Connecticut Climate Change

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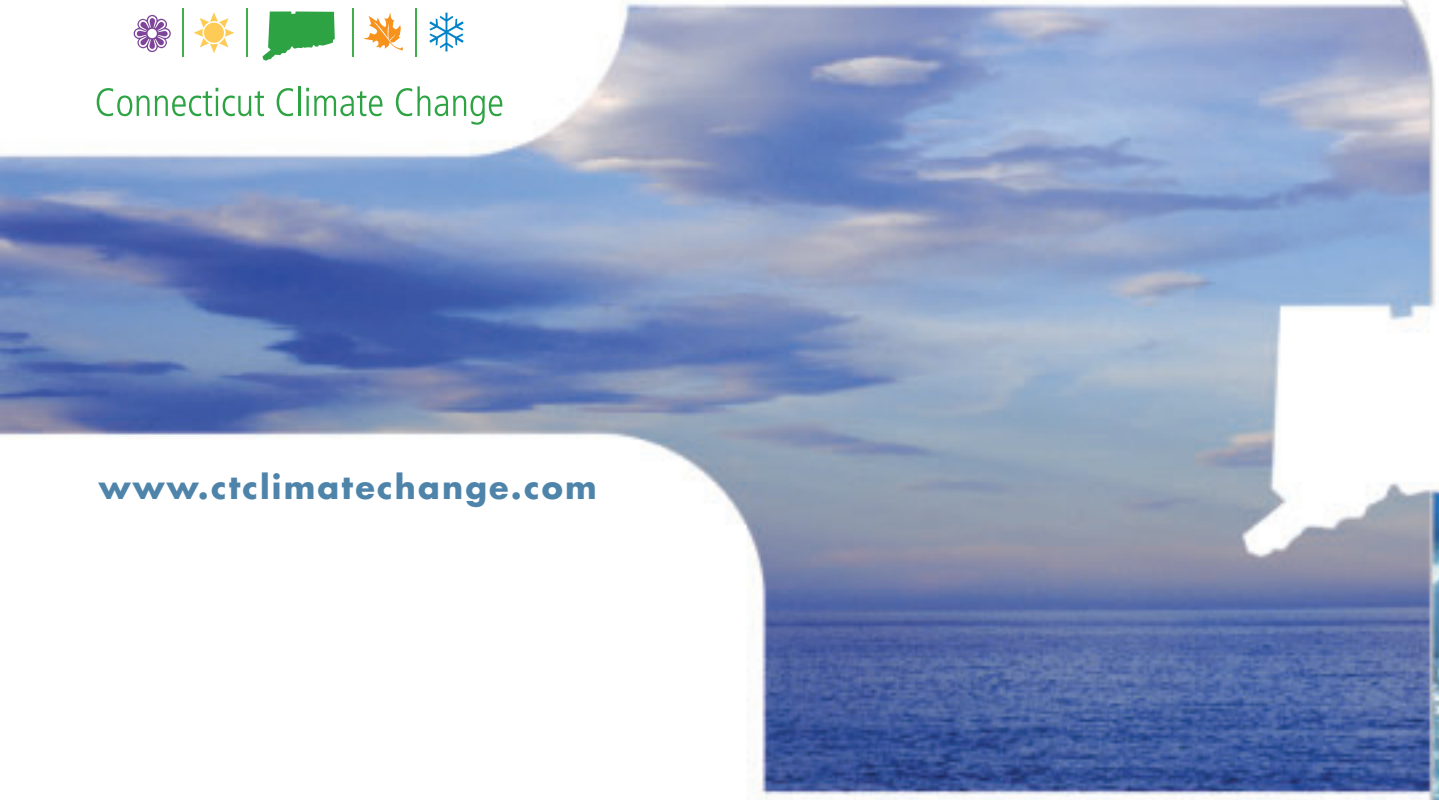

CONNECTICUT GREENHOUSE GAS INVENTORY 1990-2000

NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT (NESCAUM)

CONNECTICUT DEPARTMENT OF ENVIRONMENTAL PROTECTION

CONNECTICUT CLEAN ENERGY FUND

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This inventory of Connecticut's greenhouse gas emissions for the years 1990 through 2000 was produced by Northeast States for Coordinated Air Use Management (NESCAUM) and the Connecticut Department of Environmental Protection, with support from the Connecticut Clean Energy Fund. Inventory calculations were carried out using the State Greenhouse Gas Inventory Tool, an Excel-based software package produced by the State and Local Climate Change Program of the U.S. Environmental Protection Agency (EPA). The Inventory Tool incorporates revisions to EPA's guidelines for estimating greenhouse gas emissions up through November 2002. This report utilizes all revised modules of the Inventory Tool issued through May 30, 2003.

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The text of this report was written by Jennifer Weeks and Susan Green, with substantial contributions by Marika Tatsutani, all from NESCAUM.

EXECUTIVE SUMMARY

A. Background and context

In recent decades a concern has emerged that the earth's climate is being altered by increased concentrations of certain heat-trapping ("greenhouse") gases in the atmosphere as a result of human activity. In 1992, the United States joined more than 160 other countries in signing and ratifying the Framework Convention on Climate Change, an international convention aimed at stabilizing concentrations of greenhouse gases (GHGs) in the atmosphere "at a level that would prevent dangerous anthropogenic interference with the climate system."[1]

> "There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activity."

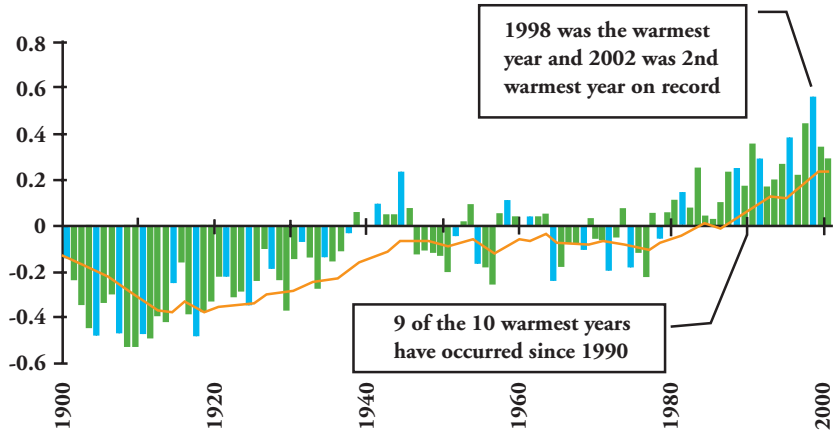
Since 1992, a growing body of scientific analysis and climatological evidence has continued to lend weight to these concerns. Most recently, in its Third Assessment Report, released in 2001, the Intergovernmental Panel on Climate Change (IPCC) concluded that "There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activity."[2]

In the same year, the Conference of New England Governors and Eastern Canadian Premiers adopted a regional climate action plan covering all six New England states, including Connecticut, and the five eastern Canadian provinces of Quebec, New Brunswick, Nova Scotia, Newfoundland, and Prince Edward Island. The NEG/ECP climate plan sets overall targets for the region of stabilizing aggregate GHG emissions at 1990 levels by 2010, and then reducing emissions

[1] United Nations, "Report of the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change on the Work of the Second Part of Its Fifth Session, Held at New York From 30 April to 9 May, 1992," UN Document A/AC.237/18, Part II (May 15, 1992).
[2] Intergovernmental Panel on Climate Change, Climate Change 2001: The Scientific Basis, Summary for Policymakers, p. 10 (Geneva: IPCC, 2001).

Global Temperatures

Deviation from mean 1961-90 (°C)



Note: Temperature are average surface observations, over land and sea
Source: The Met Office - Hadley Centre for Climate Change Prediction and Research, IPCC 2001 report

ten percent below 1990 levels by 2020 and substantially further (by as much as 75 to 85 percent) in subsequent years. The plan does not require states and provinces to meet these specific targets individually; on the contrary, it assumes opportunities for reductions will vary from one jurisdiction to another, and that some jurisdictions will reduce emissions by higher percentages than others. However, as a party to the action plan, Connecticut has made a commitment to pursue significant reductions in its GHG emissions.

NEG - ECP Climate Change Action Plan 2001 Adopted by:

U.S. States -
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont

Canadian Provinces -
New Brunswick, Newfoundland, Nova Scotia, Prince Edward Island, Quebec

This inventory provides a detailed accounting of Connecticut's GHG emissions for the years 1990 through 2000. The inventory covers all major GHG sources in Connecticut, and summarizes emissions of the six major GHGs covered in national inventories: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

B. Summary of Inventory Results

In the year 2000, the state of Connecticut emitted the equivalent of more than 48 million metric tons of carbon dioxide (CO_2), in the form of actual CO_2 and other heat-trapping gases that contribute to global climate change. About 90 percent of these emission came from combustion of fossil fuels – oil, gas, and coal – to power the state's cars and factories, heat and cool its homes and buildings, and generate electricity. Other sectors of Connecticut's economy also contributed to its greenhouse gas emissions: the most notable were municipal solid waste management and industrial production processes. Carbon stored in forests and soils offsets about four percent of Connecticut's annual GHG emissions, slightly less than in the early 1990s.

In comparison to the United States as a whole, Connecticut is relatively energy-efficient and its economy is less carbon-intensive: the state generates fewer GHGs per capita or per dollar of gross state product than the national average. However, total state emissions rose by over 9 percent from 1990 to 2000, so Connecticut will need to improve on its current performance if it seeks to slow and reduce its contribution to climate change.

This inventory provides some clear directions for Connecticut as it develops a policy for addressing global climate change. Notable issues for consideration include the state's heavy reliance on oil, which accounts for most of its greenhouse gas (GHG) emissions from fossil fuel combustion, and relatedly, its need for increased sources of clean energy in coming decades. As in other states and the nation as a whole, transportation accounts for a large and steadily growing share of Connecticut's GHG emissions.

Notable issues for consideration include the state's heavy reliance on oil, which accounts for most of its greenhouse gas (GHG) emissions from fossil fuel combustion, and relatedly, its need for increased sources of clean energy in coming decades.

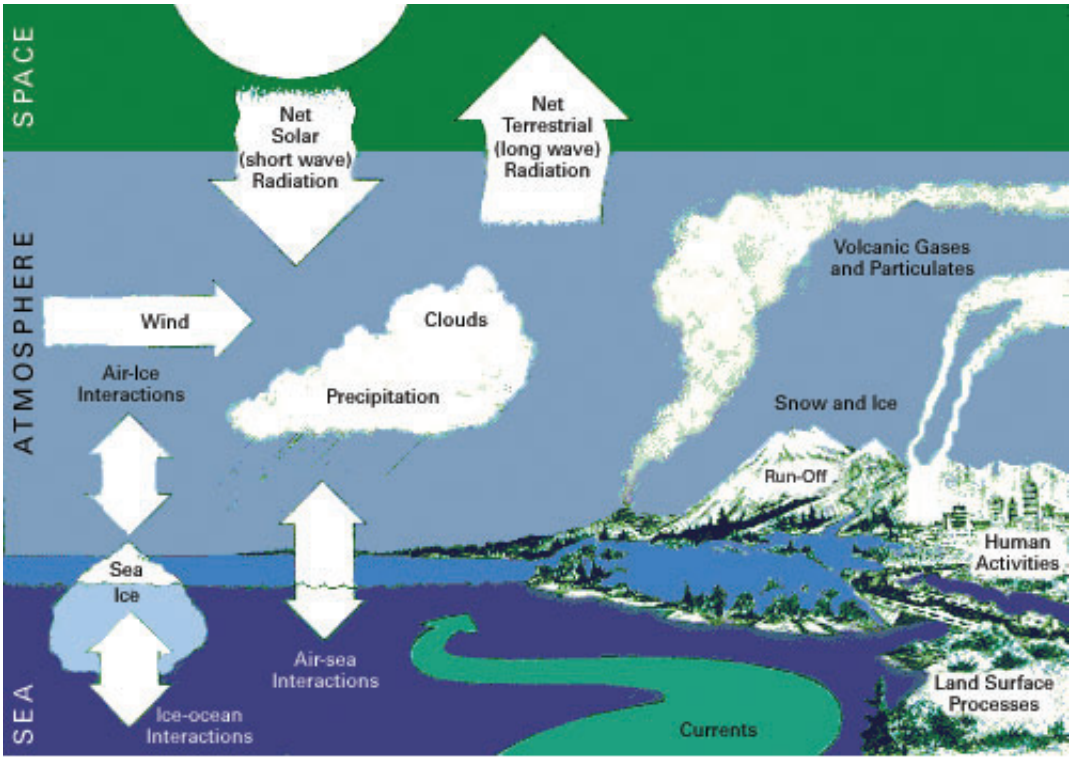
Because it is already engaged in regional actions to address climate change, as well as developing its own state action plan, Connecticut is well positioned to be a leader in responding to global warming.

Finally, the inventory illustrates the extent to which climate change transcends political borders: Connecticut's electric power demand and waste disposal policies generate GHG emissions beyond its borders, and similar actions in other states contribute to Connecticut's emissions inventory. These trends demonstrate the need for broad cooperation to develop effective policies for reducing GHG emissions. Because it is already engaged in regional actions to address climate change, as well as developing its own state action plan, Connecticut is well positioned to be a leader in responding to global warming.

I. BACKGROUND AND INTRODUCTION

A. Global Climate

As understanding of the environmental impacts of human activities has grown, it has become increasingly clear that the Earth's biosphere depends on a dynamic set of interrelated systems. Humans and other species have adapted to climatic conditions that depend on a complicated balance between the amount of solar energy that enters and leaves the atmosphere. In recent decades, a concern has emerged that human activities are interfering with this balance. Scientists have postulated that increasing concentrations of certain heat-trapping gases in the atmosphere could lead to changes in global climate patterns, a phenomenon that has become widely known as "global warming" or "global climate change."



Source: Government of Canada

Conditions hospitable to life on Earth have always depended on an existing, naturally occurring phenomenon that is often described as the "greenhouse effect." Incoming solar radiation is absorbed by the atmosphere and the Earth's surface. Some of it is re-radiated back from the surface as long-wave radiation,

and trapped by water vapor and other trace gases in the atmosphere. Because these gases allow solar energy to enter the atmosphere, but prevent some of it from leaving, they create a heat-trapping effect similar to what happens in a glass-enclosed greenhouse. Without this effect, the Earth's average temperature would be about 16°C (60°F) cooler, and climate conditions on the planet would be much closer to those that prevail on Mars.

A number of gases can absorb the Earth's re-radiated heat and contribute to the greenhouse effect. These include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and certain halocarbons and related compounds (such as CFC-11 and CFC-12). Other than halocarbons, all of these gases occur naturally. With the exception of water vapor, which makes up approximately one percent of the Earth's atmosphere, greenhouse gases exist only in trace amounts in the atmosphere. The most abundant, CO_2, constitutes less than 0.04 percent of the atmosphere. Nevertheless, these gases play a crucial role in determining climatic conditions on Earth.

Atmospheric measurements and analysis of air trapped in polar ice cores reveal that atmospheric concentrations of a number of these gases are increasing. For instance, measured concentrations of carbon dioxide in the atmosphere have increased from pre-industrial levels of 278 parts per million (ppm) to 370 ppm in 2000. Methane has increased from 0.7 ppm to 1.75 ppm over the same period.[3] Experts widely agree that human activities are responsible for these increases – most notably, fossil fuel combustion and tropical deforestation in the case of CO_2, and rice cultivation, animal husbandry, coal mining, natural gas handling, and waste disposal in landfills in the case of methane.[4]

Scientists have attempted to gauge the impacts of these changes on the global climate system with sophisticated computer models. The most recent assessment by the Intergovernmental Panel on Climate Change (IPCC), an international team of meteorologists and climate scientists convened under the auspices of the United Nations, found that global average surface temperature had increased by about 0.6°C (1°F) over the 20th century, and concluded that "In the light

[3] Data from the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, online at http://www.cmdl.noaa.gov/milestones/2001/fy2001_3.html.

