 12

Data from Chapter 7. Land Use

Table A.13. Forest Conversion: Loss of C storage capacity

	A	B	C	D	E	F
Land Type Converted	1987 Area	1992 Area	Annual Forest Conversion	Forest C Storage	C Storage Lost	**CO2 Storage Lost**
	(1,000 acres)	(1,000 acres)	(acres/yr)	(lbs/ac)	(tons C/yr)	(TTCDE/yr)
Forest	17,584	17,557	5,440	62,444	169,848	**623**

Table A.14. Natural methane production in wetlands

	A	B	C	D	E	F
Land Type Converted	1992 Area	Wetland CO2 Absorption	Wetland Methane Production	Total CO2 Absorption	Total Methane Production	**Net Emissions**
	(1,000 acres)	(lbs/ac/yr)	(lbs/ac/yr)	(TTCDE/yr)	(TTCDE/yr)	(TTCDE/yr)
Wetland	5,511.7	753	71	2,075	4,330	**2,255**

Table A.13. Forest Conversion: Loss of C Storage Capacity

Column: **A: 1987 Forested Area (1,000 acres)**
Source(s): Soil Conservation Service. 1994. Summary Report: 1992 National Resources Inventory. U.S. Department of Agriculture, Washington, DC. (Table 2)
Notes: Forested area in Maine was determined in 1987 by the Soil Conservation Service using aerial photographs as well as field visits to many sites in Maine.

Column: **B: 1992 Forested Area (1,000 acres)**
Source(s): Soil Conservation Service. 1994. Summary Report: 1992 National Resources Inventory. U.S. Department of Agriculture, Washington, DC. (Table 2)
Notes: Forested area in Maine was determined in 1992 by the Soil Conservation Service using aerial photographs as well as field visits to many sites in Maine.

Column: **C: Annual Forest Conversion (acres / year)**
Source(s): (calculated)
Notes: This represents the number of acres converted from forest to other uses on an annual basis. The total decrease in forest area between 1987 and 1992 was divided by five years.
column C = (column A - column B) * 1000 / 5

Column: **D: Forest C Storage (lbs. C / acre)**
Source(s): Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. U.S.D.A. Forest Service, General Technical Report WO-59. (Table 2.2)
Notes: This represents the average amount of carbon stored in Maine forests in the vegetation and forest floor. These are the components that would normally be removed in forest conversion. The carbon stored in mineral soil was assumed to be left in place after conversion. The actual amount of forest C storage lost will depend on the subsequent use of the land and how much C the use will hold.

Column: **E: C Storage Lost (tons C / yr)**
Source(s): (calculated)
Notes: This represents the total C storage lost in 1990 from forest conversion.
column E = column D * column C / 2000

Column: **F: CO_2 Storage Lost (TTCDE / yr)**
Source(s): (calculated)
Notes: This represents the total C storage lost in 1990 from forest conversion. Tons of C were converted into TTCDE. We assume that the biomass removed during conversion was already accounted for in Table A.11: C release by Harvesting and so is not included in calculation of the Land Use impacts on the Augmented Greenhouse Effect. The total from this column makes up a part of that total.
column F = column E * 44 / 12 / 1000

Table A.14. Natural Emissions from Wetlands

Column: **A: 1992 Wetland Area (1,000 acres)**
Source(s): Soil Conservation Service. 1994. Summary Report: 1992 National Resources Inventory. U.S. Department of Agriculture, Washington, DC. (Table 15)
Notes: Wetland area in Maine was determined in 1992 by the Soil Conservation Service using aerial photographs as well as field visits to many sites in Maine.

Column: **B: Wetland CO_2 Absorption (lbs CO_2 / acre / yr)**
Source(s): Frolking, S. 1993. Regional freshwater wetlands and their trace gas exchange with the atmosphere. *In* Proceedings of A Regional Response to Global Climate Change: New England and Eastern Canada, Portland, ME May 19-21.
Notes: This value represents the average flux of CO_2 into long-term storage in the deep, peat soils. Wetland systems vary considerably in terms of soil moisture, soil depth and microbial activity. Thus, this value is merely an approximation.

