Inventory of

Hawaii Greenhouse Gas Emissions

Estimates for 1990

July 1997

State of Hawaii
Department of Business, Economic Development, and Tourism
Energy, Resources, and Technology Division
and
t of Health
r Branch

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TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

1.1 Overview

This study is Phase I of the Program for Developing, Implementing, and Evaluating a Greenhouse Reduction Strategy for the State of Hawaii which is being jointly conducted by the State of Hawaii Department of Business, Economic Development, and Tourism's (DBEDT) Energy, Resources, and Technology Division; and the Department of Health's (DOH) Clean Air Branch. This work was performed with the support of a grant from the U.S. Environmental Protection Agency (USEPA). It was part of the USEPA's State and Local Outreach Program which has been working with the states to assist them in the following:

- identifying their greenhouse gas emissions sources and estimating their overall contribution to radiative forcing;
- assessing the areas of the state that are most vulnerable to climate change; and
- developing state-specific greenhouse gas mitigation strategies (USEPA, 1995b, v).

The purpose of this study was to conduct a state-wide inventory of the greenhouse gas emissions produced by anthropogenic activity in Hawaii in 1990. The primary focus was on the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In addition, data on Hawaii emissions of the photochemically important gases carbon monoxide (CO), oxides of nitrogen (NOx), and nonmethane volatile organic compounds (NMVOCs) were also collected and are summarized in this report. The inventory is a basis for future efforts to reduce Hawaii's contribution to global warming, which could cause significant future negative effects on Hawaii's environment and economy.

The Hawaii greenhouse gas inventory used the year 1990 as its baseline year. The Framework Convention on Climate Change, to which the United States is a party, set a goal of attempting to reduce emissions to 1990 levels by 2000. While it no longer appears feasible for the United States and other signatories to reach that goal, the year provides a useful baseline for evaluating future efforts to reach future goals.

This work is part of the national effort under the Climate Change Action Plan to assist the United States in meeting its goals under the Framework Convention. The Climate Change Action Plan includes initiatives spanning all areas of the economy and focuses on cost-effective reductions. These primarily voluntary initiatives call for cooperation between government, industry, and the public (USEPA, 1995b, iv-v).

As will be discussed below, an understanding of Hawaii's greenhouse gas emissions is important as a first step toward developing mitigation measures, which will be the second phase of this program.

1.2 Organization of the Study

As noted above, the Hawaii inventory was developed jointly by DBEDT and DOH. In addition, other departments participated in the inventory effort by providing data, technical assistance, and review. These departments and their representatives are listed in Appendix A.

DBEDT was responsible for the overall management of the project. DBEDT also conducted the inventory for the energy sector sources of Hawaii's greenhouse gas emissions. DOH managed the inventory of non-energy anthropogenic emissions, contracting the University of Hawaii Environmental Center to conduct the inventory.

1.3 Greenhouse Gases and Climate Change

1.3.1 The Greenhouse Gases

This section is intended to provide the reader with background information on the relationship of the greenhouse gases being inventoried to global climate change. As noted above, the primary focus is on the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In addition, data on Hawaii emissions of the photochemically important gases carbon monoxide (CO), oxides of nitrogen (NOx), and nonmethane volatile organic compounds (NMVOCs) are collected and summarized in this report. The remainder of this section, based closely upon the description in the *State Workbook* (USEPA, 1995b, iii), discusses the nature of each of the gases.

1.3.1.2 Description of Greenhouse Gases

Carbon dioxide. The combustion of liquid, solid, and gaseous fuels is the main anthropogenic source of CO_2 emissions. Some non-energy processes, notably cement production and biomass burning, also produce CO_2.

In nature, CO_2 is cycled between various atmospheric, oceanic, land biotic, and marine biotic reservoirs. The largest fluxes are between the atmosphere and land biota, and between the atmosphere and the surface water of the oceans. There are also terrestrial non-biotic sources (soils) and crustal (sedimentary rock) sources.

Methane. Methane is produced through anaerobic decomposition of organic matter in biological systems. Enteric fermentation in animals, decomposition of animal wastes, and decomposition of municipal solid waste produce methane. Methane is also emitted in the production and distribution of natural gas (synthetic natural gas in Hawaii) and oil and by incomplete fuel combustion.

The major sink for methane is its interaction with the hydroxyl radical (OH) in the troposphere. This results in chemical destruction of the methane compound as the hydrogen molecules in methane combine with the oxygen in OH to form water vapor (H_2O) and CH_3. After a number of other chemical interactions, the remaining CH_3 turns into CO which itself reacts with OH to produce CO_2 and hydrogen (H).

Nitrous Oxide. Anthropogenic sources of N_2O of concern include use of fertilizers, fossil fuel combustion, and biomass burning.

Halogenated Fluorocarbons, HFCs, and PFCs. Halogenated fluorocarbons are man-made compounds that include: chlorofluorocarbons (CFCs), halons, methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). All of these compounds not only enhance the greenhouse effect, but also contribute to stratospheric ozone depletion (USEPA, 1995b, iii). While many of these gases may have been used in Hawaii, none is known to have been manufactured in the state. The United States phased out production and use of all halons, CFCs, HCFCs, and other ozone depleting substances under the 1987 Montreal Protocol and 1992 Copenhagen Amendments (Cook, 1996, 9). Perfluorinated carbons (PFCs) and hydrofluorocarbons (HFCs), a family of CFC and HCFC replacements, not covered under the Montreal Protocol, are also powerful greenhouse gases (USEPA, 1995b, iii).

1.3.1.3 Description of Photochemically Important Gases

The photochemically important gases play a role in increasing production of tropospheric ozone (also known as urban smog). These gases – NOx, CO, and NMVOCs -- are known as criteria pollutants and are regulated under the Clean Air Act of 1970 and subsequent amendments. Ozone itself is both produced and destroyed in the atmosphere through natural processes. Approximately 90 percent resides in the stratosphère, where it controls the absorption of solar ultraviolet radiation; the remaining 10 percent is found in the troposphere and could play a significant greenhouse role.

Oxides of Nitrogen. Oxides of nitrogen, NO and NO_2, are created from biomass burning, fossil fuel combustion, and are generated in the stratosphere from nitrous oxide. They contribute to formation of ozone.

Carbon Monoxide. CO is created when carbon-based fuels are burned incompletely. CO elevates concentrations of CH_4 and tropospheric ozone through chemical reactions with atmospheric constituents (e.g., OH) that would otherwise assist in destroying methane and ozone. It eventually oxidizes to CO_2.

Nonmethane Volatile Organic Compounds. NMVOCs include propane, butane, and ethane. They participate, along with NOx, in the formation of ground-level ozone and other photochemical oxidants. VOCs are primarily emitted by transportation and industrial processes (USEPA, 1995b, iii).

1.3.2 Climate Change: The Summary for Policymakers

The following section on climate change was extracted from *Climate Change 1995: The Science of Climate Change, Summary for Policymakers and Technical Summary of the Working Group I Report*, published in 1996 by the Intergovernmental Panel on Climate Change (IPCC). The IPCC was jointly established by the World Meteorological Organization and the United Nations Environmental Programme to provide an authoritative international statement of the current understanding of climate change (IPCC, 1996, 2). The Summary for Policymakers, approved in detail at the fifth session of the IPCC Working Group I in Madrid, 27-29 November 1995, represents the IPCC's formally agreed statement on the current understanding of the science of climate change (7).

While there are many who disagree with elements or all of the IPCC statement, it is supported by the United States government and is the basis for the actions taken in the United States Climate Action Program. As a basis for understanding the need to inventory greenhouse gases, a major excerpt of the Summary for

Policymakers is presented here (including its use of British spelling). While the summary also discussed CFCs, HCFCs, and other aerosols, those sections are not included below as Hawaii is not a manufacturer of such gases. Their use in Hawaii is being phased out as specified by United States law. The excerpt focuses on the principal greenhouse gases discussed in this report: CO_2, CH_4, and N_2O.

Summary for Policymakers

Considerable progress has been made in the understanding of climate change science [1]

Greenhouse gas concentrations have continued to increase

Increases in greenhouse gas concentrations since pre-industrial times (i.e., since about 1750) have led to a positive *radiative forcing* [2] of climate, tending to warm the surface and to produce other changes of climate.

- The atmospheric concentrations of greenhouse gases, inter alia carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have grown significantly: by about 30%, 145% and 15% respectively (values for 1992). These trends can be attributed largely to human activities, mostly fossil fuel use, land-use change, and agriculture.
- The growth rates of CO_2, CH_4 and N_2O concentrations were low during the early 1990s. While this apparently natural variation is not yet fully explained, recent data indicate that the growth rates are currently comparable to those averaged over the 1980s.
- The direct radiative forcing of the long-lived greenhouse gases (2.45 Wm^{-2}) is due primarily to increases in CO_2 (1.56 Wm^{-2}), CH_4 (0.47 Mm^{-2}) and N_2O (0.14 Wm^{-2}) (values for 1992).

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[1] Climate change in the IPPC Working Group I usage refers to any change in climate over time whether due to natural variability or as a result of human activity. This differs from the usage in the Framework Convention on Climate Change where climate change refers to a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

[2] A simple measure of the importance of a potential climate change mechanism. Ratiative forcing is the perturbation to the energy balance of the Earth-atmosphere system (in watts per square metre [Wm^{-2}])

- Many greenhouse gases remain in the atmosphere for a long time (for CO_2 and N_2O, many decades to centuries), hence they affect radiative forcing on long time-scales. . . .
- If carbon dioxide emissions were maintained at near current (1994) levels, they would lead to a nearly constant rate of increase in atmospheric concentrations for at least two centuries, reaching about 500 ppmv [parts per million by volume] (approaching twice the pre-industrial concentration of 280 ppmv) by the end of the 21st century.
- A range of carbon cycle models indicates that stablisation of atmospheric CO_2 concentrations at 450, 650, or 1000 ppmv could be achieved only if global anthropogenic CO_2 emissions drop to 1990 levels by, respectively, approximately 40, 140 or 240 years from now, and drop below 1990 levels subsequently.
- Any eventual stabilised concentration is governed more by the accumulated anthropogenic CO_2 emissions from now until the time of stabilisation, than by the way those emissions change over the period. This means that, for a given stabilised concentration value, higher emissions in early decades require lower emissions later on . . . .
- Stabilisation of CH_4 and N_2O emissions at today's levels would involve reductions of 8% and more than 50% respectively. . . .