[4] National Research Council, Committee on the Science of Climate Change, Climate Change Science: An Analysis of Some Key Questions (Washington, DC: National Academy Press, 2001), p. 2.

of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." The panel projected that from 1990 through 2100, global average surface temperature would rise by 1.4 to 5.8°C (2.5-10.4°F).[5]

Though climate change predictions remain fraught with uncertainties, scientists have pointed out that even small changes in mean global temperature could have significant impacts. For example, average global temperatures during the last major ice age about 11,000 years ago were only about 3°C (5.4° F) lower than at present. Over subsequent millennia, average global temperatures have varied no more than 1.5°C (2.7°F). Moreover, the rate of climate change, as much as its eventual magnitude, may be critical to the ability of humans and nature to adapt. A 2002 report by a special committee of the National Academy of Sciences warned that the impacts of climate change might not be gradual and linear: rather, increasing atmospheric greenhouse gas concentrations could push the climate system across thresholds that would trigger abrupt climate changes, such as alterations in major ocean currents or sudden regional increases in both floods and droughts.[6]

In addition to impacts on ecosystems and agricultural productivity, scientists have theorized that global climate change could have potentially devastating consequences in terms of sea level rise and the increased incidence and severity of major storms and other extreme weather events. A series of particularly damaging and costly hurricanes, cyclones, and typhoons, which led to unprecedented property losses in the last several years, has recently prompted the global insurance industry to pay increased attention to the threat of climate change. As early as 1992, international awareness of the many potential risks associated with global warming led to the adoption by more than 160 countries, including the United States, of the Framework Convention on Climate Change. The stated objective of the Convention was to:

[5] Intergovernmental Panel on Climate Change, Working Group I, Climate Change 2001: The Scientific Basis, Summary for Policymakers, pp. 2, 10, 13 (quote on p. 10).

[6] Committee on Abrupt Climate Change, National Research Council, Abrupt Climate Change: Inevitable Surprises (Washington, DC: National Academy Press, 2002).

> . . . achieve . . . stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[7]

Toward this objective, signatories pledged to work to stabilize greenhouse gas emissions. A number of industrialized countries, including the United States, adopted the specific near-term goal of returning year 2000 greenhouse gas emissions to 1990 levels. It subsequently became evident that most countries, including the United States, were not on track to meet this objective. In response, in 1997 parties to the Framework Convention adopted the Kyoto Protocol, which included targets and timetables for reducing GHG emissions to specific levels for each country. As of early 2003, 102 countries had ratified or acceded to the Protocol. The United States has yet to do so with the administration citing concerns about the economic impact of reducing GHG emissions on the time scale required under the agreement.

Meanwhile, however, many state and local leaders had become sufficiently concerned during the 1990s about the predicted impacts of climate change to adopt a range of measures aimed at reducing GHG emissions within their jurisdictions, in advance of any Federal requirement to do so. This trend began with a few leading states in the early 1990s, but has accelerated recently: in 2001 and 2002, approximately one-third of the states passed new legislation or executive orders specifically aimed at reducing greenhouse gas emissions.[8] These policies ranged from comprehensive state action plans with quantitative GHG reduction targets to regulations or laws limiting emissions from a specific sector such as electric power generation.

NEG - ECP
CLIMATE CHANGE ACTION PLAN 2001
Greenhouse Gas Emission Reduction Targets

- Stabilize emissions to 1990 levels by 2010
- Reduce emissions 10% below 1990 levels by 2020
- Reduce emissions 75-85% below 1990 levels over the long term

[7] United Nations, "Report of the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change on the Work of the Second Part of Its Fifth Session, Held at New York From 30 April to 9 May, 1992," UN Document A/AC.237/18, Part II (May 15, 1992).

[8] Additionally, other states adopted measures that were not expressly aimed at climate change but clearly were driven at least in part by the issue of global warming. Barry G. Rabe, Statehouse and Greenhouse: The Evolving State Government Role in Climate Change (Arlington, VA: Pew Center on Global Climate Change, November 2002), p. 7.

One of the most notable state-based measures was the regional climate change action plan adopted by the Conference of New England Governors and Eastern Canadian Premiers in 2001. Under this plan, which covers a region with GHG emissions greater than all but about a dozen nations worldwide, the jurisdictions pledged to work toward a region-wide goal of stabilizing total GHG emissions at 1990 levels by 2010, and then reducing emissions 10 percent below 1990 levels by 2020 and lower in subsequent decades (up to 75 to 85 percent below 1990 levels) as necessary to prevent dangerous threat to the climate. One action item in the plan calls for the states and provinces to produce updated greenhouse gas inventories at three-year intervals, so that the region can track its total emissions and identify promising areas for reductions.[9]

Among the drivers that moved the New England states to undertake this commitment were studies of the potential regional impacts of climate change in the United States. According to projections from the Canadian General Circulation Model and the United Kingdom's Hadley Climate Model, average temperatures in New England could increase by 3.1-5.3°C (about 6-10°F) by the year 2090. A study funded by the U.S. Global Change Research Program noted that the projected warming at the lower end of this range would raise average year-round temperature in Boston to a level currently measured in Richmond, Virginia, while under the higher estimates, Boston's climate would be comparable to that of Atlanta, Georgia.[10] Projected effects of temperature rises in this range included more frequent and intense storms; increased damage (especially to infrastructure) in coastal areas from flooding and erosion; higher

Projected effects of temperature rises in this range included more frequent and intense storms; increased damage (especially to infrastructure) in coastal areas from flooding and erosion; higher numbers of heat-related deaths during summer heat waves; spreading breeding grounds for disease-carrying rodents and insects, leading to wider outbreaks of illnesses such as West Nile virus; and a variety of stresses on regional forests, fishing grounds, and coastal ecosystems.

[9] Conference of New England Governors and Eastern Canadian Premiers, Climate Change Action Plan 2001, adopted August 2001, online at www.cmp.ca/negecp/en-ccap.pdf.

[10] New England Regional Assessment Group, Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change, New England Regional Overview (University of New Hampshire: U.S. Global Change Research Program, 2001), pp. 6-7.

numbers of heat-related deaths during summer heat waves; spreading breeding grounds for disease-carrying rodents and insects, leading to wider outbreaks of illnesses such as West Nile virus; and a variety of stresses on regional forests, fishing grounds, and coastal ecosystems.

B. Greenhouse Gases and "Global Warming Potential"

As noted previously, a number of gases in the atmosphere have a heat-trapping effect. The heat-trapping properties of these gases vary. In order to clarify their relative importance, the concept of "global warming potential" (GWP) has been developed. Using carbon dioxide as the standard, researchers have assigned a GWP index number to each greenhouse gas, which gives its estimated climate impact, over a specified period of time, expressed as an equivalent release by weight of carbon dioxide. For example, the current 100-year GWP assigned to methane is 21, which means that one ton of methane emissions is estimated to have the same global warming impact over 100 years as 21 tons of carbon dioxide emissions. The 100-year GWP values currently used in national and international GHG reporting are:

- Methane (CH_4) – 21
- Nitrous oxide (N_2O) – 310
- Hydrofluorocarbons (HFCs) – various (up to 11,700)
- Perfluorocarbons (PFCs) – various (up to 9,200)
- Sulfur hexafluoride (SF_6) – 23,900

The most important greenhouse gas is water vapor. However, water vapor is not generated directly by human activities in quantities that are significant relative to natural sources. From the standpoint of anthropogenic emissions, the greenhouse gas of greatest concern is carbon dioxide. CO_2 is a natural by-product of the oxidation of carbon in organic matter, through either the combustion of carbon-based fuels or the decay of biomass. Thus, the chief anthropogenic sources of CO_2 are fossil fuel combustion and deforestation. In the year 2000, CO_2 was responsible for 83 percent of total U.S. greenhouse gas emissions by weight.

The second most important anthropogenic greenhouse gas is methane, which when converted to CO_2-equivalent terms based on its GWP, constituted almost nine percent of U.S. greenhouse gas emissions in 2000. Methane is primarily produced by anaerobic decay of organic material in landfills, rice fields, and

natural wetlands, and by the digestive tracts of ruminant domestic animals (notably cattle, sheep, and goats). Nitrous oxide constituted about six percent of total U.S. greenhouse gas emissions in 2000; N_2O is primarily produced by fertilizer use, fuel combustion, and certain industrial processes. The remaining gases covered in this inventory – HFCs, PFCs, and sulfur hexafluoride (SF_6) -- together accounted for about two percent of U.S. greenhouse emissions in 2000. These chemicals are generated by a narrower set of sources, such as aluminum and magnesium production, semiconductor manufacture, substitution of ozone depleting compounds by HFCs, and electric power transmission and distribution.

C. Units and Conversions

Several different measurement units may be employed to summarize greenhouse gas emissions. GHG inventories are typically presented in either metric tons (or a comparable metric unit) or short tons. One short ton equals 2,000 pounds; one metric ton equals 1,000 kilograms, or 1.1023 short tons. Additionally, GHG inventories can be presented either in units of carbon equivalent or of carbon dioxide equivalent. The molecular weight of carbon is 12, and the molecular weight of oxygen is 16; therefore, the molecular weight of CO_2 is 12 + [16*2], or 44, as compared to 12 for carbon alone. Thus carbon comprises 12/44ths of carbon dioxide by weight, and one metric ton of carbon equivalent yields 3.667 (i.e., 44/12) metric tons of carbon dioxide equivalent.

Throughout this inventory, quantities of greenhouse gases are expressed in metric tons of carbon dioxide equivalent (often abbreviated as $MTCO_2E$, or $MMTCO_2E$ for millions of metric tons of CO_2 equivalent). These units were used to make the inventory as comparable as possible to other benchmarks such as the U.S. national inventory and other industrialized countries' reported inventories. Beginning in 1999, U.S. national inventories have been reported in teragrams of CO_2 equivalent (one teragram equals one million metric tons), consistent with international practices, and EPA has recalculated U.S. inventories back to 1990 in teragrams CO_2E. Additionally, nearly all GHG emission or emission reduction trades to date have been denominated in $MTCO_2E$. The 1990 and 1995 Connecticut GHG inventories developed by the University of Connecticut were reported in short tons of CO_2 equivalent; for consistency with national and international inventories, this report uses metric units instead.[11]

[11] To convert short tons to metric tons, multiply by .9072; to convert metric tonnes to short tons, multiply by 1.1023.

D. The Connecticut 1990-2000 Inventory Project

Climate change is a serious environmental concern for Connecticut, given its potential impact on shorelines, coastal wetlands and other habitat, as well as on crops, wildlife, and human health and safety. In March 1999, the Connecticut Department of Environmental Protection published an inventory of the state's greenhouse gas emissions for 1990 and 1995, which was produced by the University of Connecticut with support from EPA's State and Local Climate Change Outreach Program. Like other state GHG inventories published during the 1990s, this analysis required gathering data on numerous activities across Connecticut's economy and performing hundreds of sector-by-sector calculations to estimate total state greenhouse gas emissions for the target years. Because this process was time- and labor-intensive, it was prohibitively difficult for states to produce inventories for more than one or two years.

Climate change is a serious environmental concern for Connecticut, given its potential impact on shorelines, coastal wetlands and other habitat, as well as on crops, wildlife, and human health and safety.

This inventory is intended to update and supplement the 1999 report; to fulfill Connecticut's commitment under the NEG/ECP climate action plan to produce regular, updated GHG inventories; and to serve as a resource for the proposed development of a state climate change action plan. It was produced using a software package (the State GHG Inventory Tool) developed by EPA to make the inventory process less time- and resource-intensive, so that states can regularly update their measurements of greenhouse gas emissions and so that future state inventories will use standardized methodologies and data sources that will make the final products directly comparable. The Inventory Tool incorporates changes to U.S. inventory guidance up through November 2002 and provides state-specific default data that states can either use or customize in areas in which they have more representative information.[12]

This inventory was developed by Northeast States for Coordinated Air Use Management (NESCAUM) and the Connecticut Department of Environmental Protection with support from the Connecticut Clean Energy Fund. The methodologies employed are described in the sector chapters and appendices.

[12] The appendices to this report specify areas in which non-default data were used, along with the rationales for doing so and the sources of customized data.

Methodologies for estimating GHG emissions are constantly evolving, and key conversion factors (such as the assigned GWP values for non-CO_2 gases) change periodically in response to current scientific guidance. Additionally, some key data sets (such as U.S. Department of Energy figures on state energy consumption) are currently undergoing revision to capture trends such as increased use of combined heat and power (CHP) and changing ownership of electric generation plants. Due to these factors, results here are comparable but not identical to the results of the previous inventory for 1990 and 1995.[13] Differences primarily reflect the fact that developing GHG inventories is an iterative process, rather than errors in producing either inventory. It is likely that future Connecticut inventories will revise and update some of the estimates in this report as scientific understanding, inventory methodologies, and data sources continue to improve.

[13] Additionally, as noted above, the earlier inventory was calculated in short tons rather than metric tons, the unit used for this inventory.

II. 1990-2000 CONNECTICUT GREENHOUSE GAS EMISSIONS

A. Summary of Inventory Results

This inventory presents estimated greenhouse gas emissions from all major sources in Connecticut for the years 1990 through 2000. Sources considered include fossil and biomass fuel combustion, industrial production processes, gas and oil activities, landfills and waste water treatment, agricultural sources, and land-use changes and forestry.

With two exceptions, this inventory accounts only for emissions produced within Connecticut's borders. The exceptions are:

- Emissions associated with electricity imports from other states, which accounted for one-third to nearly one-half of Connecticut's total electricity consumption in several of the years covered in this inventory. These emissions are presented separately to distinguish them from emissions that occurred within state borders and to avoid double-counting problems with other states' inventories. In other words, they are not part of Connecticut's emissions inventory, since they occurred at power plants in other states, but they are a direct reflection of energy demand in Connecticut, and so are presented separately to show the total GHG impact of Connecticut's energy use.[14]

- Emissions associated with municipal solid waste generated in Connecticut and landfilled or burned in other states. As with imported electric power, these emissions occurred in other states, and therefore are not counted as part of Connecticut's GHG inventory. At the same time, however, they reflect the total magnitude of waste generation in Connecticut, and so are presented separately to show the state's total GHG impact in the waste sector.

Inventory results are summarized in Table II-1. In 2000, Connecticut generated an estimated 48 million metric tons of CO_2 equivalent ($MMTCO_2E$),

[14] According to the U.S. Environmental Protection Agency's eGRID 2002 database, Connecticut exported power in 1994, 1995, and 2000, but net electricity exports in each of these years accounted for at most one percent of total net generation in Connecticut. In other words, 99 percent or more of the power generated in Connecticut in each of these years was consumed in-state, and emissions associated with power exported from Connecticut in these years accounted for only a tiny fraction of the state's GHG inventory.

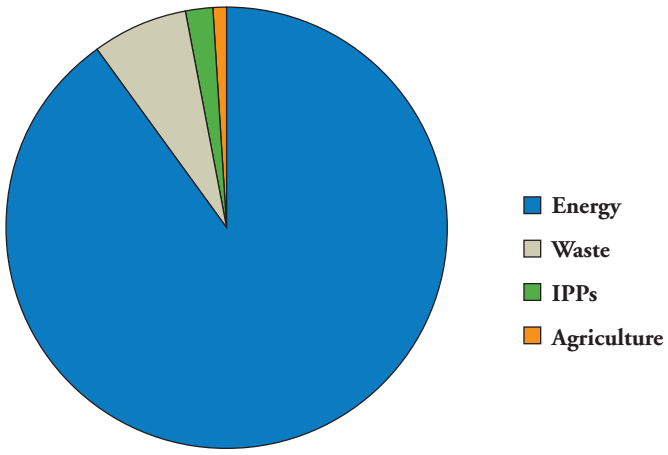
an increase of about 9.1 percent from its 1990 output of 44 $MMTCO_2E$. Energy activities were by far the largest source of state GHG emissions, producing about 90 percent of emissions annually. Nearly all of this amount (about 88 percent of total state emissions per year) was CO_2 from fossil fuel combustion in both stationary and mobile sources; other energy-related emissions – including CH_4 and N_2O from fossil fuel combustion, and CH_4 from natural gas transmission and distribution – added two to three percent per year. Waste management accounted for nearly all of the balance, or roughly 6.5 to 8.5 percent of total state GHG emissions per year. Industrial production processes produced approximately one to two percent of annual emissions, and agriculture contributed less than one percent.