Column: **C: Wetland Methane Production (lbs methane / acre /yr)**
Source(s): Frolking, S. 1993. Regional freshwater wetlands and their trace gas exchange with the atmosphere. *In* Proceedings of A Regional Response to Global Climate Change: New England and Eastern Canada, Portland, ME May 19-21.
Notes: This value represents the average flux of CO_2 into organic C and then into methane. Wetland systems vary considerably in terms of soil moisture, soil depth and microbial activity. Thus, this value is merely an approximation.

Column: **D: Total CO_2 Absorption (TTCDE / yr)**
Source(s): (calculated)
Notes: This is the total amount of CO_2 absorbed annually by wetlands in Maine.
column D = column A * 1000 * column B / 2000 / 1000

Column: **E: Total Methane Production (TTCDE / yr)**
Source(s): (calculated)
Notes: This is the total amount of methane produced annually by wetlands in Maine.
column E = column A * 1000 * column C / 2000 * 22 / 1000

Column: **F: Net Emissions (TTCDE / yr)**
Source(s): (calculated)
Notes: This is the average net emissions of greenhouse gases (CO_2 and methane) from Maine wetlands each year in terms of global warming potential. This is a natural flux and, therefore, is not used in the calculation of greenhouse gas emissions in this inventory.
column F = column E - column D

Appendix B

Table B.1. Relative accuracy of estimates

Table B.1. is intended to serve as an indicator of where future research or monitoring efforts should be increased. The accuracy classes are assigned subjectively and are not based on any statistical test or analysis. A value of high accuracy was assigned to those estimates based on actual measured values and known conversion factors. A value of low accuracy was assigned to those estimates that had more than one of the following attributes: (a) data was estimated but not measured, (b) unknown variables affected emission factors, or (c) contributing factors were omitted based on lack of empirical evidence. A value of moderate accuracy was assigned to those estimates that fell in between.

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Table B.1. Relative Accuracy of Emission Estimates

Source	Relative Accuracy*
Energy Production	
Fossil Fuels	
Residential	high
Commercial	high
Industrial	high
Transportation	high
Utilities	high
Biomass Fuels	mod
Industry	
Cement Production	high
Waste Management	
Landfills	low
Wastewater	low
Agriculture	
Domesticated Animals	high
Animal Manure	low
Fertilizer Use	low
Blueberry Cultivation	mod
Land Use	
Storage by Forests	mod

*High accuracy is within: 10%
Mod. accuracy is within: 10 - 50%
Low accuracy is within: 50 - 100%

Appendix C

Additional References

Appendix C. Additional References for Compiling National and State Greenhouse Gas Emissions Inventories

General Inventory Information

EIA. *Emissions of Greenhouse Gases in the United States*, DOE/EIA-0573. DOE, EIA, Office of Energy Markets and End Use. Annual.
Contact: Louise Guey-Lee (EIA), 202-586-1156.

USEPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993*, EPA, EPA 230-R-94-014. USEPA, Office of Policy Planning and Evaluation, Washington, DC. September 1994.
Note: This is the official U.S. submission to the IPCC. State level methods were based on those used to derive this document.
Contact: Bill Hohenstein (USEPA), 202-260-7019.

Fuel Combustion

Energy Information Administration (EIA). *State Energy Data Report*, DOE/EIA-0214. DOE, EIA, Office of Energy Markets and End Use. Annual.
Note: Presents extensive state level fossil fuel comsumption statistics.
Contact: Julia F. Hutchins (EIA), 202-586-5138.

EIA. *Petroleum Supply Annual*, DOE/EIA-0340. DOE, EIA, Office of Oil and Gas. Annual.
Note: Presents mostly national, but some state level petroleum data.
Contact: Ronald W. O'Neill (EIA), 202-586-9884.

EIA. *Natural Gas Annual*, DOE/EIA-0131. DOE, EIA, Office of Oil and Gas. Annual.
Note: Presents mostly national, but some state level natural gas data.
Contact: Kendrick E. Brown (EIA), 202-586-9884.

EIA. *Coal Industry Annual*, DOE/EIA-0584. DOE, EIA, Office of Coal, Nuclear, Electric and Alternate Fuels. Annual.
Contact: Frederick L. Freme (EIA), 202-254-5367

EIA. *Quarterly Coal Report*, DOE/EIA-0121, DOE, EIA, Office of Coal, Nuclear, Electric and Alternate Fuels. Quarterly.
Contact: National Energy Information Center, 202-586-8800.