Climate has changed over the past century

At any one location year-to-year variations in weather can be large, but analyses of meteorological and other data over large areas and over periods of decades or more have produced evidence for some important systematic changes.

- Global mean surface air temperature has increased by between about 0.3 and 0.6°C since the late 19th century; the additional data available since 1990 and the re-analyses since then have not significantly changed this range of estimated increase.
- Recent years have been among the warmest since 1860, i.e., in the period of instrumental record, despite the cooling effect of the 1991 Mt. Pinatubo volcanic eruption.
- Night-time temperatures over land have generally increased more than daytime temperatures.
- Regional changes are also evident. For example, the recent warming has been greatest over the mid-latitude continents in winter and spring, with a few areas of cooling, such as the North Atlantic Ocean. Precipitation has increased over land in

high latitudes of the Northern Hemisphere, especially in the cold season.

- Global sea level has risen by between 10 and 25 cm [3.9 to 9.75 inches] over the past 100 years and much of the rise may be related to the increase in global mean temperature.
- There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th century. On regional scales there is clear evidence of changes in some extremes and climate variability indicators (e.g., fewer frosts in several widespread areas; an increase in the proportion of rainfall from extreme events over the contiguous states of the USA). Some of these changes have been toward greater variability; some have been toward lower variability.
- The 1990 to mid-1995 persistent warm-phase of the El Nino-Southern Oscillation (which causes droughts and floods in many areas) was unusual in the context of the last 120 years.

The balance of evidence suggests a discernible human influence on global climate

Any human-induced effect on climate will be superimposed on the background "noise" of natural climate variability, which results both from internal fluctuations and from external causes such as solar variability or volcanic eruptions. Detection and attribution studies attempt to distinguish between anthropogenic and natural influences. "Detection of change" is the process of demonstrating that an observed change in climate is highly unusual in a statistical sense, but does not provide a reason for that change. "Attribution" is the process of establishing cause and effect relations, including the testing of competing hypotheses.

Since the 1990 IPCC Report, considerable progress has been made in attempts to distinguish between natural and anthropogenic influences on climate. This progress has been achieved by including effects of sulphate aerosols in addition to greenhouse gases, thus leading to more realistic estimates of human-induced radiative forcing. These have been used in climate models to provide more complete simulations of the human-induced climate change "signal." In addition, new simulations with coupled atmospheric-ocean models have provided important information about decade to century time-scale natural internal climate variability. A further major area of progress is the shift of focus from studies of global-mean changes to comparisons of modeled and observed spatial and temporal patterns of climate change.

The most important results related to the issues of detection and attribution are:

- The limited available evidence from proxy climate indicators suggests that the 20th century global mean temperature is at least as warm as any other century since at least 1400 AD. Data prior to 1400 AD are too sparse to allow the reliable estimation of global mean temperature.
- Assessments of the statistical significance of the observed global mean surface temperature trend over the last century have used a variety of new estimates of natural internal and externally forced variability. These are derived from instrumental data, palaeodata, simple and complex climate models, and statistical models fitted to observations. Most of these studies have detected a significant change and show that the observed warming trend is unlikely to be entirely natural in origin.
- More convincing recent evidence for the attribution of a human effect on climate is emerging from pattern-based studies, in which the modeled climate response to combined forcing by greenhouse gases and anthropogenic sulphate aerosols is compared with observed geographical, seasonal and vertical patterns of atmospheric temperature change. These studies show that such pattern correspondences increase with time, as one would expect as an anthropogenic signal increases in strength. Furthermore, the probability is very low that these correspondences could occur by chance as a result of natural internal variability only. The vertical patterns of change are also inconsistent with those expected for solar and volcanic forcing.
- Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long-term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate.

Climate is expected to continue to change in the future

The IPCC has a developed a range of scenarios, IS92a-f, of future greenhouse gas and aerosol precursor emissions based on assumptions concerning population and economic growth, land-use, technological changes, energy availability and fuel mix during the period 1990 to 2100. Through understanding of the global climate cycle and of atmospheric chemistry, these emissions can be used to project atmospheric concentrations of greenhouse gases and aerosols and the perturbation of natural radiative forcing. Climate models can then be used to develop projections of future climate.

- The increasing realism of simulations of current and past climate by coupled atmosphere-ocean climate models has increased our confidence in their use for projection of future climate change. Important uncertainties remain, but these have been taken into account in the full range of projections of global mean temperature and sea level change.
- For the mid-range IPCC emission scenario, IS92a, assuming the "best estimate" value of climate sensitivity[3] and including the effects of future increases in aerosol, models project an increase in global mean surface air temperature relative to 1900 of about 2°C [3.6°F] by 2100. This is due primarily to lower emission scenarios (particularly for CO_2 and the CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle. Combining the lowest IPCC emission scenario (IS92c) with a "low" value of climate sensitivity and including the effects of future changes in aerosol concentrations leads to a projected increase of about 1°C [1.8°F] by 2100. The corresponding projection for the highest IPCC scenario (IS92e) combined with a "high" value of climate sensitivity gives a warming of about 3.5°C [6.3°F]. In all cases the average rate of warming would probably be greater than any seen in the last 10,000 years, but the actual annual to decadal changes would include considerable natural variability. Regional temperature changes could differ substantially from the global mean value. Because of the thermal inertia of the oceans, only 50-90% of the eventual equilibrium temperature change would have been realized by 2100 and temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilised by that time.

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[3] In IPCC reports, climate sensitivity usually refers to the long term (equilibrium) change in global mean surface temperature following a doubling of atmospheric equivalent CO_2 concentration. More generally, it refers to the equilibrium change in surface air temperature following a unit change in radiative forcing (C/Wm^{-2}).

- Average sea level is expected to rise as a result of thermal expansion of the ocean and melting of glaciers and ice-sheets. For the IS92a scenario, assuming the "best estimate" values of climate sensitivity and of ice melt intensity to warming, and including the effects of future changes in aerosol, models project an increase in sea level of about 50 cm [19.5 inches] from the present to 2100. This estimate is approximately 25% lower than the "best estimate" in 1990 due to the lower temperature projection, but also reflecting improvements in the climate and ice melt models. Combining the lowest emission scenario (IS92c) with the "low" climate and ice melt sensitivities and including aerosol effects gives a projected sea level rise of about 15 cm [5.85 inches] from the present to 2100. The corresponding projection for the highest emission scenarios (IS92e) combined with the "high" climate and ice melt sensitivities gives a sea level rise of about 95 cm [37.05 inches] from the present to 2100. Sea level would continue to rise at a similar rate in future centuries beyond 2100 even if concentrations of greenhouse gases were stabilized by that time, and would continue to do so even beyond the time of stabilisation of global mean temperature. Regional sea level changes may differ from the global mean value owing to land movement and ocean current changes.

- Confidence is higher in the hemispheric-to-continental scale projections of coupled atmosphere-ocean climate models than in the regional projections, where confidence remains low. There is more confidence in temperature projections than hydrological changes. . . .

- A general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days.

- Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events. Knowledge is currently insufficient to say whether there will be any changes in the occurrence or geographic distribution of severe storms, e.g., tropical cyclones.

- Sustained rapid climate change could shift the competitive balance among species and even lead to forest dieback, altering the terrestrial uptake and release of carbon. The magnitude is

> uncertain, but could be between zero and 200 GtC [giga-tonnes of carbon] over the next one to two centuries.
>
> **There are still many uncertainties**
>
> Many factors currently limit our ability to project and detect future climate change. In particular, to reduce uncertainties further work is needed on the following priority topics.
>
> - estimation of future emissions and biogeochemical cycling (including sources and sinks) of greenhouse gases, aerosols and aerosol precursors and projections of future concentrations and radiative properties;
> - representation of climate processes in models, especially feedbacks associated with clouds, oceans, sea ice and vegetation, in order to improve projections of rates and regional patterns of climate change;
> - systematic collection of long-term instrumental and proxy observations of climate system variables (e.g., solar output, atmospheric energy balance components, hydrological cycles, ocean characteristics and ecosystem changes) for the purposes of model testing, assessment of temporal and regional variability and for detection and attribution studies.
>
> Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve "surprises." In particular these arise form the non-linear nature of the climate system. When rapidly forced, non-linear systems are especially subject to unexpected behavior. Progress can be made by investigating non-linear processes and sub-components of the climatic system. Examples of such non-linear behavior include rapid circulation changes in the North Atlantic and feedbacks associated with terrestrial ecosystem changes. (IPCC, 1996, 8-13)

1.4 Potential Effects on Hawaii

In 1995, the Intergovernmental Panel on Climate Change (IPCC) Working Group II completed a "review of the state of knowledge concerning climate change on physical and economic systems, human health and socio-economic sectors" (United Nations, 1995). The following is based upon the *Summary for Policy Makers: Scientific-Technical Analysis of Impacts, Adaptations and Mitigations of*

Climate Change (United Nations, 1995) which is available on the United Nations Environmental Programme website at www.unep.ch/ipcc/wg2.html.

The IPPC report discussed a wide range of potential vulnerabilities to climate change faced by human societies. They note that the stresses posed by human-induced climate change add an important additional stress to ecological and socio-economic systems already affected by pollution, increasing resource demands and nonsustainable management practices. The report addresses effects on agriculture and food security; sea levels, oceans, and coastal areas; biological diversity and ecosystems; water resources; human health; infrastructure, industry, and human settlement; and climatic disasters and extreme events. (United Nations, 1995)

Hawaii, directly or indirectly, is potentially vulnerable to negative effects in each of these areas. While the IPPC report did not specifically address Hawaii's vulnerabilities and a scientific assessment of Hawaii's vulnerabilities is beyond the scope of this report, the following is a brief summary of global warming-induced climate change effects which may impact Hawaii as suggested by IPCC Working Group II.

- **Forests.** Models suggest that a sustained increase of 1 degree C in global mean temperature could cause climate changes which would affect forest growth. The greatest changes will be at high latitudes, and tropical areas (such as Hawaii) would be least affected.
- **Coastal systems.** As an island state, Hawaii is highly vulnerable to potential impacts on coastal systems. "Climate change and a rise in sea level or changes in storms and storm surges could result in erosion of shores and associated habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, a change in the pattern of chemical and microbiological contamination in coastal areas, and increased coastal flooding. Some coastal ecosystems are particularly at risk, including . . . coral reefs . . . . Changes in these ecosystems would have major negative effects on tourism, freshwater supplies, fisheries, and biodiversity"(United Nations, 1995).