Table II-1
Connecticut Greenhouse Gas Emissions, 1990-2000

Emissions (MMTCO2E)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Energy	40.270	39.518	39.476	38.582	37.656	37.578	41.002	44.130	43.748	44.133	44.159
CO_2 from Fossil Fuel Combustion	38.882	38.081	38.179	37.083	36.166	36.063	39.505	42.679	42.318	42.722	42.853
Stationary Combustion	0.201	0.203	0.217	0.215	0.210	0.230	0.236	0.214	0.204	0.199	0.223
Mobile Combustion	0.680	0.708	0.719	0.744	0.744	0.752	0.731	0.712	0.703	0.693	0.676
Natural Gas and Oil Systems	0.508	0.526	0.361	0.540	0.536	0.533	0.530	0.525	0.523	0.520	0.408
Industrial Processes	0.314	0.325	0.311	0.397	0.419	0.528	0.634	0.700	0.740	0.722	0.840
Agriculture	0.330	0.321	0.335	0.344	0.350	0.336	0.313	0.307	0.335	0.329	0.326
Enteric Fermentation	0.124	0.121	0.124	0.121	0.121	0.120	0.110	0.106	0.109	0.107	0.109
Manure Management	0.046	0.045	0.044	0.047	0.047	0.046	0.044	0.042	0.045	0.044	0.042
Agricultural Soil Management	0.160	0.155	0.167	0.176	0.182	0.170	0.159	0.159	0.181	0.178	0.175
Forest Management and Land-Use Change	(2.719)	(2.650)	(2.658)	(2.069)	(2.039)	(2.058)	(2.052)	(2.015)	(2.009)	(2.035)	(2.035)
Waste	3.499	3.598	3.598	3.590	3.689	3.662	3.245	3.312	3.230	3.130	3.159
Municipal Solid Waste	3.239	3.337	3.337	3.329	3.425	3.400	2.983	3.049	2.966	2.863	2.883
Wastewater	0.260	0.262	0.261	0.261	0.264	0.262	0.262	0.263	0.264	0.267	0.277
Gross Emissions	**44.414**	**43.762**	**43.720**	**42.914**	**42.115**	**42.103**	**45.194**	**48.450**	**48.053**	**48.364**	**48.485**
Sinks	**(2.719)**	**(2.650)**	**(2.658)**	**(2.069)**	**(2.039)**	**(2.058)**	**(2.052)**	**(2.015)**	**(2.009)**	**(2.035)**	**(2.035)**
Net Emissions	**41.695**	**41.112**	**41.063**	**40.844**	**40.076**	**40.045**	**43.142**	**46.435**	**46.044**	**46.329**	**46.450**

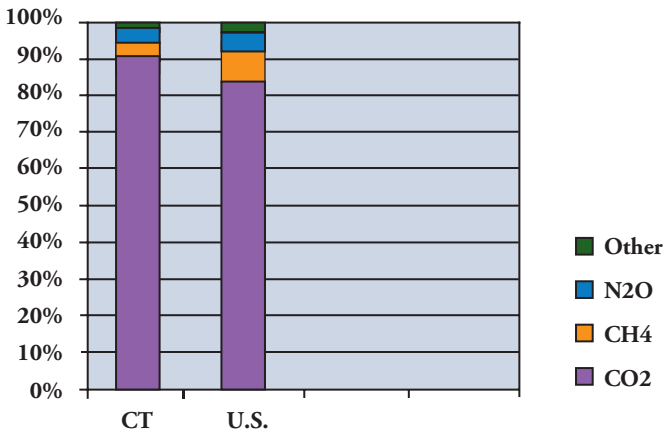
Land use change and forestry provided a net carbon sink for Connecticut throughout the decade -- i.e., this sector sequestered more carbon than it produced as GHG emissions. Biological sequestration (carbon stored in ecosystems) offset approximately six percent of the state's GHG emissions annually at the start of the decade, declining to slightly over 4 percent by 2000. Over the decade, Connecticut's net GHG emissions (total emissions minus carbon sequestered) increased by about 11.4 percent, from 41.69 $MMTCO_2E$ in 1990 to 46.45 $MMTCO_2E$ in 2000. Figure II-1 illustrates the relative contributions of various sectors to Connecticut's GHG emissions in 2000 .

Figure II-1
GHG Emissions by Sector, 2000



In terms of the various greenhouse gases, CO_2 accounted for 91 percent of state GHG emissions in 2000, followed by CH_4 (4 percent) and N_2O (3.3 percent). HFCs, PFCs, and SF_6 together accounted for about 1.7 percent of state GHG emissions. As illustrated in Figure II-2, this allocation is fairly close to the breakdown of gases in the 2000 U.S. GHG inventory. Connecticut's emissions are more dominated by CO_2 than the nation's as a whole because the state has a relatively small agricultural sector and does not have other sources that produce significant amounts of CH_4 nationally, such as coal mines and oil and gas production.

Figure II-2
Breakdown of Connecticut and U.S. GHG Emissions in 2000 by Gas



Connecticut's gross GHG emissions actually declined by about 5.2 percent from 1990 through 1995, a trend that was also reflected in the earlier inventory of 1990 and 1995 GHG emissions developed for the state by the University of Connecticut. The UConn analysis attributed the decline to two major factors: a shift from reliance on petroleum products to increased use of natural gas in the energy sector (particularly for electric power generation), and greater use of combustion rather than landfilling for solid waste disposal. Additionally, Connecticut's economy was in recession from early 1989 through late 1992, and its population declined slightly between 1991 and 1995.[15]

However, as illustrated in Figure II-3, the trend subsequently reversed. Connecticut's population increased by about 4 percent from 1995 through 2000, and the state experienced rapid economic growth during this period. Moreover, as discussed in Chapter III, developments in the electric power industry in the second half of the decade increased emissions from electricity generation. Connecticut's gross GHG emissions grew by over 15 percent from 1995 through 2000, for a total increase over the decade of about 9.1 percent.

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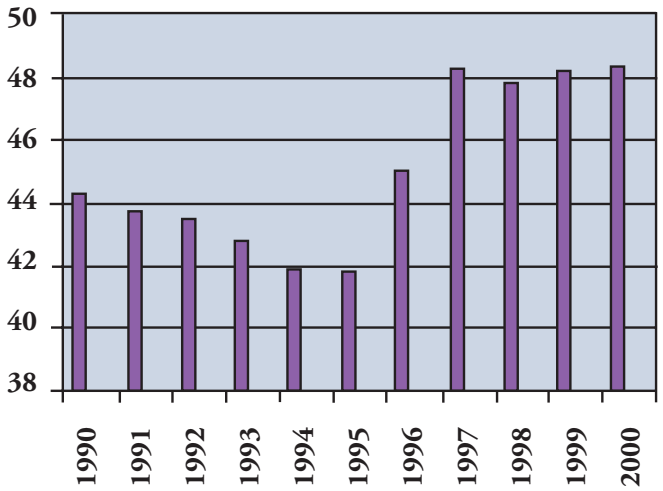
[15] Office of the State Comptroller, "A Demographic Profile of Connecticut," (1997), online at http://www.osc.state.ct.us/reports/economic/97cmprpt/crptdemo.htm. GHG emissions generally decline during periods of poor economic performance because fewer goods and services are consumed and manufacturing output falls.

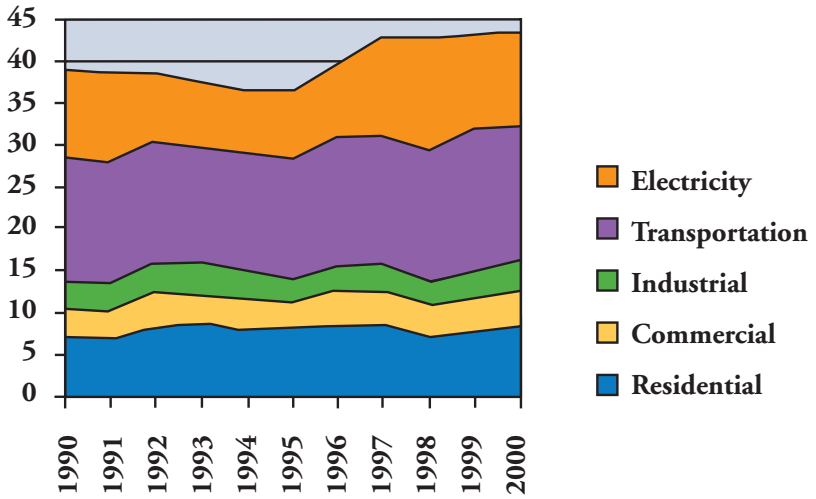
Figure II-3
Total Connecticut GHG Emissions, 1990-2000
(million metric tons CO_2 equivalent)



Connecticut's GHG emissions profile for the 1990s still contrasts favorably with national GHG emissions, which grew by 14.2 percent from 1990 through 2000. However, the fact that Connecticut's notable emissions decline from 1990-95 was erased in 1995-2000 illustrates that emissions reductions can be highly sensitive to developments in major sectors such as electricity and transportation. Furthermore, even if market trends (such as fuel-switching in the electric utility sector) lead to falling emissions, these reductions may be reversed if they are not locked into place through public policy measures.

Nearly all of Connecticut's energy-related emissions consist of CO_2 from fossil fuel combustion, including both stationary sources (such as power plants, industrial facilities, and home heating systems) and mobile sources (motor vehicles and other transportation modes). Figure II-4 illustrates the relative contribution of major sectors to the state's fossil fuel CO_2 emissions.

Figure II-4
CO_2 Emissions from Fossil Fuel Combustion, 1990-2000
(million metric tons)



Throughout the 1990s, transportation accounted for about 37 to 40 percent of fossil fuel CO_2 emissions annually. Primary energy consumption in the residential sector accounted for about 20 percent of fossil CO_2 emissions annually, while primary energy consumption in the industrial and commercial sectors each contributed 7 to 10 percent.[16] The most dramatic fluctuations from year to year occurred in the electric utility sector, whose contribution to fossil fuel CO_2 emissions varied from about 18 percent to 30 percent, with peak emissions occurring in 1997-1998 during a period when several nuclear power plants in Connecticut were taken out of service for extended periods and the state was proportionally more reliant on fossil-fired power plants. Trends in each of these sectors are discussed in more detail in Chapter III.

As noted above, waste management accounts for most of Connecticut's non-energy emissions. Total GHG emissions from this sector decreased by about 9.7

[16] A distinction is frequently made between "primary" and "end-use" energy consumption. Fuels, such as natural gas, oil, and coal, are considered primary forms of energy. Thus, primary energy refers to the direct consumption of a fossil, nuclear, or biomass fuel. The energy content of these fuels may be used to serve an immediate end-use, such as moving a car, or it can be transformed into another energy form, such as electricity. Electricity is produced from primary fuels to serve other energy end-uses, such as lighting. Thus the residential, commercial, and industrial sectors are all primary energy users to the extent that they directly burn fuels like natural gas and oil for space and water heating, and they are also end-users of energy in the form of electricity. Electricity production, by contrast, is a primary energy use sector, but not an end-use sector.

percent from 1990 through 2000; emissions from municipal solid waste (MSW) management, which accounted for 80 to 90 percent of total waste emissions throughout the decade fell by about 11 percent, while emissions from wastewater treatment increased slightly from 1990 through 2000. Since the late 1980s, Connecticut has shifted its MSW management system from reliance on landfilling to a hierarchical strategy with first priority on source reduction, followed by recycling, composting, resource recovery, and finally landfilling. According to the state Department of Environmental Protection, by 1998 over 25 percent of Connecticut's MSW was managed through source reduction and recycling.[17] The state operates six resource recovery facilities (RRFs), which burn MSW to produce electricity and currently handle most of the MSW that requires disposal instate. Additionally, since MSW disposal at municipal incinerators ended in 1995, Connecticut has shipped about 10 percent of its MSW annually out of state for disposal. (Emissions from exported waste are not counted as part of this inventory, but are discussed further in Chapter VI.)

B. Connecticut's Emissions in Perspective

Connecticut's GHG emissions relative to population and economic activity are significantly lower than the national average. In 2000, Connecticut had 1.2 percent of the U.S. population and produced 0.7 percent of national emissions, or 14.2 metric tons of CO_2 equivalent per person, compared to the national per capita average of 24.9 metric tons per person. Relative to economic output, Connecticut generated 0.03 metric tons of CO_2 equivalent per dollar of gross state product in the year 2000, compared to the national average of 0.07 tons per dollar of total gross domestic product.[18] In sum, Connecticut's economy already is much less GHG-intensive than the nation's as a whole.

However, Connecticut is a significant generator of GHG emissions in the aggregate. The state is the third-largest emitter in the region covered by the NEG/ECP climate change action plan, surpassed only by Massachusetts and the province of Quebec, and produces approximately thirteen percent of the

[17] Connecticut Department of Environmental Protection, Proposed Solid Waste Management Plan Executive Summary, updated April 2000, online at http://dep.state.ct.us/wst/solidw/swplan.htm.
[18] Data on gross state product for 2000 at http://www.bea.gov/bea/regional/gsp/; national and state population data at http://quickfacts.census.gov/qfd/states/90999.htm

region's total GHG emissions.[19] On the international level, Connecticut's total GHG emissions in the year 2000 were greater than the national GHG emissions of Estonia, Latvia, Iceland, and Luxembourg combined, and were only about three to eight percent lower, respectively, than the national emissions reported by Slovakia and Switzerland.[20]

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For Connecticut, meeting the overall reduction targets in the NEG/ECP regional climate action plan would require stabilizing total emissions at about 44.41 million metric tons CO_2 equivalent per year (the state's gross 1990 emissions) by 2010, and reducing emissions to about 39.9 $MMTCO_2E$ by 2020. As noted above, these targets are not binding on individual states and provinces, but they are in line with the overall magnitude of the region's ambitions to reduce GHG emissions.

According to the U.S. Energy Information Administration's most recent forecast, New England's CO_2 emissions from energy use are projected to increase by about 32 percent from 2001 through 2020 (approximately 1.5 percent annually). During this period, EIA assumes that the overall energy intensity of the U.S. economy will decline by 1.5 percent per year and per capita energy use will rise by 0.7 percent annually.[21] To reduce GHG emissions on the scale contemplated in the NEG/ECP plan while maintaining economic growth, Connecticut will have to reduce the energy intensity of its economy at a considerably higher rate than that forecast by EIA for the nation as a whole. Chapter III analyzes Connecticut's GHG emissions from energy activities in greater detail in an effort to provide a basis for doing so.

[19] Based on estimates generated by NESCAUM in 2002 for the Conference of New England Governors and Eastern Canadian Premiers. The NEG/ECP region includes the six New England states and the five eastern Canadian provinces (Quebec, Nova Scotia, New Brunswick, Newfoundland, and Prince Edward Island).

[20] GHG emissions for Annex I countries are online at http://unfccc.int/program/mis/ghg/index.html.

[21] U.S. Energy Information Administration, Annual Energy Outlook 2003, DOE/EIA-0383 (Washington, DC: U.S. Department of Energy, January 9, 2003), overview and Table I.

III. FOSSIL FUEL AND BIOMASS COMBUSTION

In Connecticut, as in the United States as a whole, combustion of carbon-based fuels – including all fossil fuels and biomass – is the predominant anthropogenic source of greenhouse gas emissions. CO_2 and, to a much smaller extent, methane, nitrous oxide, and other pollutants, are released as direct by-products of fuel combustion. The EPA Inventory Tool calculates CO_2 emissions from fossil fuel combustion separately from CH_4 and N_2O emissions; results are totaled in Table III-1. (CO_2 emissions from all activities, including transportation, are included in the first line; CH_4 and N_2O emissions are from both stationary sources, such as factories, and mobile sources).

Table III-1
Total GHG Emissions from Fossil Fuel Combustion, 1990-2000
(million metric tons CO_2 equivalent)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
CO_2	38.882	38.081	38.179	37.083	36.166	36.063	39.505	42.679	42.318	42.722	42.853
CH4	0.164	0.166	0.174	0.175	0.171	0.181	0.181	0.155	0.148	0.152	0.158
N2O	0.718	0.746	0.762	0.784	0.784	0.801	0.786	0.770	0.760	0.740	0.740
TOTAL	39.764	38.993	39.115	38.042	37.121	37.045	40.472	43.60	43.226	43.614	43.751

CO_2 emissions from fossil fuel combustion, which account for about 90 percent of Connecticut's total GHG emissions, are broken down by sector in Table III-2.