Non-Fuel Use

EIA. *Annual Energy Review*, DOE/EIA-0384. DOE, EIA, Office of Energy Markets and End Use. Annual.
Note: Contains only aggregate national data. Quantities for specific uses have not been well documented.
Contact: W. Calvin Kilgore (EIA), 202-586-1617.

International Bunker Fuels and Mobile Sources

EIA. *Fuel Oil and Kerosene Sales*. DOE/EIA-0535. DOE/EIA, Office of Oil and Gas. Annual.
Note: Contains state level data for residual oil and distillate oil for various transportation categories. Use the "adjusted" data.
Contact: Alice Lippert (EIA), 202-586-9600.

Federal Aviation Administration (FAA). *Fuel Cost and Consumption Survey*. DOT, FAA, DAI-10. Monthly.
Note: Records national level data on airline fuel consumption by U.S. carriers.
Contact: Pat Beardsley (FAA) 202-267-8032

FAA. *General Aviation Activity Survey*, Report FAA-APO-93-10. DOT, FAA, Office of Aviation Policy, Plans and Management Analysis, Washington, DC. Annual.
Note: Fuel consumption data by aircraft type based on a survey of aircraft owners.
Contact: Pat Beardsley (FAA), 202-267-8032.

U.S. Environmental Protection Agency (USEPA). *National Air Pollutant Emission Trends*, EPA-454/R. USEPA, Office of Air Quality Planning and Standards. Annual.
Note: Contains national and state emissions for mobile sources and stationary sources.
Coantct: Sharon Nizich (USEPA), 919-541-2825.

USEPA. *MOBILE5A, Mobile Source Emissions Model*. USEPA, Office of Air Quality Planning and Standards.
Notes: An executable version of the model and supporting documentation are available on-line on USEPA's Technology Transfer Network.
Contact: Terry Newell (USEPA), 313-668-4462.

Electricity Transfer

EIA. *Inventory of Power Plants in the United States*, DOE/EIA-0095. DOE, EIA, Office of Coal, Nuclear, Electric and Alternate Fuels. Annual.
Note: Presents a list of jointly owned plants, which are ones likely to involve electricity transfer to other regions.
Contact: Karen McDaniel (EIA), 202-254-5672.

EIA. *Electric Trade in the United States*, DOE/EIA-0531. DOE, EIA, Office of Coal, Nuclear, Electric and Alternate Fuels. Annual.
Note: Deals with sales of electricity on a dollar basis. It doesn't present data which, by itself, would yield an accurate estimate of interstate electricity transfer.
Contact: John Makens (EIA), 202-254-5629.

FERC. FERC Form 714, *Annual Electric Control and Planning Area Report*.
Note: The first six to eight schedules of this form present power flows between control regions in the U.S.
Contact: William Booth (FERC), 202-208-0849.

Conversion Factors (Heat Contents)

EIA. *Cost and Quality of Fuels for Electric Utility Plants*, DOE/EIA-0191. DOE, EIA, Office of Coal, Nuclear, Electric and Alternate Fuels. Annual.
Contact: Howard Walton (EIA), 202-254-5500.

EIA. *State Energy Data Report*, DOE/EIA-0214. DOE, EIA, Office of Energy Markets and End Use. Annual.
Note: Presents extensive state level fossil fuel consumption statistics as well as national and some state level heat contents.
Contact: Julia F. Htuchins (EIA), 202-586-5138.

EIA. *Natural Gas Annual*, Vol. II, DOE/EIA-0131. DOE, EIA, Office of Oil and Gas. Annual.
Contact: Kendrich E. Brown (EIA), 202-586-6077.

Carbon Content Coefficients and Emission Factors

Science Applications International Corporation (SAIC). *Analysis of the Relationship Between the Heat and Carbon Content of U.S. Coals: Final Task Report*. Prepared by SAIC, Norristown, PA for EIA, Washington, DC. September, 1992. p. 40.
Note: Gives carbon content coefficients for ranks of coal by state of origin.
Contact: Not Available.

USEPA. *Compilation of Air Pollutant Emission Factors*, fifth edition, AP-42. USEPA, Office of Air Quality Planning and Standards, Washingtion, DC.
Notes: Contains extensive information on emission factors for stationary and mobile sources. Available on-line on USEPA's Technology Transfer Network.
Contact: Information Chief Help Desk, 202-541-5285.