- **Oceans.** Hawaii's ocean resources are important to its economy. According to Working Group II, "Climate change will lead to changes in sea level, increasing it on average, and also could lead to altered ocean circulation, vertical mixing, wave climate and reductions in sea-ice cover. As a result, nutrient availability, biological productivity, the structure and functions of marine ecosystems, and heat and carbon storage capacity may be affected, with important feedbacks to the climate system. These changes would have implications for coastal regions, fisheries, tourism and recreation, transport, off-shore structures, and communication"(United Nations, 1995).

- **Fisheries.** Globally, Working Group II projects that marine fisheries production is expected to remain about the same. Principal impacts will be at local levels as species mix and centers of production shift. The specific effects on Hawaii are not clear from the report; however, this issue warrants further study.

- **Human Infrastructure.** "Climate change and resulting sea-level rise can have a number of negative impacts on energy, industry, and transportation infrastructure; human settlements; the property insurance industry; tourism; and cultural systems and values" (United Nations, 1995). Potential effects on Hawaii include climate change effects on energy demand and renewable energy production (such as hydroelectricity and biomass). Transportation infrastructure and settlements will be more vulnerable to flooding and coastal erosion. Property insurance is vulnerable to extreme climate events, as Hawaii homeowners found after Hurricane Iniki when hurricane coverage became nearly impossible to obtain until the state set up a program. As noted above, however, "knowledge is currently insufficient to say whether there will be any changes in the occurrence or geographic distribution of severe storms, e.g., tropical cyclones" (IPCC, 1996, 12). Climate change could also make Hawaii less of a paradise for visitors, depending upon temperature effects on weather, particularly extreme weather.

- **Human Health.** While no specific vulnerabilities are necessarily indicated for Hawaii, direct health effects could include increases in mortality and illness due to an anticipated increase in the intensity and duration of heat waves. Increased exposure to other diseases which may be inadvertently brought to Hawaii and may be supported by a warmer climate are possibilities.

The preceding summary is only a cursory look at some of the potential impacts which Hawaii may face.

1.5 Energy Use Sector Definitions Used in This Report

The section of this study which examines greenhouse gas emissions produced by energy use in Hawaii analyzes these emissions by sector. The sectors include the residential, commercial, industrial, electricity, and transportation sectors. While electricity is used in the residential, commercial, and industrial sectors, the greenhouse gas emissions from electricity generation for sale to customers in these sectors is reported in the electricity sector, not by end use. The electricity sector includes greenhouse gases emitted from generators operated by the electric utilities and by independent power producers which operate primarily to produce electricity for sale to the electric utilities. Industrial cogenerators, notably sugar mills, which also produce electricity, but primarily for their own use are reported in the industrial sector despite the fact that they also sell significant amounts of electricity to the electric utilities. The following sector definitions, modified to include independent power producers in the electricity sector are based upon those used in the U.S. Department of Energy, *State Energy Data Report 1993* (USDOE, 1995b), and will be used in this report:

1.5.1 Residential Sector

The residential sector is considered to consist of all private residences, whether occupied or vacant, owned or rented, including single-family homes, multifamily housing units, and mobile homes. Secondary homes, such as summer homes, are also included. Institutional housing, such as school dormitories, hospitals, and military barracks, generally is not included in the residential sector; however, it is included in the commercial sector.

1.5.2 Commercial Sector

The commercial sector consists of business establishments that are not engaged in transportation or in manufacturing or other types of industrial activity (agriculture, mining, or construction). Commercial establishments include hotels, motels, restaurants, wholesale businesses, retail stores, laundries and other service enterprises; religious and non-profit organizations; health, social, and educational institutions, and federal, state, and county governments. Street lights, pumps, bridges, and public services are also included if the establishment operating them is considered commercial.

1.5.3. Industrial Sector

The industrial sector comprises manufacturing industries, which make up the largest part of the sector, along with mining, construction, agriculture, fisheries, and forestry. In Hawaii, establishments in this sector range from sugar plantations to small farms to a wide variety of light industries.

1.5.4 Electricity Sector

The electricity sector in Hawaii consists of privately owned establishments that generate, transmit, distribute, or sell electricity primarily for use by the public and are regulated by the State of Hawaii Public Utilities Commission. Independent power producers which produce electricity and sell their production to the utilities, are included in this sector.

1.5.5 Transportation Sector

The transportation sector consists of private and public vehicles that move people and commodities. These include automobiles, trucks, buses, motorcycles, aircraft, ships, and barges.

1.6 Additional Work Performed in Phase I

In addition to the inventory included in this report, DBEDT contracted with Systematic Solutions, Inc. (SSI), to calibrate the ENERGY 2020 computer model of Hawaii's energy system to provide greenhouse gas emissions forecasts for use in testing the effects of energy sector greenhouse gas mitigation policies to be developed in the second phase. The ENERGY 2020 model is linked with an economic model developed by Regional Economic Models, Inc. (the REMI model). This will also enable economic effects of mitigation measures to be forecast. The model was calibrated and a baseline forecast was prepared.

1.7 Next Steps

In Phase II of Hawaii's Greenhouse Gas Program, a Greenhouse Gas Reduction Strategy will be developed which will include a 20-year reduction strategy and 5-year action plan designed to reduce Hawaii's greenhouse gas emissions. Based upon the inventory of 1990 emissions and the forecast of future emissions developed in Phase I, the Phase II study will examine potential greenhouse gas mitigation actions and policies, determine their costs and benefits, and provide recommended priorities for implementation of greenhouse gas emissions reductions plans.

The Phase II effort will also develop a technical review and public involvement process to take advantage of scientific and technical expertise in Hawaii and which will ensure open, public participation, especially in the policy development and evaluation components of the project. The ultimate objective will be to integrate the relevant portions of the 20-year strategy and the 5-year action plan into appropriate state agencies' functional plans and the Hawaii Energy Strategy.

CHAPTER 2 1990 HAWAII GREENHOUSE GAS EMISSIONS

2.1 Overview

This chapter presents a summary of Hawaii's estimated emissions of the greenhouse gases carbon dioxide, methane, and nitrous oxide, and the photochemically important greenhouse gas precursors -- nitrogen oxides, carbon monoxide, and non-methane volatile organic compounds -- in 1990. The calculation of these estimates is detailed in subsequent chapters of this report. All tonnages are in English (avoirdupois) short tons. These weights are in terms of compounds, not elements (e.g., CO_2 rather than C). While some calculations are carried out to several decimal points, the basis of such calculations is often an estimate and should not be considered necessarily accurate to that level.

2.2 Estimated 1990 Hawaii Greenhouse Gas Emissions

Table 2.1 summarizes Hawaii's 1990 greenhouse gas emissions.

Table 2.1 Estimated Greenhouse Gas Emissions in Hawaii, 1990
(Tons)

Sector/Fuel	Net CO_2	CH_4	N_2O
Energy Use			
Residential Sector	94,760	2	N/A
Commercial Sector	278,767	6	13
Industrial Sector	816,606	27	391
Electricity Sector	7,647,046	109	13
Transportation Sector	5,914,370	18,460	505
Subtotal	14,751,549	18,604	922
Non-Energy Sources			
Oil Industry	N/A	237	N/A
Cement Industry	109,274	N/A	N/A
MSW Management	189,684	53,490	N/A
Wastewater Treatment	N/A	1,027	N/A
Domestic Animals	N/A	13,368	N/A
Manure Management	N/A	6,056	N/A
Sugarcane Burning	N/A	543	8
Fertilizer	N/A	N/A	196
Changes in Biomass	(415,158)	N/A	N/A
Abandoned Lands	(519,237)	N/A	N/A
Subtotal	(635,437)	74,721	204
Total	14,116,112	93,325	1,126

As depicted on Table 2.1, an estimated 14,116,112 tons of CO_2, 93,325 tons of CH_4, and 1,126 tons of N_2O comprised Hawaii greenhouse gas emissions in 1990. These emissions were produced by energy uses, industrial processes in the oil and cement industries, and non-energy sources within the state. CO_2 emissions from the burning of bagasse, macadamia nut shells, and wood chips to generate electricity and process heat are not included in this total as those fuels sequester similar amounts of CO_2 in the growing stage and are assumed to be replanted. In addition, the estimate does not include exports, overseas uses or military uses of fuels sold, distributed, or refined in Hawaii. The reasons for the exclusion of these quantities of fuel are explained in detail in the discussion of Hawaii's energy system in Section 3.2. A summary of emissions from overseas and military is provided in Section 2.4.

Table 2.2 Percent Contribution to Estimated Greenhouse Gas Emissions in Hawaii, 1990

Sector/Fuel	Net CO_2	CH_4	N_2O
Energy Use			
Residential Sector	1%	0.002%	N/A
Commercial Sector	2%	0.01%	1%
Industrial Sector	5%	0.03%	35%
Electricity Sector	51%	0.1%	1%
Transportation Sector	39%	20%	45%
Subtotal	98%	20%	82%
Non-Energy Sources			
Oil Industry		0.3%	
Cement Industry	1%		
MSW Management	1%	57%	
Wastewater Treatment		1%	
Domestic Animals		14%	
Manure Management		6%	
Sugarcane Burning		1%	1%
Fertilizer			17%
Subtotal	2%	80%	18%
Total	100%	100%	100%

* CO_2 uptake not included in computation of percentage contribution to Hawaii GHG emissions

Table 2.2 summarizes the percentage contribution of each source to the estimated greenhouse gas emissions. Hawaii's energy sector clearly dominated production of CO_2 and N_2O, while non-energy sources led in CH_4 production. The uptake of CO_2 caused by changes in biomass and by abandoned lands are negative as shown on Table 2.1, but these are not included in this table as the focus is on CO_2 production by human activities in Hawaii.

2.3. Estimated Global Warming Potential of Hawaii Greenhouse Gas Emissions

Global Warming Potential, or GWP, is used to compare the relative effects of each of the different greenhouse gases on radiative forcing of the atmosphere over some future time horizon. To do this, an index is needed which translates the level of emissions of each gas into a common metric. The index used in this report will convert CH_4 and N_2O emissions into their CO_2 equivalent. This is the methodology used by the Intergovernmental Panel on Climate Change (IPCC) as recommended by the *State Workbook* (USEPA, 1995b, vii).