Table III-2
CO_2 Emissions from Fossil Fuel Combustion, 1990-2000
(million metric tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	1990-2000
Residential	7.14	7.05	8.33	8.44	7.85	7.59	8.32	8.17	7.07	7.89	8.31	+16.4%
Commercial	3.51	3.36	3.99	3.66	3.96	3.7	4.04	4.22	3.92	4.19	4.36	+24.2%
Industrial	2.96	3.12	3.42	3.5	3.08	2.91	3.32	3.26	3.07	3.07	3.2	+8.1%
Transportation	14.59	14.4	14.49	14.67	14.61	14.33	15.08	15.12	15.36	16.64	16.1	+10.3%
Electricity	10.68	10.15	7.95	6.81	6.67	7.53	8.75	11.91	12.91	10.93	10.88	+2%
TOTAL	38.88	38.08	38.18	37.08	36.17	36.06	39.51	42.68	42.33	42.72	42.85	

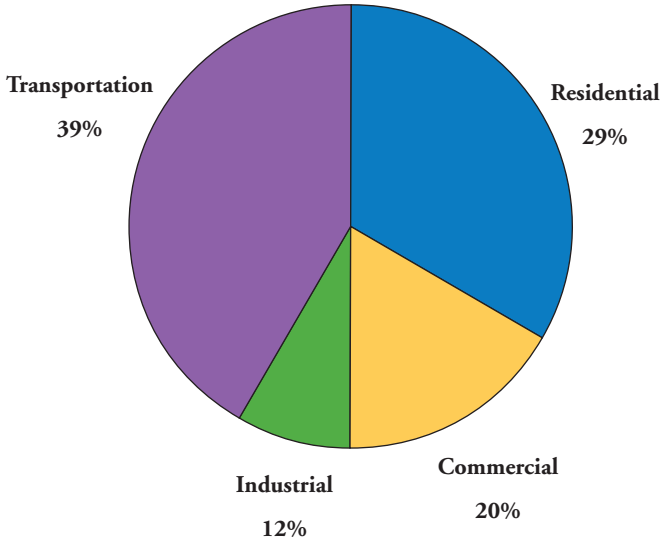
As the table illustrates, emissions from these sectors grew at differing rates from 1990 to 2000. Commercial sector CO_2 emissions increased by 25 percent during the decade; however, given this sector's relatively small share of total fossil CO_2 emissions, this figure is less significant than the growth rate for transportation CO_2 emissions, which increased by over 10 percent from 1990 through 2000. Residential sector CO_2 emissions increased by 16.4 percent during the decade, and industrial sector CO_2 emissions grew by 8.1 percent. (It should be noted that, as discussed below, when emissions from electric power generation are allocated across end-use sectors, the contributions from the residential and commercial sectors represent a much larger share of total state energy use than is the case when emissions from electric power generation are counted separately.)

Emissions from electric power generation showed only two percent net growth from 1990 through 2000, but this figure masks significant fluctuations: from 1990 through 1994, electric power emissions fell by 37 percent, then rose by over 60 percent from 1994 through 2000. These shifts reflected significant changes taking place in the electric power industry which are discussed below.

Another view of Connecticut's energy use can be obtained by allocating emissions from electricity production across end-use sectors. As Figure III-1 illustrates, when electricity generation emissions for the year 2000 are distributed across end-use sectors, the transportation sector remains the single largest source of energy-related GHG emissions, but the residential and commercial sectors together account for half of Connecticut's GHG emissions from energy use.[22]

[22] Shares of electricity consumed by other sectors were derived from EIA, Electric Power Annual 2000, Volume I, Tables A21-A24.

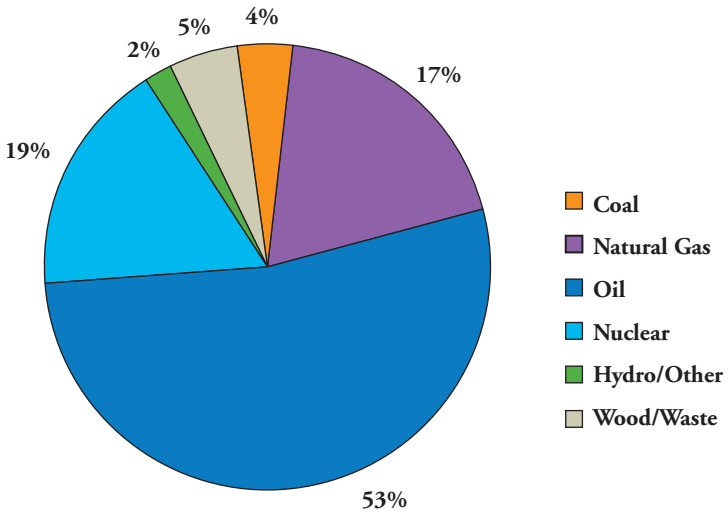
Figure III-1
Emissions from Primary Energy Demand, 2000



Like most other states, Connecticut is heavily although not exclusively reliant on fossil fuel for energy activities. Figure III-2 presents an estimation of the state's fuel mix in 2000.[23] About 26 percent of total in-state energy consumption was satisfied by non-GHG-emitting or low-emitting sources, including nuclear power, hydroelectric power, wood and waste, and renewable energy sources.

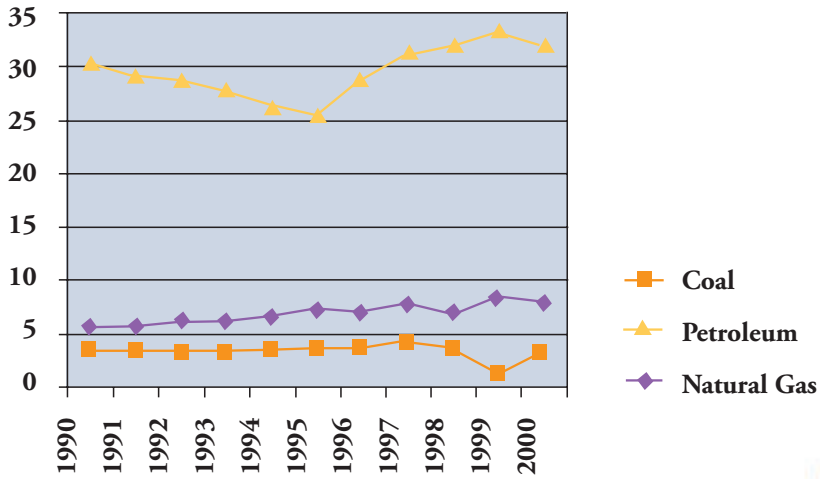
[23] Based on EIA, State Energy Data 2000, Table S1; see Appendix A for modifications. The contributions from hydroelectric power (1.6%) and other renewables, including geothermal, wind, photovoltaic, and solar thermal energy (.03%) were combined for visual clarity.

Figure III-2
Energy Use by Source, 2000 (percentage of total Btu consumption)



Connecticut's fossil fuel use, and particularly its relatively high reliance on oil, have significant implications for its GHG emissions. On average, natural gas consumption generates one metric ton of CO_2 per gigajoule, while oil produces 1.4 tons and coal produces 1.9 tons. Like the rest of New England, Connecticut consumes more oil per capita than the national average, due to a high regional reliance on oil for home heating and (to a lesser extent) for electricity production. Petroleum is the main source of CO_2 emissions from fossil fuel consumption in Connecticut, and is a major emissions source in all sectors of the state's economy: throughout the 1990s, oil accounted for roughly 75 percent of the state's fossil fuel CO_2 emissions, as illustrated in Figure III-3.

Figure III-3
CO_2 Emissions from Fossil Fuel Combustion by Fuel Type
(million metric tons)

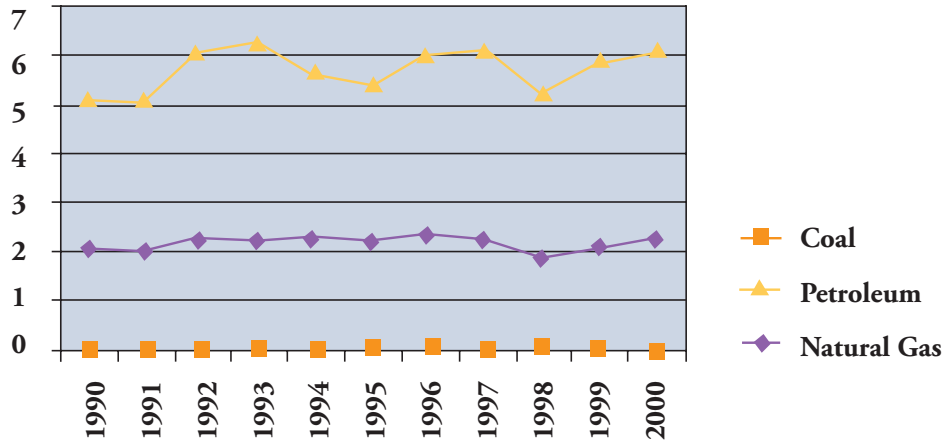


B. Emissions of Carbon Dioxide from Primary Energy Use by Sector

1.Residential Fuel Consumption

Carbon dioxide emissions from direct residential sector consumption of fossil fuels (i.e., not including indirect emissions from residential electricity consumption) are summarized in Figure III-4. Distillate fuel oil and natural gas, which are common fuels for space heating and water heating in Connecticut, are the main contributors. As of 2000, petroleum accounted for over 52 percent of home heating fuel use in Connecticut, followed by gas at 29 percent and electricity at 14.6 percent.[24] As shown above in Figure III-I, when the emissions associated with electricity consumption in the residential sector (based on the residential share of total electricity demand) are added to primary residential energy use, this sector accounted for nearly 30 percent of Connecticut's energy-related GHG emissions in 2000.

Figure III-4
Residential Emissions from Primary Energy Consumption by Fuel Type, 1990-2000 (million metric tons CO_2)

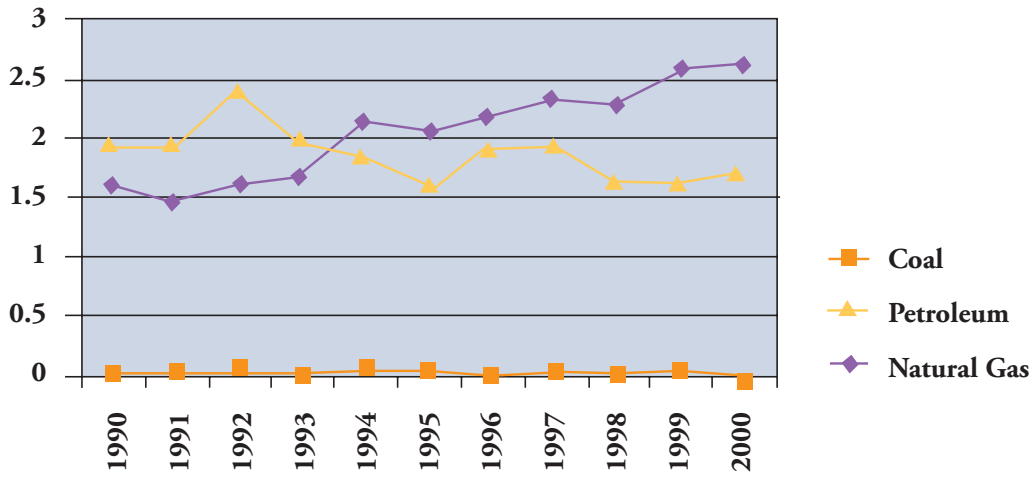


[24] New England Gas Association, "Home Heating Fuels, New England, Year 2000, U.S. Census Bureau," at www.nega.com/industry_trends/home_heating.htm.

2. Commercial Fuel Consumption

Carbon dioxide emissions from direct commercial sector consumption of fossil fuels are summarized in Figure III-5. As in the residential sector, space and water heating account for the bulk of emissions associated with primary energy use in the commercial sector. However, in contrast to Connecticut's residential sector, natural gas had surpassed petroleum as a source of CO_2 in commercial sector emissions from primary energy consumption by the mid-1990s. When the commercial sector's share of emissions from electricity generation is factored in, this sector accounted for 20 percent of total state energy-related emissions in 2000.

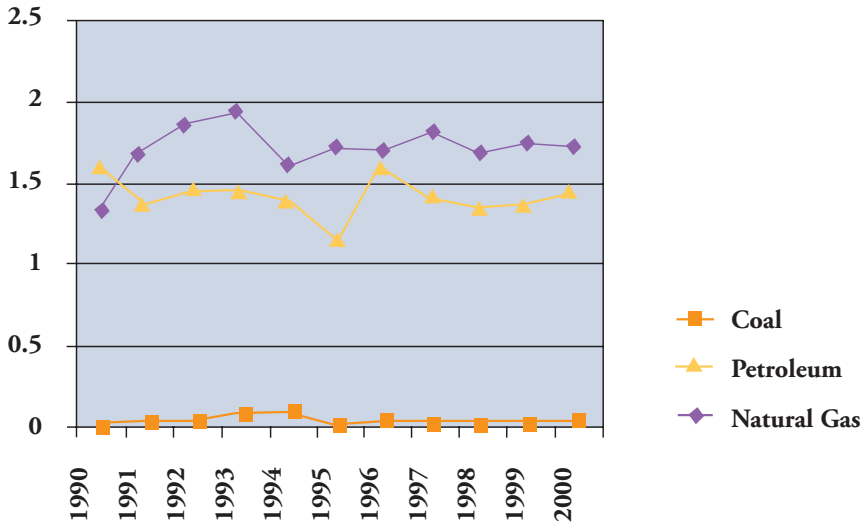
Figure III-5
Commercial Emissions from Primary Energy Consumption by Fuel Type, 1990-2000 (million metric tons CO_2)



3. Industrial Fuel Consumption

Figure III-6 depicts CO_2 emissions from primary energy consumption in the industrial sector. In calculating industrial emissions, the State GHG Inventory Tool takes into account the fact that not all fossil fuels used in this sector are combusted.[25] The totals here may under-report industrial emissions slightly because as noted in Appendix A, NESCAUM moved EIA's reported consumption of coal by non-utility electric power generators from the industrial sector, where it was reported by EIA, to the electricity sector. According to EIA, while some fraction of this coal may have been used to produce process heat at combined heat and power facilities, the majority was likely used to generate electric power.[26] When the industrial sector's share of electricity-related emissions is included, it accounted for about 12 percent of Connecticut's energy-related GHG emissions in 2000.

Figure III-6
Industrial Emissions from Primary Energy Consumption by Fuel Type, 1990-2000 (million metric tons CO_2)

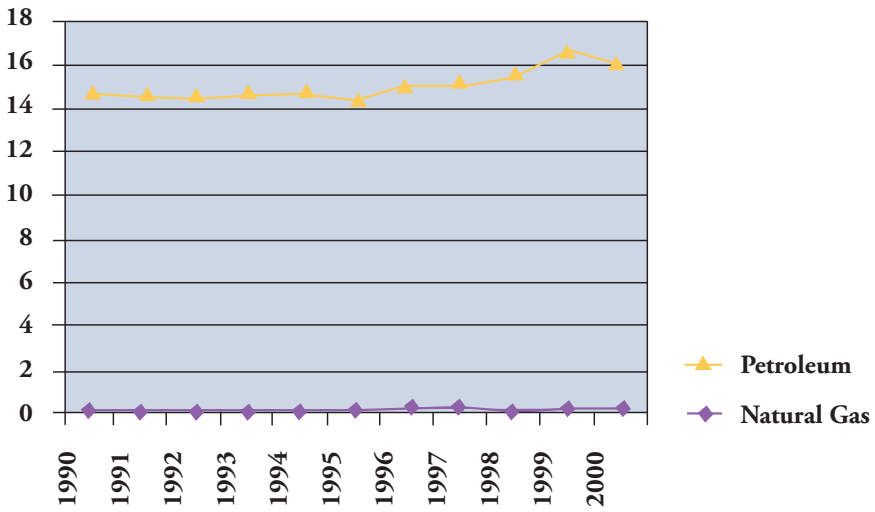


[25] As discussed in Appendix A, some fossil fuels are used in the industrial sector for non-energy purposes, such as asphalt and road oil used for highway construction. Depending on the specific non-fuel use, carbon in the fossil fuel input may be oxidized (thereby contributing carbon dioxide emissions) or stored (in which case no emissions are produced).
[26] See Appendix A for further details.

4. Transportation Fuel Consumption

Transportation accounts for the largest contribution from any sector to Connecticut's greenhouse gas emissions, with nearly all transportation emissions coming from consumption of petroleum fuels. Carbon dioxide emissions from transportation are summarized in Figure III-7. These figures are based on fuel consumption: throughout the decade, motor gasoline accounted for 77 to 80 percent of transportation CO_2 emissions, followed by distillate fuel (diesel vehicles) at about 15 percent per year and jet fuel at about 6 percent annually.

Figure III-7
Transportation Emissions from Primary Energy Consumption by Fuel Type, 1990-2000 (million metric tons CO_2)



This estimate overstates Connecticut's emissions very slightly because it does not subtract international bunker fuels used at Bradley International Airport from total fuel use in the transportation sector. International bunker fuels are fuels used in international aviation and marine transport, which are sold in-state but supplied to ships and aircraft which consume it during international transport activities. In accordance with international inventory practices, if state-level data on international bunker fuel use are available, related emissions may be reported by the state of origin but not included in the state's total emissions figures.

According to contacts at Bradley Airport, the contractor responsible for jet fuel sales has not kept separate records on fuel use for international flights for several years, so data were not available to calculate the related GHG emissions. However, Bradley Airport offers only a few international flights daily to Canada and the Caribbean, so the amount of international bunker fuel consumption in Connecticut is very likely quite small. The state GHG inventory for 1990 and 1995 developed by the University of Connecticut included figures for international bunker fuel use that amounted to approximately one percent of total jet fuel consumption in Connecticut for each of those years, and as noted above, jet fuel accounts for about six percent of the state's annual transportation CO_2 emissions.