The IPCC method is a comparison of the radiative forcing effect of the concurrent emission into the atmosphere of an equal quantity of CO_2 and another greenhouse gas. Each gas has a different instantaneous effect and the atmospheric concentration of each gas declines at a different rate over time. In general, other greenhouse gases have a much stronger instantaneous radiative effect than CO_2, but CO_2 has a longer atmospheric lifetime and slower decay rate. The atmospheric concentrations of some greenhouse gases may decline due to atmospheric chemical processes, which in turn create other greenhouse gases or contribute to their creation or longevity. These indirect effects are uncertain and will not be included in calculating the Hawaii GWP (vii).

GWP is defined as "the time-integrated commitment to climate forcing from the instantaneous release of 1 kilogram of trace gas expressed relative to that from 1 kilogram of carbon dioxide" (viii). The value is time sensitive and, for the purposes of this report, a 100-year time horizon was used. Over this time period, CH_4 has 22 times the radiative forcing direct impact as CO_2, and N_2O has 270 times the direct impact (viii). Thus, to calculate GWP of Hawaii's 1990 emissions of these greenhouse gases, CH_4 emissions in tons were multiplied by 22 and N_2O emissions in tons were multiplied by 270 to yield tons CO_2 equivalent.

Table 2.3 Global Warming Potential of Greenhouse Gas Emissions in Hawaii, 1990
(Tons CO_2 equivalent)

Sector	CO_2	CH_4	N_2O	Total
Energy Use				
Residential Sector	94,760	33	N/A	94,793
Commercial Sector	278,767	132	3,522	282,421
Industrial Sector	816,606	594	N/A	817,200
Electric Utility Sector	7,647,046	2,398	3,524	7,652,968
Transportation Sector	5,914,370	406,120	136,342	6,456,832
Subtotal	14,751,549	409,277	143,388	15,304,213
Non-Energy Sources				
Oil Industry	N/A	5,214	N/A	5,214
Cement Industry	109,274	N/A	N/A	109,274
MSW Management	189,684	1,176,780	N/A	1,366,464
Wastewater Treatment	N/A	22,594	N/A	22,594
Domestic Animals	N/A	294,096	N/A	294,096
Manure Management	N/A	133,232	N/A	133,232
Sugarcane Burning	N/A	11,946	2,160	14,106
Fertilizer	N/A	N/A	52,920	52,920
Subtotal	298,958	1,643,862	55,080	1,997,900
Total	15,050,507	2,053,139	198,468	17,302,113
Percent	**87%**	**12%**	**1%**	**100%**

Table 2.3 presents the GWP of CO_2, CH_4, and N_2O emissions in Hawaii, in 1990 which were the equivalent of 17,302,113 tons of CO_2. This value was not reduced by the amount of CO_2 uptake from changes and biomass and uptake by abandoned lands since the focus is on emissions as a basis for future consideration of mitigation measures. The GWP of each of Hawaii's emission sources is important as it allows comparison of sources which emit different greenhouse gases and will assist in identifying areas for focus in developing greenhouse gas mitigation measures.

In Figure 2.1, a comparison of the relative GWP of the amounts of the three major greenhouse gases emitted in Hawaii in 1990 is depicted. CO_2 emissions were 87% of Hawaii's greenhouse gas emissions, followed by CH_4 at 12% and N_2O at 1%.

Figure 2.1 Global Warming Contribution of Hawaii Greenhouse Gas Emissions, 1990

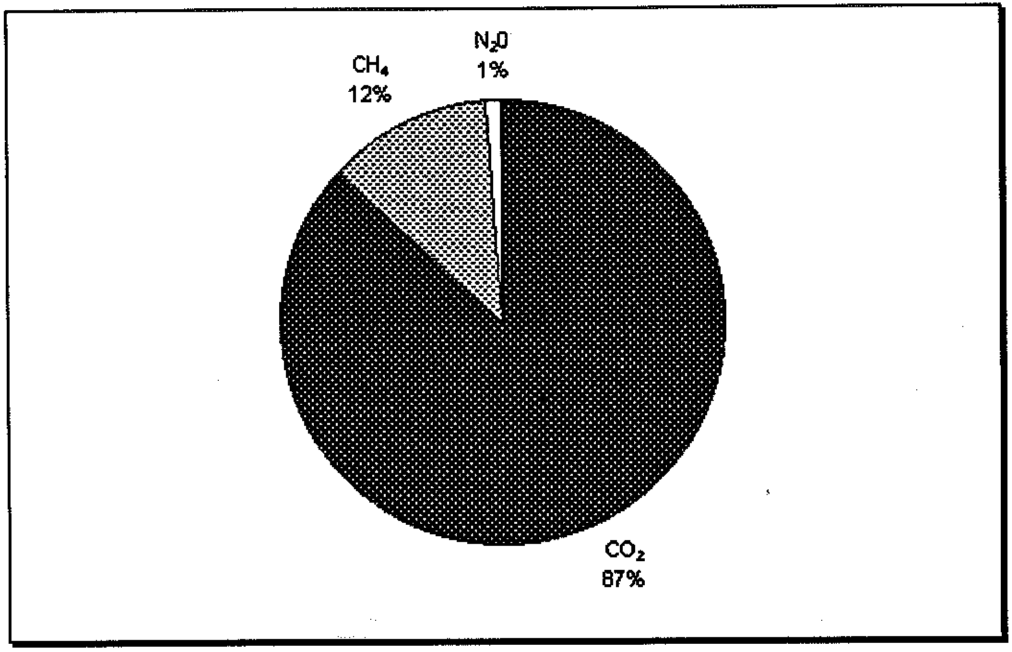
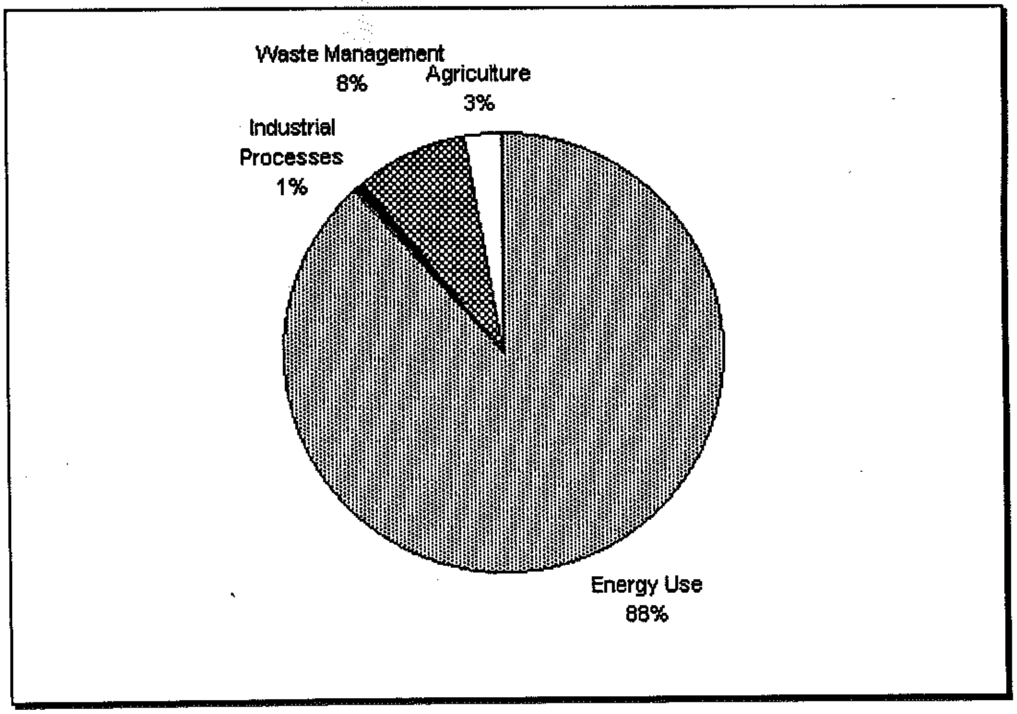


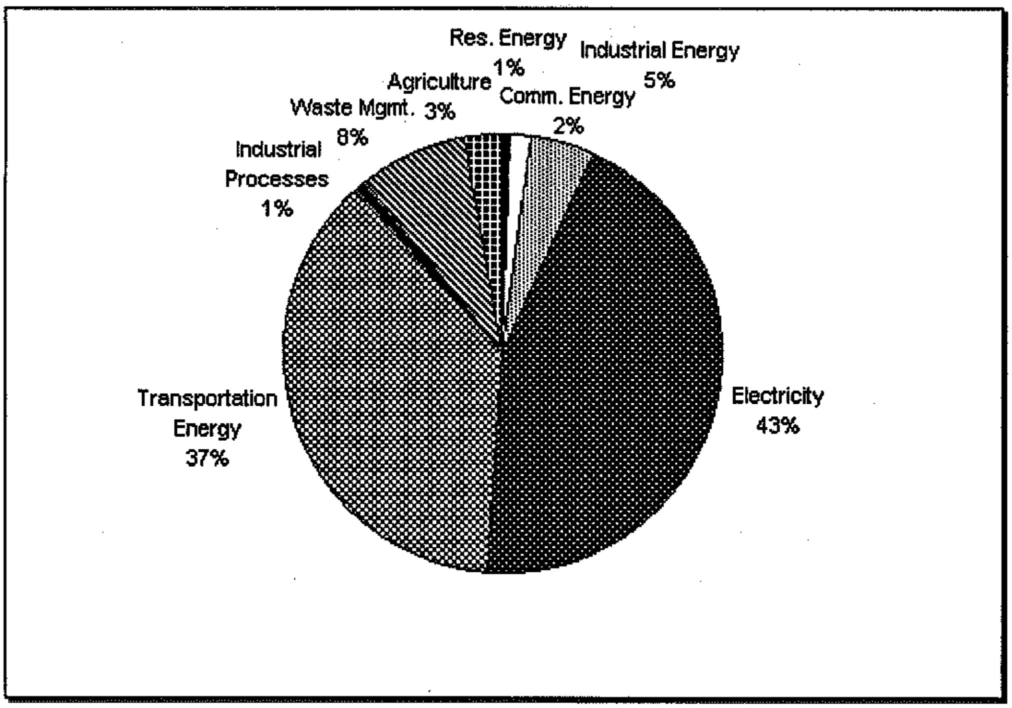
Figure 2.2 shows the result of a comparison of the relative GWP of Hawaii greenhouse gas emissions by source category.