5. Electricity Production and Electricity Imports

Electricity production was the second-largest source of fossil fuel CO_2 emissions in Connecticut after transportation throughout most of the 1990s, and total emissions from this sector fluctuated more dramatically than in any other sector. This was due to several factors, including an ongoing shift from oil to gas and the shutdown of all three units at the Millstone nuclear plant for several years.[27]

Another significant development occurred in 1998 when Connecticut passed electric utility restructuring legislation which required that utilities sell their non-nuclear generating assets by January 2000 and their nuclear generating assets by 2004. From 1998 through 2000, nearly all of Connecticut's electric generating plants were sold and reclassified as non-utility plants.[28] While this shift did not change actual emissions at Connecticut's electric power plants, it affected the data used to calculate those emissions: utility and non-utility generators report their fuel use and operating information separately to the U.S. Department of Energy's Energy Information Administration (EIA), and EIA's State Energy Data Reports (SEDR) on energy consumption to produce electricity in 1998-2000 do not currently reflect most fossil fuel consumption at nonutility power plants.

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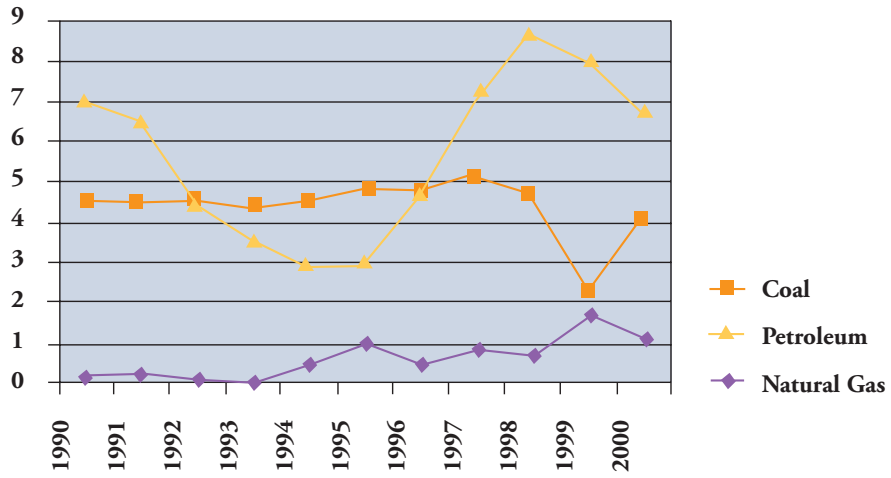
[27] Millstone 1 ended operation permanently in November 1995; Millstone 2 and 3 were shut down in 1996 due to safety concerns. Unit 3 resumed operation in June 1998 and Unit 2 followed in April 1999.

[28] See EIA, Inventory of Electric Utility Power Plants in the United States 2000, Table 17, and Inventory of Nonutility Electric Power Plants in the United States 2000, Table 6. The Millstone nuclear plant, which accounts for most of the utility generating capacity in the former report, was sold to Dominion Resources in late 2000. For an overview of changes in the electric power industry and definitions of the various categories of nonutility generators, see EIA, Electric Power Annual 2000, Volume II, pp. 1-5, 85-88.

EIA is revising its reporting format to provide better data on the changing electric power industry, and expects to provide a more accurate depiction of the electric power sector in the 2001 edition of SEDR, scheduled for publication in 2004. For the purposes of this inventory, NESCAUM inserted data on fossil fuel consumption for power generation in 1998-2000 from the May 2003 version of the Environmental Protection Agency's Emissions and Generation Resource Integrated Database (eGRID), to provide as comprehensive a picture as possible of total emissions from electric power production in Connecticut.[29] The resulting estimates should be viewed as approximations to be revisited when SEDR 2001 data become available.

Figure III-8 summarizes CO_2 emissions from electric power generation. Coal plays a significant role throughout the decade, while emissions from petroleum use fluctuate significantly, peaking in 1997-98 during the outage at Millstone noted above. In addition to the availability of nuclear capacity, these shifts may also be partly explained by trends in the price of oil, since some Connecticut power plants can be run on either oil or natural gas and shift between the two fuels depending on their relative prices. Natural gas accounts for a steadily rising share of emissions from 1990 to 2000, reflecting the ongoing national and regional shift to increased use of gas for electric power generation.

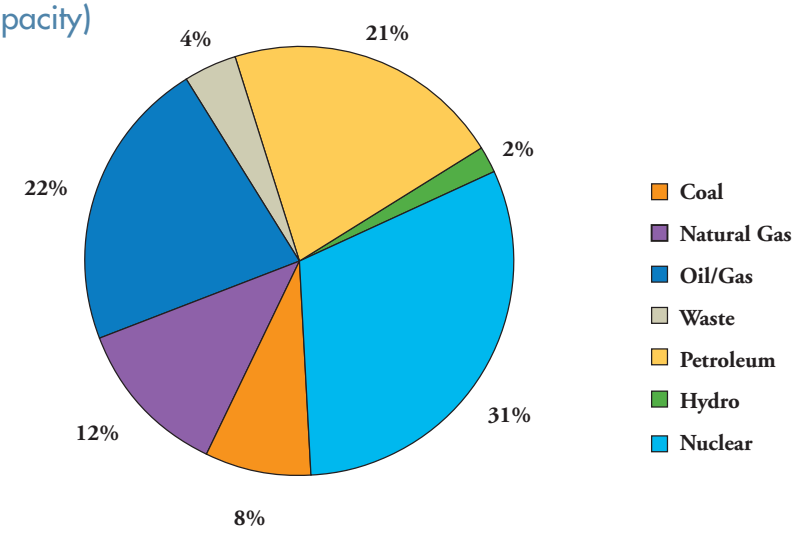
Figure III-8
Electric Power Production Emissions by Fuel Type, 1990-2000
(million metric tons CO_2)



[29]See Appendix A for details and sources. eGRID contains information on the environmental characteristics of virtually all electric power generated in the United States, and integrates 24 different Federal data sources; for more information, see http://www.epa.gov/cleanenergy/egrid.htm.

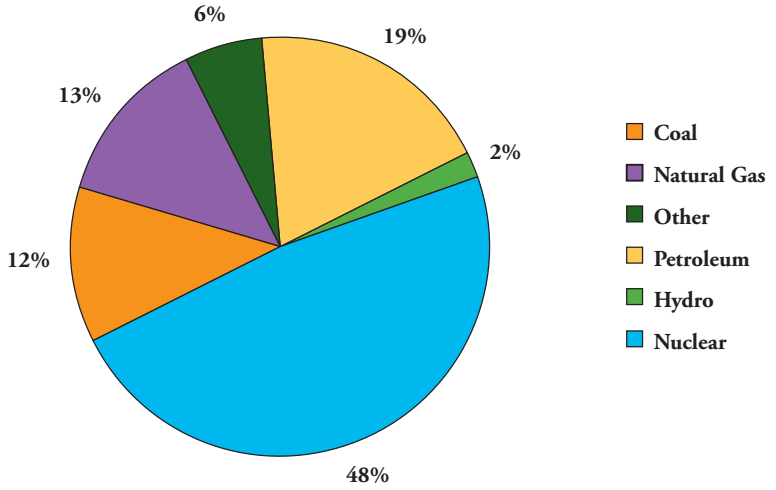
In terms of generating capacity, Connecticut's electricity sector relies on a mix of fossil fuel and nuclear power, with small contributions from hydropower and waste. Figure III-9 illustrates the total nameplate capacity at electric utility and nonutility plants in 2000.[30]

Figure III-9
Nameplate Capacity at Electric Power Plants, 2000
(share of total in-state capacity)



Connecticut's actual electric power generation in 2000 varied somewhat from the capacity mix, as illustrated in Figure III-10.

Figure III-10
Percent of Electricity Generated by Energy Source, 2000[31]



[30] EIA, Inventory of Electric Utility Power Plants in the United States 2000, Table 17, and Inventory of Nonutility Electric Power Plants in the United States 2000, Table 6.
[31] EIA, Electric Power Annual 2000, Volume I, p. 9. In this chart, energy from waste is captured in the "Other" category.

Although it uses more petroleum to generate electric power than the national average, Connecticut's electric power sector is less carbon-intensive overall than that of the United States as a whole. Nationwide, fossil fuels accounted for over 70 percent of electricity production in 2000, mainly from coal (51.8 percent, along with 16.1 percent from gas and 2.9 percent from petroleum). However, most of Connecticut's non-GHG-emitting electric power comes from the Millstone nuclear plant, which is scheduled to retire sometime in the next several decades.[32] In the near term, Connecticut's renewable energy portfolio standard sets quantitative targets for electric power production from qualified renewable sources, starting at 4 percent in 2004 and rising to 10 percent by 2010. Connecticut's success in meeting (and in the longer term, exceeding) these targets will be a key determinant of future GHG emissions from the electric power sector.

In the near term, Connecticut's renewable energy portfolio standard sets quantitative targets for electric power production from qualified renewable sources, starting at 4 percent in 2004 and rising to 10 percent by 2010. Connecticut's success in meeting (and in the longer term, exceeding) these targets will be a key determinant of future GHG emissions from the electric power sector.

During several of the years covered in this inventory, Connecticut also generated significant GHG emissions from electricity imported from other states. Since these emissions resulted from fuel consumption at plants outside of Connecticut, they are not counted in this inventory, but they are estimated here to provide a full picture of the GHG impact of energy demand in Connecticut. Table III-3 summarizes GHG emissions from Connecticut's electric power imports during the 1990s.[33] A negative value signifies that Connecticut was a net power exporter; emissions associated with generating electricity exported to other states are already captured in this inventory, since they are part of the overall output from Connecticut power plants for the relevant years, and so are not estimated here.

[32] Millstone 2 is licensed to operate through 2015 and Millstone 3 is licensed through 2025. Dominion Resources plans to apply to the Nuclear Regulatory Commission for license extensions, which would allow each unit to operate for an additional 20 years.

[33] See Appendix A for data sources. EIA State Energy Data Reports indicate that Connecticut was also a net power importer in 1991 and 1992, but estimates of net power imports for those years were not available.

Table III-3
Emissions from Interstate Electric Power Imports

Year	Net Imports (GWh) and % of total state consumption	NEPOOL Marginal CO2 Emission Rate (Lbs/MWh)[34]	Emissions from Imports (MMTCO2E)	Emissions from In-State Generation (MMTCO2E)	Total Emissions (MMTCO2E)
1994	-62	n/a	n/a	6.67	6.67
1995	-380	n/a	n/a	7.53	7.53
1996	10,137 (36%)	1.653	7.60	8.75	16.35
1997	12.436 (44%)	1,484	8.37	11.91	20.28
1998	11,229 (39%)	1,520	7.74	12.91	20.65
1999	3,880 (13%)	1,578	2.77	10.93	13.7
2000	-301	n/a	n/a	10.88	10.88

As discussed above, during the outage at the Millstone nuclear plant from 1996-98, Connecticut's GHG emissions from in-state electric power generation rose significantly. At the same time, the state's economy was expanding, and 1998 was the hottest year on record in terms of world average annual surface temperature. As a result, Connecticut was required to import substantial quantities of electric power from elsewhere in the New England power pool to meet in-state demand, and these electricity imports generated substantial GHG emissions (nearly equal to those from in-state electric power production in 1996). If these emissions had been counted as part of Connecticut's GHG inventory, they would have increased total state emissions for the relevant years by as much as 20 percent.[35]

C. Other Greenhouse Gas Emissions

Carbon dioxide is the dominant but not the only greenhouse gas produced through the combustion of fossil fuels. Other important greenhouse gases include methane (CH_4) and nitrous oxide (N_2O). As discussed above, one ton of CH_4 has a 100-year GWP value of 21, meaning that it has 21 times the global warming impact over a 100-year period as the same amount of CO_2; a ton of N_2O has a 100-year GWP of 310.

[34] It should be noted that marginal emissions rates represent the emissions that would be generated by the last unit of output, not the average emissions rate for the power pool. These rates are calculated annually for the New England Power Pool (the regional electricity market that includes Connecticut) to measure the impact of programs aimed at reducing electricity demand by estimating the amount of additional (marginal) emissions that would have resulted if such programs were not in place. Values cited here represent annual averages across seasons.

[35] While emissions from electric power imports are not counted as part of Connecticut's formal GHG inventory, they have an equivalent impact on the environment: unlike some other air pollutants, greenhouse gases mix uniformly in the atmosphere, and a ton of CO2 equivalent causes as much warming in Connecticut whether or not it is generated within the state.

Emissions of CH_4 and N_2O from fossil fuel combustion at stationary sources, such as furnaces, electric power plants, and industrial boilers, vary with the type of fuel combusted, the size and age of the combustion technology, the age and maintenance of the technology, and the type of pollution control used. CH_4 and N_2O are also produced by mobile sources, both as fuel is burned and under certain conditions when exhaust gases pass through post-combustion controls such as catalytic converters.

As illustrated above in Table III-1, non-CO_2 gases account for a small fraction of total GHG emissions from fossil fuel combustion. Throughout the 1990s, CH_4 and N_2O emissions from stationary source combustion accounted for about 0.4 percent of Connecticut's GHG emissions each year, while CH_4 and N_2O emission from mobile combustion represented about 1.5 percent of state GHG emissions annually.

Other pollutants generated by fossil fuel combustion do not have direct warming effects in the atmosphere, but do contribute to chemical reactions that alter or create greenhouse gases, such as tropospheric ozone. Pollutants with an indirect greenhouse effect include carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOCs). Black carbon (soot) particles also contribute to warming of the atmosphere, although scientists are still working to measure its impact. The climate impacts of these pollutants are generally small relative to carbon dioxide. Because their indirect influence on the greenhouse effect is highly variable and difficult to quantify, GWPs are not available for these types of pollutants, and they are not measured in this inventory.

IV. INDUSTRIAL PRODUCTION PROCESSES

In addition to its use of fossil fuels, the industrial sector produces greenhouse gas emissions when raw materials are chemically transformed from one state to another. For some industrial processes, these transformations result in the release of greenhouse gases such as CO_2, N_2O, HFCs, PFCs, and SF_6. Of these, the only processes that take place in Connecticut for which data are available are the use of substitutes for ozone-depleting substances, SF_6 use in electrical power systems, semiconductor manufacture, and limestone, dolomite, and soda ash use. There is no cement manufacturing, lime manufacturing, magnesium manufacturing, aluminum production or adipic acid production in Connecticut. No data are available on nitric acid production or HCFC-22 production for Connecticut.

Industrial production processes accounted for about 0.7 percent of Connecticut's annual GHG emissions in the early 1990s, rising to nearly 2 percent by 2000. As illustrated below in Figure IV-1, this contribution came mainly from gases with high GWP values (HFCs, PFCs, and SF_6). While these substances account for a relatively small share of state emissions, their contribution is notable because it has grown rapidly over the past decade. Emissions of high-GWP gases rose from 0.3 to 0.84 $MMTCO_2E$ during the 1990s, largely due to increased substitution of HFCs and some PFCs for ozone depleting substances (ODSs). Emissions from ODS substitutes rose from negligible levels in 1990 to approximately 0.7 $MMTCO_2E$ in 2000.

This trend reflects the U.S. decision to phase out a number of ozone-depleting substances, including chlorofluorocarbons (CFCs), by the end of 1995.[36] HFCs and PFCs are replacing CFCs in applications such as refrigeration and foam-blowing for insulation. Emissions of these gases in industrialized countries grew from small quantities in 1990 to about 125 $MMTCO_2E$ in 2000, and this trend is expected to continue and accelerate as other ozone-depleting substances are phased out by 2030.[37] HFCs and PFCs have a wide range of GWP values,

[36] Under the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, more than 30 countries pledged to eliminate production and consumption of CFCs and other substances that deplete stratospheric ozone. The United States phased out most covered chemicals by 1995; for details, see U.S. EPA, "The Accelerated Phaseout of Class I Ozone-Depleting Substances" at www.epa.gov/ozone/title6/phaseout/accfact.htm.