Figure 2.2 Global Warming Contribution of Hawaii Greenhouse Gas Emissions by Source Category, 1990



Energy use emissions dominated at 88%. Waste management, which includes municipal solid waste management and wastewater treatment, was in second place at 8%. The various agricultural sources, including domestic animals, manure management systems, sugarcane burning, and fertilizer use contributed 3% to GWP. Finally, industrial processes in oil refining and cement industries created 1% of Hawaii's GWP.

Figure 2.3 Global Warming Contribution of Hawaii Greenhouse Gas Emissions by Sector, 1990



In Figure 2.3, above, another, more detailed view of GWP is presented, this time by sector. In this breakout, electricity generation produced 43% of GWP, followed by the transportation energy sector at 37%, waste management at 8%, industrial energy use at 5%, agriculture at 3%, and commercial energy uses at 2% were significant. The remaining sectors – residential energy, and industrial processes in the cement and oil refining industries each contributed less than one percent to total GWP (rounded on Figure 2.3 to 1%).

Figure 2.4 summarizes the relative contribution to CO_2 emissions by sector. Again, the electricity and transportation sectors clearly dominate; they produced 51% and 39% of CO_2 emissions, respectively. Industrial energy accounted for 5% and commercial energy was 2%. Other uses, including waste management, the cement industry, and residential energy use combined contributed about 3% to Hawaii's total CO_2 emissions.

Figure 2.4 Hawaii Carbon Dioxide Emissions by Sector, 1990

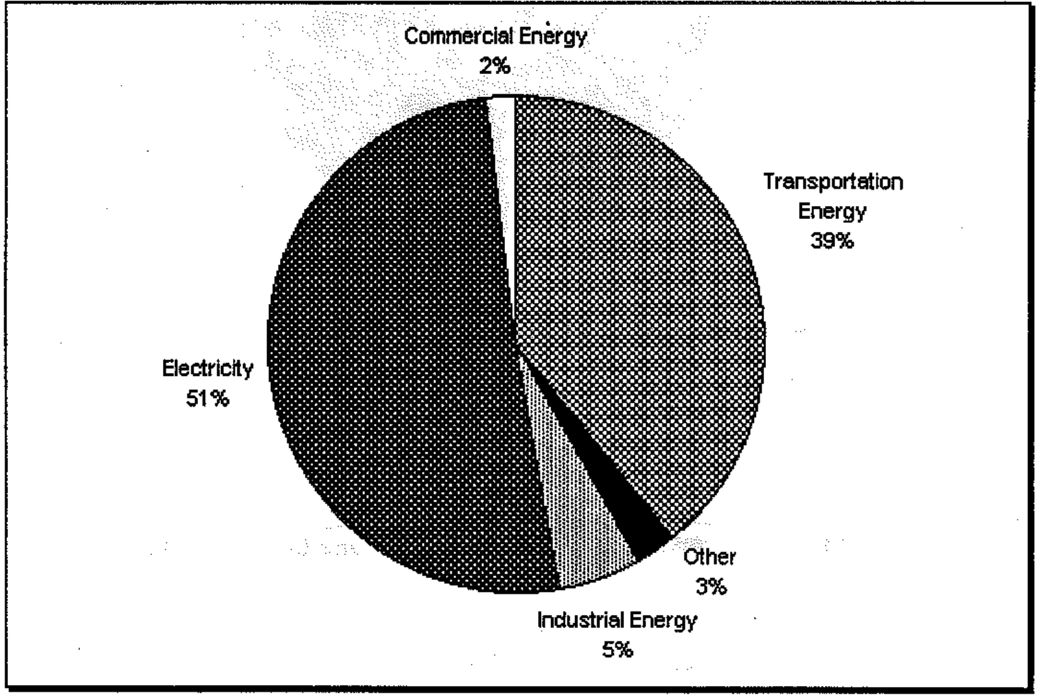
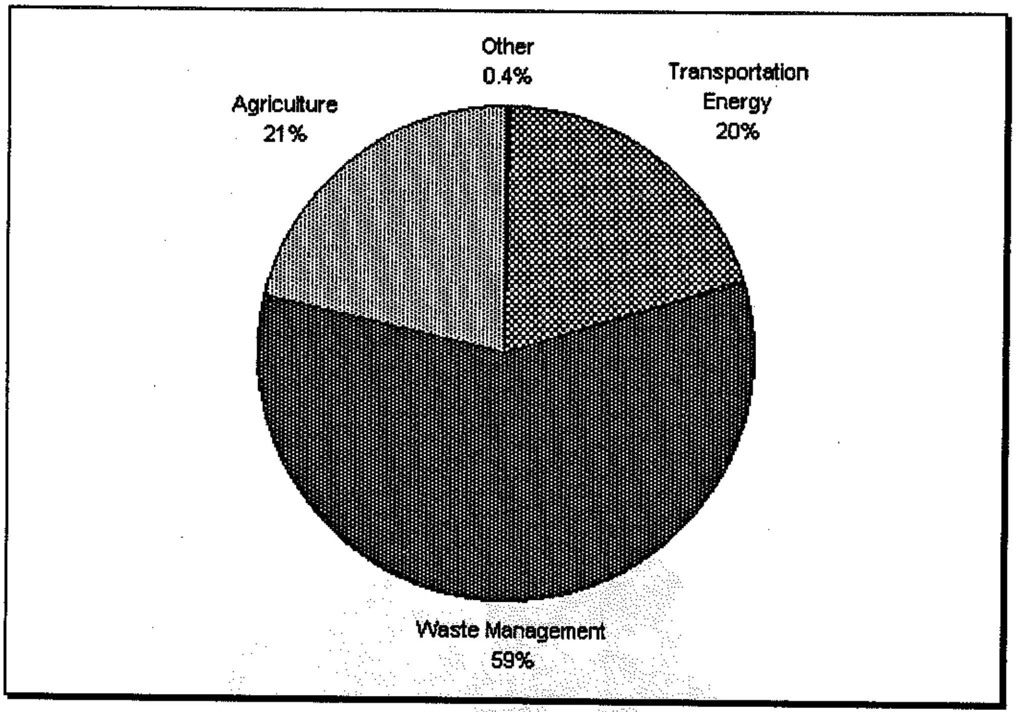


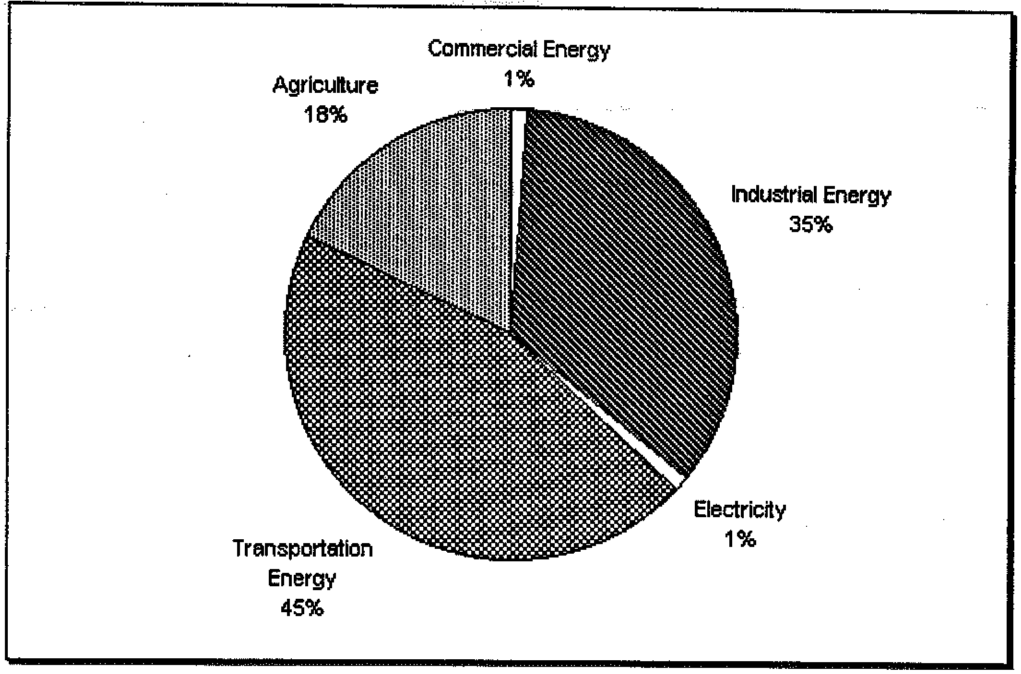
Figure 2.5, on the next page, summarizes the sources of methane emissions. Waste management produced 59%, transportation energy produced 20%, agriculture (primarily ruminant domestic animals and manure management) emitted 21%. Other energy sources were responsible for only 0.5% of CH_4 emissions.

Figure 2.5 Hawaii Methane Emissions by Sector, 1990



The largest share of N_2O emissions, as depicted on Figure 2.6., was produced by transportation energy sources (45%). Industrial energy sector (35%) and

Figure 2.6 Hawaii Nitrous Oxide Emissions by Sector, 1990



emissions from agriculture (18%) were also significant. The commercial energy sector and the electricity sector contributed about one percent each to total Hawaii N_2O emissions in 1990.

2.4. Estimated Greenhouse Gas Precursor Emissions

In this inventory, emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds were estimated. These are known as photochemically important gases, or tropospheric ozone precursors. Throughout the remainder of this report, they will be referred to as precursor gases. Although these are not greenhouse gases, they contribute indirectly to the greenhouse effect. They influence the rate at which ozone and other gases are created and destroyed in the atmosphere. NO_x contributes to the formation of ozone in the upper atmosphere. CO elevates concentrations of CH_4 and atmospheric ozone through chemical reactions with atmospheric constituents which would otherwise destroy CH_4 and ozone. It eventually oxidizes to CO_2. NMVOCs participate along with nitrogen oxides in the formation of ground-level ozone and other photochemical oxidants (USEPA, 1995b, iii).