[37] U.S. Environmental Protection Agency, Office of Air and Radiation, Non-CO2 Greenhouse Gas Emissions from Developed Countries: 1999-2010 (Washington, DC, December 2001), p. 4-3; online at http://www.bcsd.org.tw/images/doc/306/003.pdf.

so it may be possible to mitigate their contribution to climate change by favoring those compounds that contribute less to global warming, although such changes could reduce the energy efficiency of the impacted products.[38]

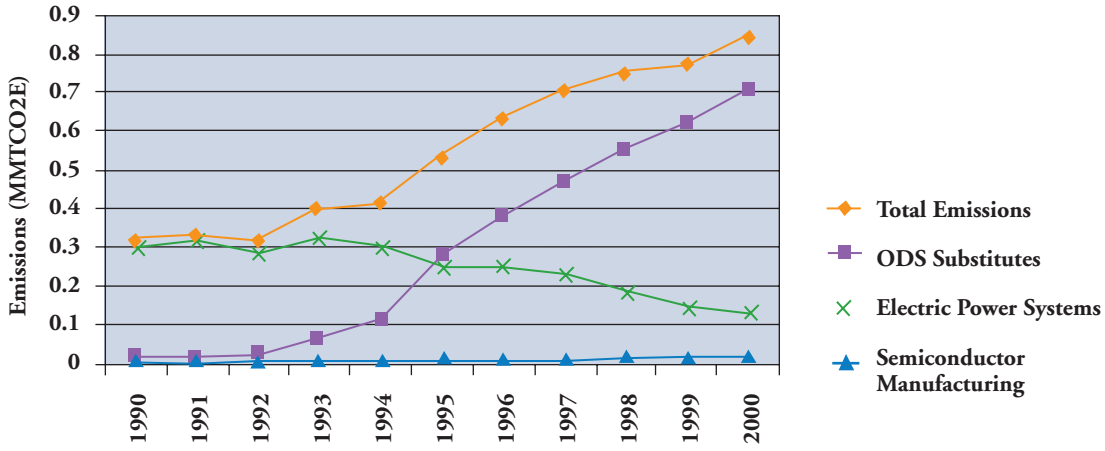
The main use of SF_6 is as an insulator in electricity transmission and distribution equipment, such as gas-insulated high-voltage circuit breakers, substations, transformers, and transmission lines. Connecticut's SF_6 emissions decreased from approximately 0.3 $MMTCO_2E$ to 0.1 $MMTCO_2E$ between 1990 and 2000, reflecting national efforts by the electric power industry to control leaks in response to SF_6 price increases and concerns about its environmental impact. Several Connecticut electric utility companies are participating in a voluntary partnership with EPA to reduce SF_6 emissions and have established SF_6 emissions reduction goals.[39]

PFCs emitted during semiconductor manufacturing accounted for a small fraction of Connecticut's GHG emissions throughout the decade. However, these emissions are likely to rise in coming decades, driven by growing demand for semiconductors. The World Semiconductor Council has pledged to reduce PFC emissions from chip manufacture at least 10 percent below 1995 levels by 2010. More than 90 percent of U.S. semiconductor manufacturing capability is represented by the WSC and its U.S. segment, the Semiconductor Industry Association.

A small amount of CO_2 emissions from this sector were generated by limestone and dolomite use in a wide variety of industrial processes and soda ash use for consumer products.

[38] John M. Reilly, Henry D. Jacoby, and Ronald G. Prinn, Multi-Gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of Non-CO2 Gases (Arlington, VA:Pew Center on Global Climate Change, February 2003), pp. 10-11.
[39] U.S. Environmental Protection Agency, SF6 Emissions Reduction Partnership For Electric Power Systems, Program Report (Washington, DC, August 2002), pp. 13-14; online at http://www.epa.gov/highgwp1/sf6/pdf/eps_program_report_2002.pdf

Figure IV-1
Industrial Production Processes High GWP Emissions, 1990 - 2000



V. NATURAL GAS AND OIL ACTIVITIES

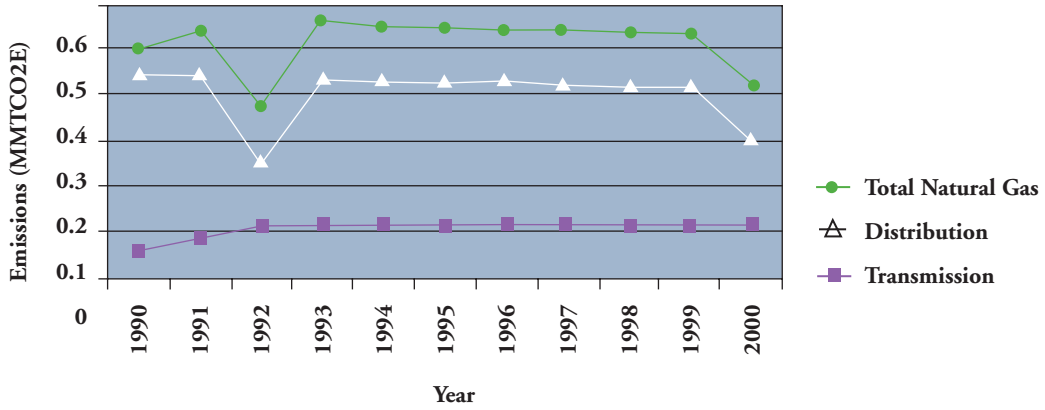
Together, oil and natural gas systems are the second largest source of methane (CH_4) in the United States, comprising 22.5 percent of CH_4 emissions and 2.0 percent of total greenhouse gas emissions in 2000. Natural gas systems alone are the third largest source of CH_4 in the United States, with emissions five times greater than CH_4 emissions from oil systems.

CH_4 is emitted during oil and gas production, storage, transportation, and distribution. There is no oil or gas production in Connecticut, so emissions occur solely through gas transmission (bringing gas from its source, such as wells in Canada, to the state) and distribution (delivering gas from transmission gate stations to end users). Major CH_4 emission sources from gas transmission pipelines include chronic leaks, fugitive emissions from compressors, compressor exhaust, vents, and pneumatic devices; for gas distribution pipelines, major CH_4 emission sources include chronic leaks, meters, regulators and mishaps.

Emissions of CH_4 from natural gas transmission and distribution systems accounted for approximately one percent of all greenhouse gas emissions in Connecticut during the 1990s. Throughout the decade, the natural gas sector produced approximately 0.53 $MMTCO_2E$ annually, except for declines in 1992 and 2000. These decreases may reflect anomalies in data reporting rather than actual declines in methane emissions. Nearly 80 percent of estimated emissions were produced by natural gas distribution systems.

With the rising popularity of gas as an energy source in New England, new construction and improvements to existing gas delivery systems are planned throughout the region. Several of the major gas transmission companies serving New England are currently participating in EPA's Natural Gas STAR Program, a voluntary partnership with the gas industry to reduce methane emissions.[40] According to the Northeast Gas Association, four companies currently provide local gas services in Connecticut.[41]

Figure V-1
Natural Gas Emissions, 1990 - 2000



[40] The companies are Algonquin Gas Transmission (a subsidiary of Duke Energy Gas Transmission), Tennessee Gas Pipeline (a subsidiary of El Paso Natural Gas), and Iroquois Gas Transmission. Of these, only Iroquois is based in Connecticut. U.S. Environmental Protection Agency, "STAR Partners," online at www.epa.gov/gasstar/partners.htm.

[41] The suppliers are Yankee Gas Services, Southern Connecticut Gas, Connecticut Natural Gas Corp., and the City of Norwich Department of Public Utilities; map online at www.nega.com/territory/ct.htm.

VI. LANDFILLS AND WASTE COMBUSTION

In landfills, methane (CH_4) and carbon dioxide (CO_2) are produced from anaerobic decomposition (i.e., in the absence of oxygen) of organic matter by bacteria. These "biogases" are approximately 50 percent CH_4 and 50 percent CO_2 by volume. Some landfills flare (burn off) recovered landfill gas, which converts the CH_4 portion of the gas to CO_2. Since CH_4 has a global warming potential value of 21, compared to 1 for CO_2, flaring reduces net GHG emissions from landfills.

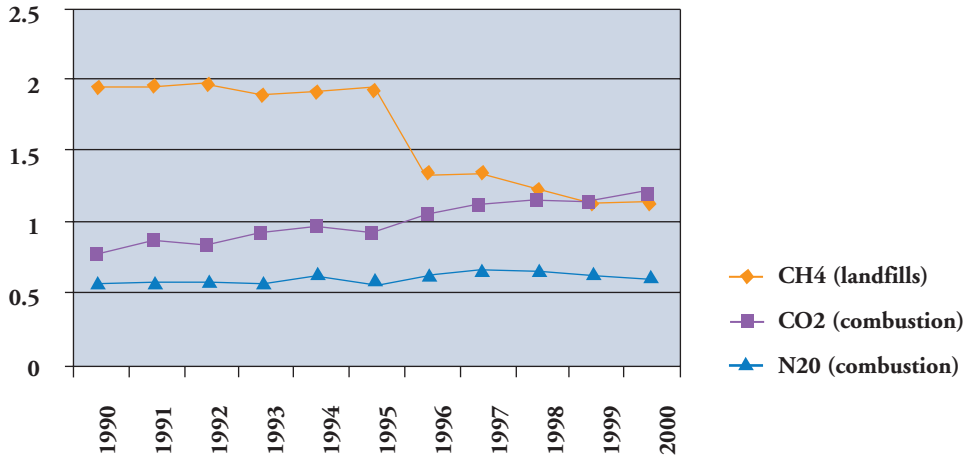
Neither the CO_2 emitted directly as biogas nor the CO_2 emitted from combusting CH_4 at flares is counted as an anthropogenic greenhouse gas emission, since the main source of this CO_2 is decomposition of organic materials derived from biomass sources such as paper, wood, and food. Current U.S. guidance assumes that these sources are harvested on a sustainable basis, and so does not view waste-related CO_2 emissions as a net contribution to global warming because carbon emissions from combustion and decomposition are offset by a corresponding sequestration of carbon in biomass regrowth.

Waste combustion emits both CO_2 and nitrous oxide (N_2O). CO_2 is produced from oxidation of organic materials in waste, such as paper, food scraps, yard trimmings, and plastic. As with CO_2 from biogas and oxidation of CH_4, CO_2 emissions from biogenic sources (e.g., paper and food scraps) are not counted as a greenhouse gas because they simply return CO_2 that plants previously absorbed through photosynthesis to the atmosphere. However, some CO_2 is from nonbiogenic sources (e.g., plastic and rubber made from petroleum), and is thus counted as a greenhouse gas. N_2O is produced at the high temperatures found in waste combustors by the combination of nitrogen (both nitrogen contained in the waste and nitrogen gas in the air) and oxygen gas in the air.

Greenhouse gas emissions from MSW disposal – including both landfilling and waste combustion – accounted for roughly six to eight percent of Connecticut's annual GHG emissions in the 1990s, and declined by nearly 10 percent from approximately 3.5 $MMTCO_2E$ in 1990 to 3.16 $MMTCO_2E$ in 2000. As discussed earlier in this report, the state has shifted its MSW management system over the past two decades away from primary reliance on landfills, and toward source reduction, recycling, composting, resource recovery, and finally landfills as a last option.

As illustrated in Figure VI-1, while overall emissions from MSW management decreased throughout the 1990s, emissions generated by MSW combustion increased. Connecticut ended the practice of burning municipal solid waste (MSW) in incinerators in the early 1990s, but currently sends most MSW to six resource recovery facilities (RRFs) that burn the waste to generate electricity. While this practice generates some GHG emissions, the RRFs emit much lower quantities of non-GHG air pollutants than incinerators, and burning waste produces lower GHG emissions than landfilling it.[42] Moreover, waste is a relatively low-carbon energy source for electric power generation compared to fossil fuels: in 2000, the CO_2 emission rates at Connecticut's RRFs averaged about 925 pounds per megawatt-hour, comparable to the state's natural gas plants, and at least 50 percent lower than most coal or oil plants.[43]

Figure VI-1
Emissions from Landfills and Waste Combustion, 1990-2000
(million metric tons CO_2 equivalent)



[42] As discussed in Appendix A, some sources – such as EPA's eGRID 2002 database – treat these facilities as electric power plants, and thus count their emissions within that sector. However, since RRFs currently handle over 80 percent of Connecticut's MSW, they are treated in this inventory as part of the waste sector.
[43] Output rates were obtained from eGRID 2002 at http://www.epa.gov/cleanenergy/egrid.htm.

The Clean Air Act requires that landfill gas must be collected and either flared or used at landfills that are designed to hold more than 2.5 million metric tons of waste and emit at least 50 metric tons per year of non-methane volatile organic compounds (NMVOCs). While few of Connecticut's landfills are large enough to fall under this requirement, the state had two landfill gas recovery programs operating as of January 2003 that were avoiding approximately 216,000 tons of CO_2 equivalent per year by using landfill gas to produce electricity, along with flaring operations at several other sites that were avoiding up to roughly 600,000 tons of CO_2 equivalent per year.[44] According to the Environmental Protection Agency, several other sites in Connecticut are suitable candidates for landfill gas recovery programs.[45]

Throughout the 1990s, Connecticut both imported MSW from other states and sent some of its own waste out of state. In each case, a portion of the waste was landfilled and the balance was burned at incinerators or RRFs. Figures VI-2 and VI-3 illustrate recent disposal patterns for MSW imported into and shipped out of Connecticut in the years for which data was available. Shipments of out-of-state waste into Connecticut fell steadily from over 600,000 tons in 1993 to about 100,000 tons in 2000, while exports of MSW generated in Connecticut to other states rose from slightly over 8,000 tons in 1993 to 304,000 tons in 2000.

[44] As noted in Appendix D, NESCAUM estimated emissions from landfill gas flaring based on Connecticut state data and assuming that sites operate at their maximum capacity, so this figure may overestimate avoided emissions.

[45] U.S. Environmental Protection Agency, Landfill Methane Outreach Program, "Current LMOP Landfill and Gas Utilization Project Database – Connecticut," updated January 29, 2003, at http://www.epa.gov/lmop/projects/projects.htm. In 1999, EPA estimated that Connecticut might be able to reduce GHG emissions by more than 750,000 tons of CO2 equivalent per year through landfill gas recovery; see EPA, "Landfill Gas-to-Energy Project Opportunities: Landfill Profiles for the State of Connecticut," (January 1999), also at http://www.epa.gov/lmop/projects/projects.htm.

Figure VI-2
Out-of-State MSW Disposal in Connecticut (thousand tons)

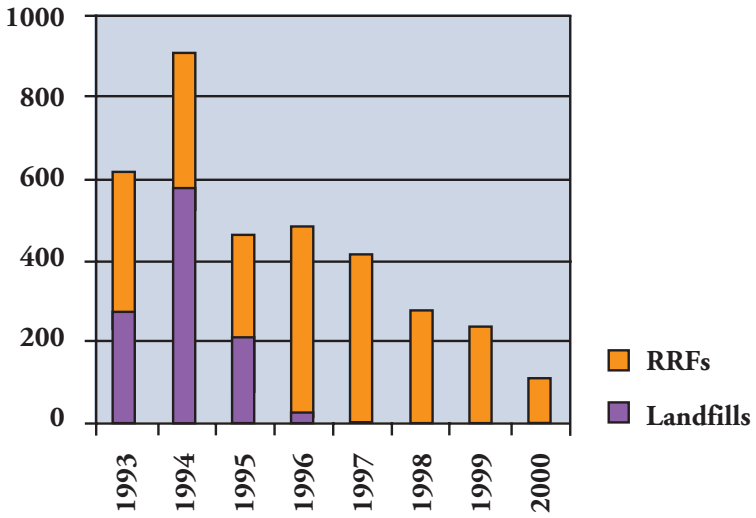
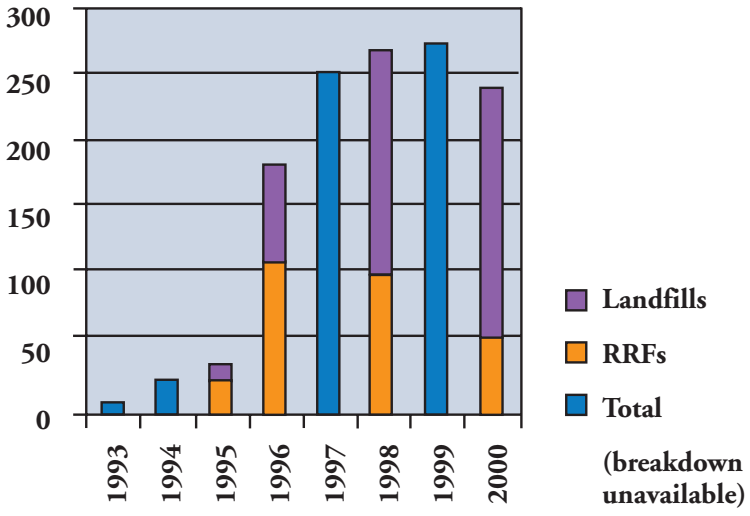


Figure VI-3
Connecticut MSW Disposal Out of State (thousand tons)



Emissions associated with landfilling or burning waste imported from other states into Connecticut are included as part of this inventory, since the emissions are generated within Connecticut's boundaries. As Figure VI-2 illustrates, however, these imports are declining, and recent shipments have helped to fuel electric power production at Connecticut's RRFs. In contrast, Connecticut shipped nearly 12 percent of its MSW out of state in 2000, and a substantial portion of this waste was sent to landfills. If emissions associated with Connecticut waste exported to other states were counted as part of this inventory, Connecticut's total emissions from landfills would have doubled for 1998 and 2000. These emissions are similar to the emissions discussed in Chapter III that are associated with Connecticut's imported electric power in 1996-99: while not formally part of the state's inventory, they reflect high demand (in this case, for MSW disposal capacity) and a potential opportunity for reducing Connecticut's overall contribution to climate change.