Table 2.4 Estimated Precursor Gas Emissions in Hawaii, 1990

	Emissions in Tons			Percent of Emissions		
Sector/Fuel	**NO_x**	**CO**	**NMVOC**	**NO_x**	**CO**	**NMVOC**
Energy Use						
Residential Sector	72	15	N/A	0.1%	0.01%	N/A
Commercial Sector	16	47	0.4	0.03%	0.03%	0%
Industrial Sector	4,570	1,883	2,635	7%	1%	12%
Electricity Sector	30,218	3,347	626	49%	2%	3%
Transportation Sector	26,968	110,954	18,327	44%	72.0%	85%
Subtotal	61,844	116,247	21,589	99.8%	75%	100%
Industrial Processes	None Reported					
Non-Energy Sources						
MSW Management	N/A	27,101	N/A	N/A	N/A	N/A
Sugarcane Burning	140	10,857	N/A	0.2%	7%	N/A
Subtotal	140	37,958	N/A	0.2%	25%	N/A
Total	61,984	154,205	21,589	100%	100%	100%

Table 2.4 details the amounts of each gas emitted in tons and the relative percentage contribution of each source. These emissions will not be included global warming potential as a conversion factor was not available from the *State*

Workbook. Virtually all NO_x and NMVOC emissions came from Hawaii's energy sector. The energy sector also produced just over three-quarters of CO emissions.

2.5 Estimated Emissions from Overseas and Military Uses

As noted in Section 2.2, above, the estimate of Hawaii greenhouse and precursor gas emissions did not include overseas or military uses of aviation and marine fuel or exports of fuel sold, distributed, or refined in Hawaii. The reasons for the exclusion of these quantities of fuel are explained in detail in the discussion of Hawaii's energy system in Section 3.2. Overseas uses included jet fuel for overseas commercial airline flights, distillate and residual fuel oil used for bunkering ships in overseas operations in Hawaii ports, and distillate and fuel oil exported from Hawaii. Military uses in mobile sources were excluded due to a lack of data on location and amount of actual use. To provide a complete record of greenhouse gas and tropospheric precursor gas emissions of all fuels sold, distributed, or refined in Hawaii, the emissions from overseas and military uses were calculated and are presented in Table 2.5.

Table 2.5 Estimated Overseas and Military Emissions, 1990 (Tons)

Fuel	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Overseas Use						
Distillate	807,253		12	39,790	599	
Jet Fuel	5,140,742	143		20,836	8,790	1,302
Residual	1,032,705		13	43,074	649	
	6,980,700	143	25	103,700	10,038	1,302
Military Use						
Avgas	589	0.02	0.01	3	1	0.2
Distillate	388,078	22	11	6,439	2,041	486
Gasoline	26,416	2	1	451	143	34
Jet Fuel	709,780	20		2,877	1,214	180
Residual	69,349	N/A	1	2,676	40	N/A
	1,194,212	44	13	12,446	3,439	700
Overseas and Military Greenhouse and Precursor Gas Emissions by Fuel						
Avgas	589	0	0	3	1	0
Distillate	1,195,331		23	46,229	2,640	
Gasoline	26,416	2	1	451	143	34
Jet Fuel	5,850,522	163		23,713	10,004	1,482
Residual	1,102,054		14	45,750	689	
	8,174,912	165	38	116,146	13,477	1,516

The global warming potential was calculated for CO_2, CH_4, and N_2O emissions from overseas and military fuel use, as presented on Table 2.6. The total GWP was equivalent to 8,188,805 tons CO_2.

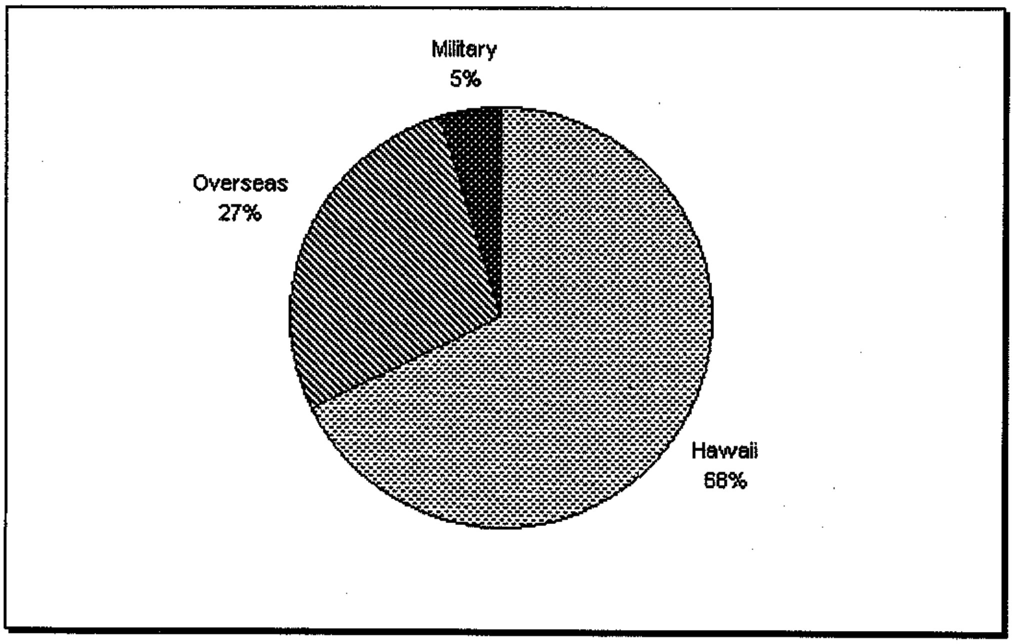
Table 2.6 Overseas and Military Greenhouse Gas Emissions Global Warming Potential, 1990 (Tons)

Fuel	CO_2	CH_4	N_2O	Total
Overseas Use				
Distillate	807,253		3,240	810,493
Jet Fuel	5,140,742	3,146		5,143,888
Residual	1,032,705		3,510	1,036,215
Subtotal	6,980,700	3,146	6,750	6,990,596
Military Use				
Avgas	589	0.4	3	592
Distillate	388,078	484	2,970	391,532
Gasoline	26,416	44	270	26,730
Jet Fuel	709,780	440		710,220
Residual	69,349		270	69,619
Subtotal	1,194,212	968	3,513	1,198,693
Total Overseas and Military Greenhouse Gas GWP by Fuel				
Avgas	589	0.4	3	592
Distillate	1,195,331		6,210	1,201,541
Gasoline	26,416	44	270	26,730
Jet Fuel	5,850,522	3,586		5,854,108
Residual	1,102,054		3,780	1,105,834
Total	8,174,912	3,630	10,263	8,188,805

When added to the 17,302,113 tons of CO_2 equivalent GWP of the emissions from in-state fuel use, industrial processes, and non-energy sector activities, the total GWP from all fuels sold, distributed, or refined in Hawaii was 25,491,402 tons of CO_2 equivalent.

As Table 2.6 and Figure 2.7 show, of that total, overseas uses of Hawaii origin fuels emitted 6,990,596 tons of CO_2 equivalent, or 27% of total GWP. Military uses produced 1,198,693 tons of CO_2 equivalent, or 5% of GWP from all sources. All in-state greenhouse gas emission sources produced a GWP of 17,302,113 tons, or 68% of the total.

Figure 2.7 Relative Contributions to GWP of Hawaii Sources and Hawaii-origin Fuels, 1990



2.6 Comparison of Estimated Hawaii Greenhouse Gas Emissions With Selected States

The global warming potential of total United States emissions of CO_2, CH_4, and N_2O in 1990 was 6,235,116,000 tons of CO_2 equivalent (USEPA, 1994, ES-3). Hawaii's GWP of 17,302,113 tons of CO_2 equivalent was 28/100 of one percent of that total.

Table 2.7 compares Hawaii's GWP in tons of CO_2 equivalent with the GWP of eleven other states which have completed greenhouse gas inventories under the EPA's State and Local Outreach Program. The GWP in pounds of CO_2 equivalent per capita, based on 1990 resident population and in pounds of CO_2 equivalence per dollar of 1990 Gross State Product (GSP) is also presented as a basis of comparison.

It should be noted that Hawaii's 1990 *de facto* population of 1,257,000, which is 114% of its resident population of 1,101,000, was used to calculate emissions produced in many of the categories in this report. However, in the absence of *facto* population data from other states, and recognizing that the emissions produced by visitors to Hawaii are an integral part of Hawaii's economy and environment, it seems logical to evaluate overall per capita emissions on the basis of resident population.

Table 2.7 Comparison of the Global Warming Potential of Emissions Produced by Selected States, 1990
(Millions of Tons CO_2 Equivalent)

Source	HAWAII	Alabama[1]	Illinois[2]	Indiana[2]	Kentucky[3]
Energy Sector	**15.3**	140.7	219.5	233.1	130.6
Industrial Processes	**0.1**	2.9	9.2	6.6	62.6
Waste Management	**1.4**	6.9	12.3	7.3	2.9
Agriculture	**0.5**	3.8	10.7	6.8	5.0
Total	**17.3**	154.3	251.7	253.8	201.1
1990 Resident Population[10]	**1,108,000**	4,041,000	11,431,000	5,544,000	3,685,000
Lbs. CO_2 Equiv./Capita	**15.6**	38.2	22.0	45.8	54.6
1990 GSP[11]	**29**	70	272	112	67
Lbs. CO_2 Equiv./$GSP	**1.2**	4.4	1.9	4.5	6.0

Source	Minnesota[2]	Maine[4]	Montana[5]	Missouri[1]	New Jersey[6]
Energy Sector	89.8	19.26	21.4	115.3	109.3
Industrial Processes	0.8	0.27	3.7	6.9	3.7
Waste Management	5.5	0.14	1.0	5.2	11.7
Agriculture	8.7	0.54	3.7	11.7	0.2
Total	104.9	20.21	29.7	139.1	124.9
1990 Resident Population[10]	4,375,000	1,228,000	799,000	5,117,000	7,730,000
Lbs. CO_2 Equiv./Capita	24.0	16.5	37.2	27.2	16.2
1990 GSP[11]	100	23	13	104	208
Lbs. CO_2 Equiv./$GSP	2.1	1.8	4.6	2.7	1.2

Source	Oregon[7]	Vermont[8]	Washington[9]	Wisconsin[1]
Energy Sector	12.2	5.7	85.2	104.9
Industrial Processes	0.5	-	44.6	0.0
Waste Management	0.6	0.1	4.8	4.6
Agriculture	0.6	0.3	2.5	9.9
Total	13.9	6.2	137.0	119.4
1990 Resident Population[10]	2,842,000	563,000	4,867,000	4,892,000
Lbs. CO_2 Equiv./Capita	4.9	11.0	28.2	24.4
1990 GSP[11]	55	11	109	101
Lbs. CO_2 Equiv./$GSP	0.5	1.1	2.5	2.4

Sources: [1] USEPA, 1997a.; [2] Noller, 1996, 21; [3] Spencer, 1996, 11; [4] USEPA, 1997b; [5] State of Montana, 1997, 66; [6] Johnson and Aucott, 1996, 11; [7] State of Oregon, 1995, Table 1B; [8] State of Vermont, 1994, 7; [9] Kerstetter, 1994, x; [10] U.S. Dept. of Commerce, 1994, Table 26, p. 27; [11] U.S. Dept. of Commerce, 1994, Table 688, p. 449.