VII. MUNICIPAL WASTEWATER

Disposal and treatment of industrial and municipal wastewater often result in methane (CH_4) emissions. Wastewater may be treated using aerobic and/or anaerobic technologies (processes with or without oxygen present), or if untreated, may degrade under either aerobic or anaerobic conditions. Methane is produced when organic material is treated in an anaerobic environment and when untreated wastewater degrades anaerobically. Nitrous oxide (N_2O) is emitted from both domestic and industrial wastewater containing nitrogen-rich organic matter. Human sewage is believed to constitute a significant portion of the material responsible for nitrous oxide emissions from wastewater.

Municipal wastewater emissions of greenhouse gases accounted for about one-half of one percent of annual greenhouse gas emissions for Connecticut during the 1990s. Annual GHG emissions from wastewater totaled approximately 0.16 $MMTCO_2E$ of methane and 0.13 $MMTCO_2E$ of nitrous oxide. In 2000, the levels increased slightly as a result of rising state population.

VIII. AGRICULTURE

Greenhouse gas emissions are generated by a number of activities in the agricultural sector, which are summarized in this section. Throughout the 1990s, agriculture accounted for about 0.6 percent of Connecticut's total greenhouse gas emissions annually.

Methane (CH_4) is a natural by-product of animal digestion. During digestion, CH_4 is produced through a process referred to as enteric fermentation that takes place in the digestive tracts of ruminant domestic animals -- notably cattle, sheep, and goats. CH_4 emissions are counted only for domesticated animals; emissions from wild animals are not considered because such emissions are not the result of human activity. Nationally, methane emissions from enteric fermentation account for approximately 20% of total U.S. CH_4 emissions.

Manure decomposition is a process in which microorganisms derive energy and material for cellular growth by metabolizing organic material in manure. When decomposition occurs under anaerobic conditions, CH4 is produced. In addition to CH4, N2O is produced during the manure decomposition process.

N_2O also is produced naturally in soils through the microbial processes of denitrification and nitrification.[46] A number of anthropogenic activities add nitrogen to soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. These activities include application of fertilizers, animal production, cultivation of nitrogen-fixing crops, and incorporation of crop residues. In Connecticut, direct N_2O emissions from agricultural soils result from fertilizer use, animal production, and N-fixing crops, while indirect N_2O emissions come from animal waste.

CO_2 emissions from liming of agricultural soils are included in the Forest Management and Land Use Change section of this report. Other agricultural activities that produce GHG emissions, such as rice cultivation and agricultural residue burning, do not take place in Connecticut.

[46] Denitrification, the process by which nitrates or nitrites are reduced by bacteria, results in the release of nitrogen into the air. Nitrification is the process by which bacteria and other microorganisms oxidize ammonium salts to nitrites, and further oxidize nitrites to nitrates.

Total yearly GHG emissions from agriculture in Connecticut ranged from approximately 0.3 to 0.35 $MMTCO_2E$ during the 1990s. The largest source of emissions in this sector is agricultural soil management, which generated approximately 0.16 $MMTCO_2E$ per year, followed closely by enteric fermentation at about 0.12 $MMTCO_2E$ per year. Manure management accounts for the remainder of the emissions at just under 0.05 $MMTCO_2E$ per year.

IX. FOREST MANAGEMENT AND LAND USE CHANGE

Forest Management and Land Use Change refers to human activities that alter land use (e.g., clearing of forests for agricultural use or cropping practices) or affect the amount of carbon or biomass in existing forest or soil stocks. This sector both emits greenhouse gases (i.e., is a source) and removes them from the atmosphere through carbon sequestration (i.e., is a sink). Forestry and land use practices hold considerable potential for offsetting greenhouse gas emissions. Because global vegetation and soils contain about three times as much carbon as the planet's atmosphere, terrestrial ecosystems offer an opportunity to absorb and sequester a significant amount of CO_2 from the atmosphere. By planting trees, following appropriate forest management practices, and changing land use practices to increase soil carbon, for example, it is possible to increase the size of carbon sinks.

The activities included in the EPA State Greenhouse Gas Inventory Tool for estimating CO_2 emissions and sequestration include liming of agricultural soils, landfilled yard trimmings and forest carbon flux. The most important of the three for Connecticut is forest carbon flux, which includes four distinct areas: (1) biomass; (2) forest floor and coarse woody debris; (3) soils; and (4) wood products and landfills.

The data in this section are reported in annual change in $MMTCO_2E$ rather than absolute numbers. The largest change occurred in the forest carbon flux data, where the level of carbon sequestration shrank from –2.71 $MMTCO_2E$ in 1990 to –2.04 $MMTCO_2E$ in 2000. This decline was driven by a decrease between 1992 and 1993 in carbon sequestered by wood products and landfills of -.47 to .098 $MMTCO_2E$. However, it is quite likely that this shift is an artifact of the data: EPA's model used data averaged over five-year intervals from 1987-1992 and 1993-1998. Thus, any change in the averaged value would be seen between years 1992 and 1993. In reality, the decline was probably more gradual and may have been a result of a policy change in Connecticut solid waste management away from landfills to combustion of waste in waste-to-energy plants.

Carbon emissions from liming of agricultural soils and landfilling yard trimmings remained near zero throughout the decade, except that landfilled yard trimmings decreased slightly over the decade due to the introduction of composting programs during the 1990s.

APPENDIX A: FOSSIL FUEL COMBUSTION

A. Data Sources

Information on fuel consumption in Connecticut by type and sector was obtained from the State Energy Data 2000 (SED) report published by the U.S. Department of Energy's Energy Information Administration (EIA).[47] This data is the basis for calculating CO_2 emissions from fossil fuel combustion and non-CO_2 emissions from stationary source combustion.

SED 2000 data were used with the following exceptions:

(1) Coal consumption by nonutility generators for electric power generation from 1990-2000. In SED 2000, EIA added a new factor in the industrial sector, dating back to 1990, to account for coal consumed by non-utility power producers. This change increased Connecticut's reported coal consumption in the industrial sector for the years covered in this inventory by several orders of magnitude over previous SEDR editions. According to EIA, most of this industrial coal use was probably for production of combined heat and power (CHP) at industrial facilities, with the majority of the fuel input going to produce electricity.

In future editions of SEDR, fuel use for CHP will be presented separately in each sector from fuel use to produce electricity only, but the current do not allow such a division. Accordingly, in order to present as comprehensive an estimate as possible of total GHG emissions from electricity production in Connecticut, NESCAUM subtracted EIA's reported values for nonutility coal consumption (denoted as "Independent Power Coal" in the State GHG Inventory Tool software) in each year from 1990 through 2000 from the industrial sector, and added them to reported coal consumption in the electric utility sector. This allocation probably overstates emissions from coal-fired electricity production somewhat, since some industrial coal use was likely to produce process heat, and should be revisited in future years when EIA has reformatted its state energy consumption data to provide more specific information on CHP use and electricity production by nonutility generators.

[47] Prior to 2000, this series was titled State Energy Data Reports and commonly abbreviated SEDR.

(2) Fossil fuel consumption for electric power generation in 1998-2000. Nearly all of Connecticut's electric power plants were sold and reclassified as nonutility plants between 1998 and 2000. Because EIA's state reports do not currently cover nonutility generators, fuel use to produce electric power in Connecticut for those years is captured only partially or not at all in SED 2000, and EIA does not specify which individual plant reports are included in its figures. As a proxy, NESCAUM substituted data on fossil fuel consumption for power generation in 1998-2000 from the May 2003 version of the Environmental Protection Agency's Emissions and Generation Resource Integrated Database (eGRID), to provide as comprehensive a picture as possible of total emissions from electric power production in Connecticut.[48] In deriving total figures for oil, coal, and gas consumption in Connecticut for each of these years, 100 percent of the reported annual fuel input at each plant was allocated to the plant's reported primary fuel for that year (i.e., if a plant's primary fuel was oil, all of its fuel input for that year was counted as oil). In most cases, the reported primary fuel accounted for 90 to 100 percent of total fuel consumption at each plant, so these figures offer a reasonable approximation of total annual fuel use in the state. All types of oil were included in a single category. Fuel use at the following plants was not included in these totals:

- Connecticut's six resource recovery facilities (RRFs), which burn municipal solid waste. Emissions from these plants are captured in the waste section of this inventory.
- The South Meadow biomass facility. The State GHG Inventory Tool and EPA guidance assume that biomass fuel for electric power generation is produced sustainably, and therefore do not include CO2 emissions from biomass combustion in state inventories.[49]
- The Exeter Energy Project, which burns tires. Appropriate emission factors for calculating GHG emissions from this facility were not available.

[48] eGRID contains information on the environmental characteristics of virtually all electric power generated in the United States, and integrates 24 different Federal data sources; for more information, see http://www.epa.gov/cleanenergy/egrid.htm.

[49] Conversely, eGRID assumes that a fraction of the plant's input is non-organic material and estimates emissions associated with burning that fraction.

Table A-1 summarizes values reported in eGRID 2002 and used in this report to calculate emissions from electric power generation using coal, gas, and oil in Connecticut in 1998-2000.

Table A-1

Fossil Fuel Consumption for Electric Power Generation in Connecticut, 1998-2000 (million Btu)

	1998	1999	2000
Coal			
AES Thames	15,758,462	14,048,193	15,680,327
Bridgeport Station	24,413,006		17,801,630
Stone Container	-	94,571	91,876
Total (MMBtu)	**40,171,468**	**14,142,764**	**33,573,833**
Gas:			
Ahlstrom Fiber	3,063,569	3,105,501	2,991,004
Bridgeport Energy	2,372,490	9,962,654	13,050,250
Capitol District	3,080,598	3,411,448	2,861,741
Downtown Cogen	227,315	230,695	214,287
Hartford Hospital	421,039	441,337	415,987
NRG Devon	-	14,216,854	-
Pfizer	734,297	-	1,061,117
Sprague Paperboard	2,770,740	971,532	720,756
Stone Container	66,847	-	-
United Technologies	1,248,411	1,128,130	1,017,522
Total (MMBtu)	**13,985,306**	**33,468,151**	**22,332,664**
Oil:			
Branford	11,008	41,627	680
Bridgeport Station	-	-	-
Cos Cob	54,005	95,009	9,356
Franklin Drive	13,002	35,032	1,985
Montville	17,069,969	13,592,931	13,417,244
New Haven Harbor	23,366,984	23,277,131	18,521,871
North Main Street	15,519	54,267	6,021
NRG Devon	14,737,397	-	10,488,335
NRG Middletown	32,668,862	25,130,343	26,546,637
NRG Norwalk	21,095,378	17,156,234	15,770,001
Pierce	15,486	21,082	12,401
Pfizer	-	897,458	-
S. Meadow	-	-	-
S. Norwalk	26,423	18,292	14,263
Torrington	15,181	36,503	2,495
Total (MMBtu)	**109,089,214**	**100,834,131**	**84,791,289**

To depict Connecticut's fuel mix for 2000 in Figure III-3, NESCAUM used SED 2000, table S1, modified to reflect the changes discussed above in the state's fossil fuel consumption for 2000. Connecticut's petroleum consumption for 2000 was increased by 84.7 TBtu, from 376 to 460.7 TBtu, and natural gas consumption was increased by 22.3 TBtu, from 129.9 to 151.5 TBtu, raising reported total consumption from 863 TBtu to 970 TBtu. These modified figures were used to calculate the percentage of consumption met with various fuels in 2000:

- Coal: 36.2 TBtu (3.7%)
- Natural gas: 151.5 TBtu (15.6%)
- Petroleum: 460.7 TBtu (47.5%)
- Nuclear: 170.7 TBtu (17.6%)
- Hydroelectric power: 15.6 TBtu (1.6%)
- Wood and waste: 44.3 TBtu (4.6%)
- Other(wind, solar, geothermal): 0.3 TBtu (.03%)

The State Inventory Tool provides default values from Department of Energy and EPA analyses for the remaining variables required to calculate CO2 emissions from fossil fuel combustion and CH4 and N2O emissions from stationary source combustion, including:

- heat contents of fossil fuels (i.e., the number of British Thermal Units or Btu per ton of coal or barrel of oil);
- carbon contents of fuels (the number of pounds of carbon contained in each fuel per million Btu);
- percentage of carbon that is stored when fossil fuels are used for various non-energy purposes such as asphalt manufacture; and
- CH_4 and N_2O emission factors by fuel type and sector.

In calculating CH_4 and N_2O emissions from stationary sources, state fuel use data from SED 2000 were used with the same modifications discussed above for calculating CO_2 emissions from fossil fuel use (i.e., nonutility coal consumption was shifted from the industrial to the electricity sector, and fossil fuel use totals from eGRID 2002 were substituted for the relevant figures in SED 2000 for 1998-2000).

Estimating CH_4 and N_2O emissions is a more complex process based on the annual number of vehicle miles traveled (VMT) in the state and emission factors derived from vehicles' age, type, and emission control systems. The State Inventory Tool provides state VMT figures from the Federal Highway Administration's Highway Statistics report, along with values for the following variables:

- distribution of VMT among vehicle types for each year;
- average vehicle age distribution;
- emission control systems by vehicle type; and
- emission factors by vehicle type

B. Methodology

The calculations required to estimate greenhouse gas emissions from fossil fuel combustion begin with state data on fuel consumption. The basic methodology for calculating CO_2 emissions consists of multiplying the quantity of fuel consumed by the carbon content of the fuel, making an adjustment for incomplete oxidation, and converting this figure to tons of CO_2.

Additionally, in the industrial sector, calculations are adjusted to reflect the fact that not all fossil fuels used are combusted: prominent examples include lubricants, asphalt and road oil used in highway construction, and natural gas and petrochemical feedstocks used in industrial processes. Depending on the non-fuel uses involved, carbon may either be oxidized (thereby contributing carbon dioxide emissions) or stored (in which case there are no emissions). Therefore, to calculate CO_2 emissions from industrial use of fossil fuels, total fuel consumption is multiplied by the fraction typically used for non-fuel purposes, based on national averages. This subset is multiplied by a factor representing the fraction of its carbon content that can be assumed to be stored in non-fuel uses. The remaining carbon content associated with non-fuel use is assumed to be oxidized, together with all of the carbon associated with fuel uses.

CO_2 emissions associated with electricity imports were calculated for this inventory by multiplying reported net imports from eGRID 2002 for the relevant years

by marginal CO_2 emission rates estimated by ISO-New England for the New England Power Pool.[50]

Emissions of CH_4 and N_2O from stationary sources are calculated by multiplying the total amounts of coal, petroleum, natural gas, and wood combusted in the residential, commercial, industrial, and electric utility sectors by appropriate emissions factors. In the industrial sector, as with the process for calculating CO_2 emissions from fossil fuel combustion, the quantities of fossil fuels that are used for non-energy purposes and are not combusted (for example, natural gas used for ammonia production or oil used to produce asphalt) are subtracted from total fuel use prior to calculating CH_4 and N_2O emissions.

As noted above, CO_2 emissions from biomass combustion are not counted as part of Connecticut's emissions because, provided that the fuel source is harvested on a sustainable basis, biomass combustion does not lead to a net increase in greenhouse gas levels in the atmosphere (the carbon contained in the fuel was sequestered from the atmosphere when the fuel source was grown, so combustion simply returns it to the atmosphere). However, the Inventory Tool does calculate CH_4 and N_2O emissions from biomass combustion, which constitute net dditions to atmospheric concentrations of these gases.

Estimating emissions of CH_4 and N_2O from mobile sources is a more complex process that involves the following steps in the State Inventory Tool:

- Obtain activity data on vehicle miles traveled (VMT);
- Calculate VMT for each vehicle type;
- Convert VMT data for use with existing emissions factors;
- Distribute VMT by vehicle age;
- Determine emissions control systems for each vehicle type; and
- For each combination of vehicle type and emission control type, multiply VMT by the appropriate emission factors for CH_4 and N_2O.

[50] ISO New England, 2001 NEPOOL Marginal Emission Rate Analysis for the NEPOOL Environmental Planning Committee (December 2002), p. 17; online at http://www.iso-ne.com/Planning_Reports/Emissions/

C. Sample Calculations

Note: for simplicity of presentation, some steps involved in converting emissions from a raw figure to tons of CO_2 equivalent have been omitted from these calculations. Numbers may not total exactly due to rounding. The following conversions and abbreviations are used in obtaining a final emission figure:

1 short ton = 0.907 metric tons
1 million grams = 1 metric ton
1 ton carbon = 3.667 tons CO_2
$MTCO_2E$ = metric tons CO_2 equivalent
$MMTCO_2E$ = million metric tons CO_2 equivalent

CO_2 from residential fossil fuel combustion:

Fuel type	Consumption (billion Btu)	Emission factor (lbs C/million Btu)	Combustion efficiency (%)	Emissions (short tons C)	Emissions (MMTCO2E)
Distillate Fuel	78,388	x 43.98	x99.0	=1,706,598	=5.675

N_2O from stationary source combustion:

Fuel type	Consumption (billion Btu)	Emission factor (metric tons N2O/BBtu)	Emissions (metric tons N20)	GWP for N2O	Emissions (MTCO2E)
Coal	792	x 0.00140	=1.1088	x310	=344

CH_4 from mobile combustion:

Vehicle class	Vehicle miles traveled (million)	Emission factor (g CH4/mile)	Emissions (g CH4)	GWP for CH4	Emissions (MTCO2E)
Light-duty gasoline Vehicles (LDGV)	5,680	x 0.048	=273,000,000	x21	=5,733

APPENDIX B: INDUSTRIAL PRODUCTION PROCESSES

A. Data Sources

The State GHG Inventory Tool provides default data from the U.S. Geological Survey for use of minerals such as limestone. As discussed below, GHG emissions from HFCs, PFCs, and SF_6 are estimated based on ratios of state consumption or activities to national levels.

B. Methodology

GHG emissions from substitutes for ozone-depleting substances are estimated by multiplying national emissions by the ratio of Connecticut's population to SF_6 emissions from electric power systems in Connecticut are calculated by multiplying state SF_6 consumption by an emissions factor. The default value for SF_6 consumption for Connecticut is apportioned from national consumption, based on the ratio of state electricity sales to national electricity sales. GHG emissions from semiconductor manufacturing in Connecticut are estimated by multiplying national emissions by the value of Connecticut's semiconductor shipments in 1997 divided by the value of the national semiconductor shipments in 1997 to yield the apportioned national emissions. All non-CO_2 emissions are converted into CO_2 equivalent.

CO_2 emissions from limestone, dolomite, and soda ash use are estimated by multiplying consumption of these substances in Connecticut by an emission factor.

C. Sample Calculation

U.S. HFC emissions, 2000(MTCO2E)	U.S. population (2000)	Per-captia HFC emisssions (MTCO2E)	State population	State emissions 2000 (MTCO2E)
58,000,000	/281,421,906	=0.21	x 10,000,000	= 2,100,000

APPENDIX C: NATURAL GAS AND OIL ACTIVITY

A. Data Sources

Data on miles of gas transmission and distribution pipelines in Connecticut are obtained from annual databases published by the U.S. Department of Transportation's Office of Pipeline Safety.[51]

B. Methodology

CH_4 emissions from natural gas transmission in Connecticut are calculated by multiplying each of the following by an emission factor:

- miles of gathering pipeline;
- number of gas processing plants;
- number of liquefied natural gas (LNG) storage stations;
- miles of transmission pipeline;
- number of gas storage stations; and
- number of gas transmission stations.

There are no gas processing plants in Connecticut. No data is available on the number of gas storage and gas transmission stations in the state, so emissions from these sources are calculated based on a factor derived from miles of transmission pipeline. All of these data are summed to yield tons of CH_4 from natural gas transmission. Methane emissions are then converted into CO_2 equivalents.

Methane emissions from distribution pipeline are calculated by multiplying each of the following by an emission factor:

- miles of cast iron distribution pipeline;
- miles of unprotected steel distribution pipeline;
- miles of protected steel distribution pipeline;
- miles of plastic distribution pipeline;
- total number of services;
- number of unprotected steel services; and
- number of protected steel services.

[51] Online at http://ops.dot.gov/DT98.htm

CH_4 emissions from distribution pipeline and services are summed and converted into CO_2 equivalents.

C. Sample Calculation

Activity	Emissions factor (metric tons CH4/activity)	Emissions (metric tons CH4)	GWP for CH4	Emissions (MTCO2E)
20 gas transmissions stations	x 975	= 19,500		
20 gas storage stations	x 955	= 19,100		
2,084 miles transmissions pipeline	x 0.61	= 1,271		
3 LNG storage stations	x 1,041	= 3,123		
Total emissions from natural gas transmission		= 42,994	x 21	=902,874

APPENDIX D: LANDFILLS AND WASTE COMBUSTION

A. Data Sources

Estimates of GHG emissions from landfills assume that landfilled waste generates CH_4 for several decades. Accordingly, the preferred method for estimating landfill GHG emissions requires data on waste that has been landfilled over the past 30 years. However, many states lack reliable data on landfills back to 1960, so the Inventory Tool also offers an option in which an estimate of landfill emissions can be made based on state data for waste landfilled annually from 1990- 2000. The Inventory Tool "backcasts" waste landfilled in the state for the years 1960-1990 based on state data for waste landfilled in 1990-2000 and population data.

The Connecticut Department of Environmental Protection (CT DEP) provided data to NESCAUM on MSW management, including:

- in-state MSW landfilled and burned at incinerators and resource recovery facilities (RRFs) from 1992 through 2000;
- out-of-state waste disposed in Connecticut landfills and burned at Connecticut RRFs from 1993 through 2000;
- Connecticut MSW sent out of state from 1993 through 2000 (with information on final disposition for some of these years); and
- a database summarizing amounts of waste in place at Connecticut landfills as of 1994.

NESCAUM added in-state and out-of-state landfilled waste to yield totals for MSW landfilled in Connecticut from 1992 through 2000. Since data were not available for 1990 or 1991, the 1992 value for in-state waste sent to landfills was inserted for those years. However, since the quantity of out-of-state waste sent to Connecticut landfills fluctuated dramatically over the years for which state data was available, no figure was inserted as a proxy for years prior to 1993.[52] The resulting values were used to estimate GHG emissions from landfills:

[52] These figures may understate landfill GHG emissions slightly, since Connecticut adopted mandatory recycling in 1991 (and thus more waste may have been landfilled in 1990 and 1991 than in 1992), and data were not available for out-of-state waste landfilled in Connecticut prior to 1993.

	1990	1991	1992	1993	1994	1995
CT MSW	694,970	694,970	694,970	603,773	410,334	517,077
OOS MSW				273,307	582,559	214,969
Total	694,970	694,970	694,970	887,080	992,893	732,046

(OOS= out-of-state; figures are in tons)

	1996	1997	1998	1999	2000
CT MSW	424,034	234,030	143,244	168,994	197,380
OOS MSW	26,956	418	-	-	-
Total	450,990	234,448	143,244	168,994	197,380

CT DEP also provided the following data on flaring at state landfills:

Location	Operation began	Permitted capacity
Canterbury	1996	325 MMcf/year
Danbury	1996	500 MMcf/year
Ellington	1996	200 MMcf/year
New Haven	1999	630 MMcf/year

NESCAUM converted these values to short tons, assuming that all facilities operated at capacity from their startup year through 2000, yielding the values for CH_4 flared at landfills of 26,626 tons/year from 1996 though 1998 and 34,919 tons/year in 1999-2000. The Inventory Tool default values for CH_4 recovered at landfill gas-to-energy projects, derived from detailed state-specific data from EPA's Landfill Methane Outreach Program, were used to estimate CH_4 recovered for energy use.

CT DEP provided figures for Connecticut-generated MSW combusted at incinerators annually from 1992-95 (after which incineration ended) and waste combusted annually from 1992-2000 at RRFs, along with data on out-of-state waste sent to the same sites for 1993-2000. NESCAUM added these values, inserting the 1992 or 1993 figures for earlier years for which data was unavailable, to derive the following totals for waste combustion in Connecticut (short tons):

	1990	1991	1992	1993	1994	1995
CT MSW to RRFs	1,553,013	1,553,013	1,553,013	1,587,634	1,716,681	1,757,011
CT MSW to incinerators	95,136	95,136	95,136	92,504	86,322	39,831
OOS to CT RRFs	344,146	344,146	344,146	344,146	326,817	252,068
Total	1,992,295	1,992,295	1,992,295	2,024,284	2,129,820	2,048,910

(OOS = out-of-state waste; figures in tons)

	1996	1997	1998	1999	2000
CT MSW to RRFs	1,712,438	1,830,465	1,972,656	1,966,956	2,047,224
CT MSW to incinerators	-	-	-	-	-
OOS to CT RRFs	454,090	412,130	276,656	235,211	109,766
Total	2,166,528	2,242,595	2,249,312	2,202,167	2,156,990

B. Methodology

Methane emissions from landfills are estimated using an EPA statistical model that calculates CH_4 emission rates as a function of the quantity of waste deposited in landfills, with emission factors varying for large versus small landfills and for arid versus non-arid climates. The methodology used in the State Inventory Tool involves these steps:

- Estimate waste in place at municipal solid waste (MSW) landfills;
- Estimate fraction of waste in place in large versus small landfills;
- Classify state as arid or non-arid;
- Estimate CH_4 generated from waste in place at large and small MSW landfills and sum these amounts;
- Adjust MSW CH_4 generation for flaring and recovery;
- Adjust MSW CH_4 for oxidation;
- Estimate CH_4 generated from industrial landfills;
- Sum MSW and industrial CH_4 generation and convert to CO_2 equivalent.

Estimates of CO_2 emissions from waste combustion of plastics, synthetic rubber and synthetic fiber are calculated by multiplying the proportion of waste discarded that consists of plastics, synthetic rubber and synthetic fiber by the tonnage of state municipal solid waste combusted, the waste's carbon content, and the fraction oxidized. Carbon emissions are converted to CO_2 equivalents. N_2O emissions are calculated by multiplying state municipal solid waste combusted by an emission factor to yield emissions of carbon. These figures are converted to CO_2 equivalents.

C. Sample Calculation

Factors*

Year	Landfills (#)		Y-Intercept		Slope		State WiP (tons)		Methane (ft^3/day)
1990 Small	(7	x	-)	+	(0.35	x	3,079,923.88)	=	1,077,973.36
1990 Large	(53	x	417,957)	+	(0.26	x	24,919,384.15)	=	28,797,943.68

*Emissions are estimated based on a regression equation. For small landfills, the Y-intercept is not applicable.

APPENDIX E: MUNICIPAL WASTEWATER TREATMENT

A. Data Sources

As discussed below, GHG emissions from wastewater treatment are extrapolated from state population and a factor for the amount of oxygen required to break down the waste. The State Inventory Tool provides default values for these inputs.

B. Methodology

CH_4 emissions from municipal wastewater treatment are calculated by multiplying the state population by a figure for per capita five-day biochemical oxygen demand[53], by the fraction of the wastewater BOD_5 that is anaerobically digested, and by an emission factor. N_2O emissions from domestic wastewater treatment are calculated by multiplying the state population by the state's annual consumption of nitrogen in protein and by the fraction of kgN/kg protein. No estimates for industrial wastewater treatment were generated due to insufficient data.

C. Sample Calculation

State population	Per capita BOD5 (kg/day)	Days/year	Unit conversion (metric tons/kg)	Emission factor (Gg CH_4/Gg BOD_5)
3,287,116	x .0650	x 365	x 0.001	x 0.60

WW BOD_5 anaerobically digested (%)	Emissions (metric tons CH_4)	CH4 GWP	Emissions (metric tons CO_2E)
x 16.25%	= 7,603.7	x 21	159,677.7

[53] BOD represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes (U.S. EPA 2002). A standardized measurement of BOD is the "5-day test," denoted as BOD5.

APPENDIX F: AGRICULTURE

A. Data Sources

The State Inventory Tool provides default data on state animal populations and crop production from the U.S. Department of Agriculture. Data on nitrogen fertilizer use was obtained from the Fertilizer Institute in Washington, DC.

B. Methodology

CH_4 emissions from enteric fermentation are derived from a model developed for estimating emission factors for individual animal types. Emissions are estimated for each type of animal by multiplying the emissions factors by the applicable animal populations in Connecticut. Emissions for each animal type are summed to arrive at total emissions for all animal types.

CH_4 emissions from manure management are obtained by multiplying the number and type of animals by the amount of volatile solids (VS) produced by each animal type. Emissions from each animal type are summed to estimate total CH_4 emissions.

Emissions of N_2O from agricultural soils include emissions from animal manure, nitrogen-fixing plants and application of fertilizer. Emissions from managed animal manure are calculated by multiplying each animal population by a typical animal mass (TAM) and by the amount of K-Nitrogen produced per kilogram of animal mass per year to calculate total K-N excreted. Direct emissions from unmanaged pasture, range and paddock are calculated by multiplying K-N by the percent of manure in pastures and an emissions factor for that system. Direct emissions from manure applied to soils are calculated by multiplying K-N for daily spread and managed systems by the percent of manure in these systems and by an emissions factor for each system. These totals are then summed and converted to N_2O. Indirect emissions from animal manure include both volatilized N_20 as well as leaching and runoff. K-N from manure is multiplied by a leaching emissions factor to give emissions from leaching and runoff. Volatilized emissions are estimated by multiplying K-N by a volatilization rate and an emissions factor to give emissions of N. These figures are then converted to N_2O.

For N-fixing crops such as legumes, emissions of N_2O are calculated by multiplying crop production by the residue-to-crop-mass ratio, the dry matter fraction, and the N-content of above-ground biomass. These values are then summed to yield total nitrogen fixed by crops, multiplied by an emission factor, and converted to N_2O.

Estimates of N_2O emissions from agricultural leaching and runoff account for applied nitrogen that migrates into groundwater, rivers, and estuaries. Emissions of N_2O from leaching and runoff are calculated by determining the amount of unvolatilized synthetic and organic nitrogen applications, estimating leaching and runoff from fertilizer application and animal waste, followed by calculating indirect emissions from the leaching and runoff in N_2O-N/yr and converting the emissions to units of N_2O.

C. Sample Calculation

Dairy cow population (thousand head)	Emission factor (kg CH4/head)	Emissions (kg CH4)	Emissions (MMTCH4)	GWP for CH4	Emission (MMTCO2E)
34.0	x 1145	= 3,889,315	= 0.0039	x 21	= 0.0819

APPENDIX G: LAND USE CHANGE AND FORESTRY

A. Data Sources

The State Inventory Tool provides estimates by the U.S. Forest Service of state Forest carbon stocks in 1987, 1992, and 1997 for each of four categories: biomass, coarse woody debris, soils, and wood products and landfills. Changes from 1987-92 and 1992-97 are each divided by 5 to determine the average annual change. For the years 1998-2000, the average annual change for 1992-97 is used as a proxy.

B. Methodology

The methodology for calculating CO_2 flux from forestry and land use practices was adapted from "Carbon in United States Forests and Wood Products, 1987 – 1997: State by State Estimates," by R.A. Birdsey and G.M. Lewis of the USDA Forest Service. EPA considers this methodology to be a placeholder, pending an agreement on revising the existing international guidance for addressing these issues. A final version of the revised guidance (Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published by the Intergovernmental Panel on Climate Change) is expected in 2003, after which EPA will finalize its guidance to reflect the most current methods in use. Future editions of the State GHG Inventory Tool will incorporate EPA's revisions.

Birdsey and Lewis used the "stock exchange" approach to estimate changes in carbon stocks (carbon flux) for the forest ecosystem that includes biomass, forest floor and coarse woody debris and soils. Harvested carbon, including wood products and landfills, is treated separately. This approach entails estimating the total stock of carbon at two points in time, taking the difference between the two estimates and converting the difference to an annual rate of change. Using data from forest inventories and intensive-site ecosystem studies, estimates of average carbon storage by age or volume classes of forest stands were made for biomass, forest floor and coarse woody debris, and soils, stratified by forest classes defined by region, forest type, productivity class, and land-use history. Carbon in biomass was estimated by applying derived factors that convert estimates of forest volume to carbon.

CO_2 emissions from liming of agricultural soils were calculated by multiplying total limestone applied to agricultural soils times by an emission factor. CO_2 emissions for yard trimmings were calculated by multiplying total MSW in CT by the ratio of yard trimmings to total national MSW, by the proportion of yard trimmings that are discarded, and by an emission factor.

C. Sample Calculation

	Biomass	Forest floor/debris	Soils	Wood products	Total sequestration
Annual change in carbon storage (million metric tons carbon), 1990	(0.16)	+ (0.12)	+ (0.29)	+ (0.13)	= (0.70)