Global warming potential displayed on this table does not include biomass emissions and the effects of land use change or carbon sinks. Gross State Product (GSP) is reported in billions of 1990 dollars

In each of these states, the energy sector was the primary source of greenhouse gas emissions, accounting for over 80% of emissions in 9 of the 12 states, including Hawaii. Of the exceptions, Kentucky and Montana had large proportional shares of emissions from production processes. Kentucky's production process emissions came primarily from CFC refrigerant production and methane emitted during coal mining (Spencer, 1996, 11, 95). Montana's major non-energy emissions were from aluminum production and domesticated animals (State of Montana, 1997, 67). Washington state's large forest products and aluminum industries also produced significant emissions (Kerstetter, 1994, 9).

Among this group of states, Hawaii produced the third lowest quantity of CO_2 equivalent emissions per capita and the fourth lowest per dollar of GSP. Oregon and Vermont produced less emissions per capita. Their electricity sectors included significant amounts of power produced by hydroelectric and nuclear plants. Both states included emissions from power production in other states which served their residents. In contrast, Hawaii's electricity sector dominated its production of greenhouse gases and about 90% of Hawaii's electricity was produced by oil-fired generators in 1990. Hawaii, of course, has no interconnections with other states or between its own islands.

Oregon and Vermont also emitted fewer pounds of CO_2 equivalent greenhouse gas emissions per dollar of GSP in 1990 due to the extensive use of hydroelectric and nuclear power in their electricity sectors. New Jersey produced about the same amount of emissions per dollar of GSP as Hawaii, but most of its electricity needs were met by nuclear power plants (USDOE, 1992, 224).

From this comparison, we can see that Hawaii's greenhouse gas emissions are relatively low compared to other states. Although fossil fuel use dominated Hawaii's energy sector; Hawaii's system was relatively efficient. In 1990, Hawaii's total per capita energy use ranked 41st in the nation and was 83 percent of the national average (11). This was aided by the lack of major space heating requirements. High energy costs also likely contributed to increased efficiency. Hawaii's energy prices in 1990 averaged $9.76 per million Btu, ranking 11th in the nation. This amounted to $1,966 per capita, ranking 22nd in the nation (USDOE, 1992b, 10-11). Additional rankings were as depicted on Table 2-8.

Table 2.8 Hawaii Energy Cost National Rankings, 1990

Category	Dollars per Million Btu	Ranking
Average Energy Prices	9.76	11
Petroleum	6.42	50
Gasoline	11.71	1
Synthetic Natural Gas [1]	12.25	1
Coal	1.82	10
Electricity	26.53	7

[1] SNG price as compared to Mainland US natural gas prices

Source: USDOE, 1992b, 10-16

While petroleum prices were relatively low, at the consumer level, petroleum refined as gasoline and synthetic natural gas were the most expensive in the nation. Oil was used to produce about 90% of Hawaii's electricity at a cost seventh in the nation. While coal was relatively inexpensive, in 1990 it was only used in relatively small amounts by two sugar plantations and a cement kiln.

These costs help explain the structure of Hawaii's energy use and resulting energy sector greenhouse gas emissions. They are also factors which must be considered in future mitigation measures. The high costs make energy efficiency measures more valuable. The low cost of fossil fuels, however, makes substitution for those fuels less attractive.

2.7 Recommendations for Improvement of Future Hawaii Greenhouse Gas Inventories

The major recommendation is for improvement of the quality of data. Data for the energy sector is generally good. Recent Department of Health Air Emissions Report forms do not collect fuel quantities used by the reporting sources as the

1990 forms previously required. Generally, however, energy use by stationary source estimates can be based instead on DBEDT data, but with less detail.

Greater resolution of the data on overseas aviation and marine fuel use could lead to separate identification of the amounts of fuel used for international and domestic overseas flights. It could be argued that domestic overseas fuel use should be included as part of Hawaii's inventory. In addition, more information on military fuel use would be useful, including imports by military logistical agencies in addition to currently available data on sales by Hawaii refiners and suppliers to the military. Detailed end use data is also needed.

This study relied on the refiners for data on their production process emissions. Given the requirements of environmental laws, fugitive emissions and other processing emissions appear to be tightly controlled. A bit more detail, particularly on flaring, and greater explanation of the sources could help identify additional measures to reduce the relatively small emissions from these sources.

Data on municipal solid waste management has greatly improved with post-1993 reporting requirements. Wastewater treatment is being upgraded in Hawaii and progress should be monitored, especially any methane control measures.

Emissions from agriculture are difficult to quantify. While emissions from domesticated animals can be calculated based on available animal population data, there is a lack of detailed data on manure management, and fertilizer use. A more detailed analysis of Hawaii land use is needed to calculate the effects of Hawaii's forests, watersheds, and agricultural areas as greenhouse gas sinks.

As noted above, this report will serve as a baseline in an effort to identify greenhouse gas reduction measures in the second phase of this project. Good data and continuing analysis of greenhouse gas emissions will be an important component of any successful effort to reduce those emissions.

CHAPTER 3 GREENHOUSE GAS EMISSIONS FROM ENERGY USE

3.1 Overview

Hawaii met most of its needs for energy and process heat in 1990 with the fossil fuels oil and coal. Biomass fuels, including sugar cane bagasse, macadamia nut shells, municipal solid waste, and wood chips, and renewable energy sources, including geothermal, hydroelectricity, wind, and solar, were also used. The fossil and biomass fuels resulted in the emission of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and tropospheric precursor gases nitrogen oxides (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOC).

This section reports the total emissions of these gases from the combustion of fossil fuels and biomass fuels in Hawaii's energy sector in 1990. The calculation of these emissions from stationary energy sources is explained in Chapter 4 and the calculation of emissions from mobile sources is reported in Chapter 5.

3.2 Hawaii's Energy System

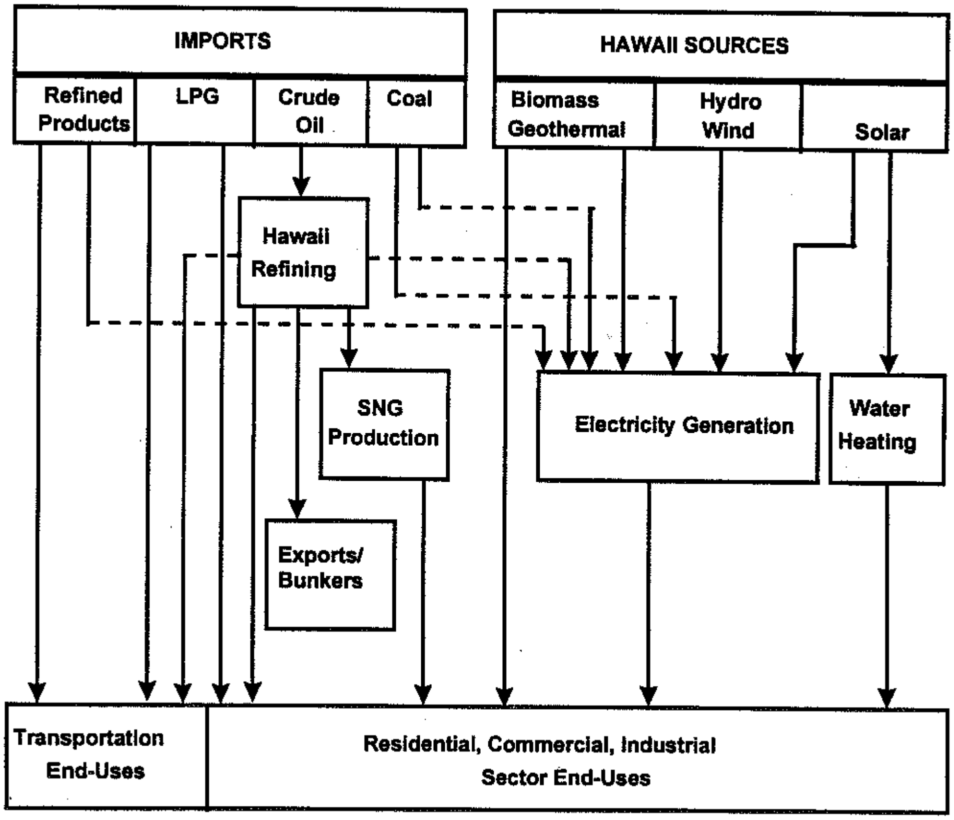
3.2.1 Energy Use In Hawaii

Figure 3.1 shows how Hawaii meets its needs for energy. At the top of the figure, energy is depicted entering the Hawaii energy system either through imports of crude oil, refined oil products, coal, and LPG, or through local production of biomass (bagasse, macadamia nut shells, municipal solid waste, and wood chips), wind, geothermal, solar, and hydropower. Hawaii has no indigenous supplies of fossil fuels.

Imported crude oil is refined on Oahu into oil products, which are either used to produce electricity, used locally, exported, or used as bunker fuel for aircraft and ships departing the islands for overseas destinations. Some refined products, particularly high-sulfur fuel oil, are exported. Principal fuels provided for overseas-bound aircraft and ships are jet fuel, residual fuel oil, and distillate fuel oil. Hawaii's refineries also produce feedstocks that are transformed into synthetic natural gas (SNG) for use as utility gas.

Imported coal and most of the locally produced forms of energy -- biomass, geothermal (not yet operational in 1990), hydroelectricity, and wind -- are used to generate electricity. Coal and biomass also provide process heat in the industrial sector. All electricity produced is obviously used locally, as transmission links with other states do not exist. In fact, each island's electrical system operates independently of the other islands. Solar energy is either directly converted into hot water by solar water heaters or into electricity by photovoltaic cells.

Figure 3.1 Hawaii's Energy System



LPG is used in all end-use sectors. LPG is both imported and manufactured locally as one of the outputs of Hawaii's refineries.

3.2.2 *Energy Use by Fuel*

Table 3.1 is a summary of Hawaii's energy sources and their use in 1990. The table lists each of Hawaii's energy sources in the first column. The amounts of energy imported into Hawaii, refined in Hawaii, or produced in Hawaii are listed in millions of British thermal units (Btu) in the second column. The third column provides the amounts sold as bunker fuel, exported, or sold to the armed forces. The emissions from these fuels will not be included in the inventory of Hawaii emissions for the reasons described below. The greenhouse gas emissions from this fuel use were not included in the Hawaii emission inventory. The fourth column summarizes the amounts of fuel or energy used in Hawaii that will be the focus of this inventory.

Table 3.1 Energy Use in Hawaii by Fuel, 1990

Fuel or Energy Source	Imported into, Refined in, or Produced in Hawaii (Million Btu)	Fuel for Overseas Bunkers, Exports, or Sold to Military (Million Btu)	Fuel or Energy Used in Hawaii (Million Btu)
Aviation Gasoline	226,272	7,804	218,467
Bagasse	17,796,000		17,796,000
Coal	527,116		527,116
Distillate Fuel Oil	32,664,859	14,967,833	17,697,026
Hydroelectric	1,070,000		1,070,000
Jet Fuel	97,191,148	74,101,797	23,089,351
Landfill Methane	128,511		128,511
LPG	3,511,495		3,511,495
Motor Gasoline	46,961,577	340,053	46,621,524
Macadamia Nut Shells	84,750		84,750
Municipal Solid Waste	4,929,840		4,929,840
Residual Fuel Oil	96,146,031	13,737,535	82,408,496
Solar Water Heating	2,340,000		2,340,000
Synthetic Natural Gas	3,480,600		3,480,600
Wood Chips	284,483		284,483
Wind	290,000		290,000
Total	307,632,682	103,155,022	204,477,659
Percent	100%	34%	66%

An estimated 307,632,682 million Btu of energy was imported, refined, or produced in Hawaii in 1990. Of that amount, 34%, or 103,155,022 Btu was not used in Hawaii. It was sold as fuel for aircraft and ships involved in overseas operations, sold to the military, or exported as cargo. However, the emissions from this fuel were calculated and reported separately to provide a complete record.

Aviation fuel in this report includes jet fuel used for overseas flights, both internationally and to the mainland United States. Distillate and residual bunker fuel oils were primarily sold to vessels in international trade or fishing vessels from foreign nations. High sulfur residual fuel oil was also exported.

The fuel purchased by the armed forces in Hawaii was also omitted from this accounting. In addition to being home to many military bases, Hawaii is a key logistics center. Unknown amounts of the fuel purchased from Hawaii refiners may be used by transient military aircraft and naval vessels or otherwise used outside of Hawaii. Wide fluctuations in military purchases from Hawaii noted in available data suggest that additional fuel is brought into Hawaii by military logistics agencies. Information on military fuel imports, local use, transient aircraft and ship use, and exports was not available from United States Pacific Command officials. However, as this report will serve as the basis for developing mitigation measures, it should also be noted that military fuel use is not subject to state influence or direction.

Fuel use by fixed military boilers and generators is included in the commercial sector of this report. It should also be noted that the Department of Defense is the largest electricity customer in the state, so significant emissions from the electricity sector result from generation of electricity for military use.

Table 3.2, on the next page, lists energy use in Hawaii by fuel. A total of 204,447,659 Btu were used. Fossil fuels provided 87% of Hawaii's in-state energy needs. Renewable energy, predominantly bagasse, met 13% of Hawaii's energy needs in 1990. Bagasse, macadamia nut shells, and wood chips used to produce energy and process heat are CO_2 neutral. Since these fuels are from crops, they absorb similar amounts of CO_2 in the growing cycle compared to the amounts emitted when burned.

Table 3.2 Energy Use in Hawaii by Fuel or Energy Source, 1990

Fuel or Source	Million Btu	Percent
Fossil Fuels		
Aviation Gasoline	43,278	218,467
Coal	24,517	527,116
Distillate Fuel Oil	2,994,980	17,697,026
Jet Fuel	8,875,219	46,621,524
LPG	4,072,196	23,089,351
Motor Gasoline	875,466	3,511,495
Residual Fuel Oil	13,107,762	82,408,496
Synthetic Natural Gas		3,480,600
	Subtotal	177,554,075
Renewable Energy		
Bagasse	1,072,015	17,796,000
Hydroelectric		1,070,000
Landfill Methane		128,511
Macadamia Nut Shells	7,500	84,750
Municipal Solid Waste	492,984	4,929,840
Solar Water Heating		2,340,000
Wind		290,000
Wood Chips	16,500	284,483
	Subtotal	26,923,584
	Total	204,477,659

Figure 3.2 Hawaii Energy Use by Fuel, 1990

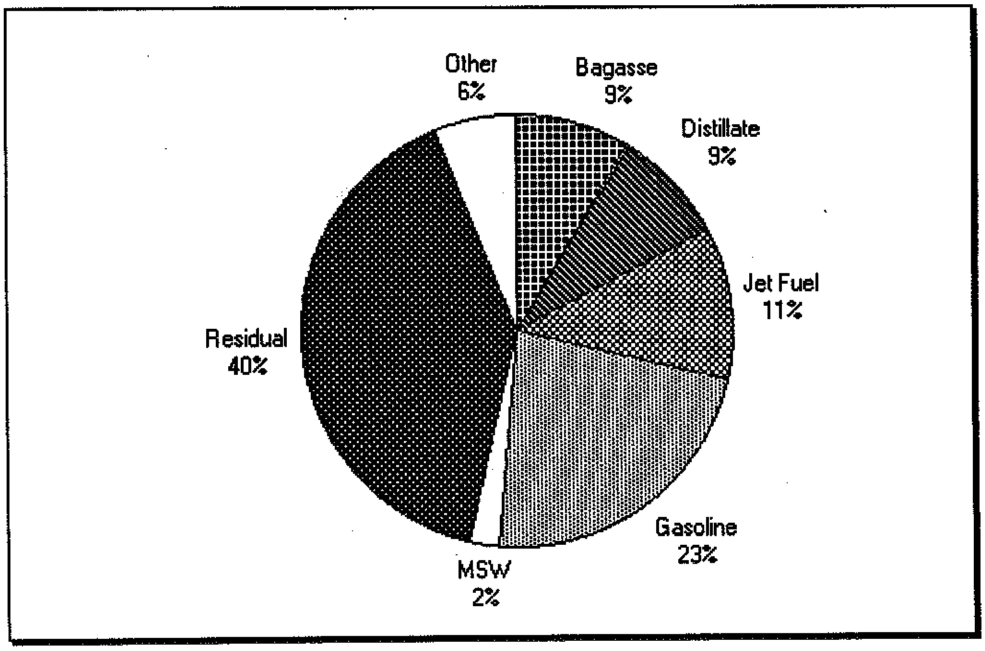


Figure 3.2, above, depicts the relative contribution of each energy source to the Hawaii energy system. Residual fuel oil, primarily used for electrical generation and some process heat, represented 40% of energy use. Gasoline, at 23%, was in

second place. Most gasoline was used in highway vehicles. Jet fuel used for interisland flights accounted for 11% of energy use. Bagasse, at 9%, was used by the sugar industry to produce process heat and electricity for its own use and to produce surplus electricity sold to Hawaii's utilities. Distillate fuel oil, including diesel, also at 9% was used for electricity generation, highway and off-highway vehicles, marine vessels, and for process heat. Burning of municipal solid waste produced about 2% of Hawaii's energy. Other fuels, including aviation gasoline, coal, LPG, synthetic natural gas, hydroelectric, landfill methane, macadamia nut shells, solar water heating, wood chips, and wind together provided a total of 6% of Hawaii's energy.

3.3 Hawaii Carbon Dioxide Emissions from Energy Use

3.3.1 Summary of Carbon Dioxide Emissions

Hawaii's greenhouse gas emissions were calculated using the estimates of fuel and energy use presented above. Table 3.3, on the next page, summarizes energy use and carbon dioxide emissions in 1990 by sector and fuel use. CO_2 emissions totaled 15,714,761 tons. However, CO_2 emissions from renewable resources, including bagasse, macadamia nut shells, and wood chips, were offset by CO_2 used in the growing cycle of these fuels. Thus, the quantity of CO_2 emissions from the energy sector to be included in the overall 1990 inventory of greenhouse gases was **14,751,549 tons**, which excluded CO_2 from these sources. While burning landfill methane and municipal solid waste also produced CO_2 and other greenhouse gas emissions, the global warming potential of these emissions was less than if the landfill methane had been allowed to escape into the atmosphere and if the MSW had been landfilled and allowed to produce unrecovered methane. Further, solar, hydroelectric, and wind energy use produced no greenhouse gas emissions.

Table 3.3 Fossil and Biomass Fuel Consumption and CO_2 Emissions in Hawaii, 1990

Sector/Fuel	Quantity	Million Btu	Tons CO_2	Net Tons CO_2	% Net CO_2
Residential Sector		**1.9%**			**0.6%**
LPG (Bbl)	219,711	881,261	60,461	60,461	64%
SNG		592,400	34,299	34,299	36%
Solar		2,340,000	None	None	None
	Subtotal	3,813,661	94,760	94,760	100%
Commercial Sector		**2.2%**			**1.9%**
Distillate (Bbl)	10,512	61,233	4,890	4,890	2%
LPG (Bbl)	381,524	1,530,293	104,989	104,989	38%
Residual (Bbl)	3,080	19,364	1,666	1,666	1%
SNG	N/A	2,888,200	167,222	167,222	60%
	Subtotal	4,499,090	278,767	278,767	100%
Industrial Sector		**14.5%**			**5.5%**
Bagasse (Tons)	1,072,015	17,796,000	922,265	Not Included	Not Included
Coal (Tons)	24,517	527,116	53,576	53,576	6.6%
Distillate (Bbl)	167,874	977,866	78,092	78,092	10%
Diesel (Off-Hwy) (Bbl)	364,552	2,374,724	169,584	169,584	21%
Gasoline (Off-Hwy) (Bbl)	34,171	179,500	13,944	13,944	2%
Hydroelectric		857,232	None	None	None
LPG (Bbl)	254,349	1,020,194	69,992	69,992	9%
LPG (Off-Hwy) (Bbl)	25	100	7	7	0.001%
Mac Nuts (Tons)	7,500	84,750	12,796	Not Included	Not Included
Residual (Bbl)	847,449	5,327,911	431,411	431,411	53%
Wind		290,000	None	None	None
Wood Chips (Tons)	16,500	284,483	28,151	Not Included	Not Included
	Subtotal	29,719,876	1,779,818	816,606	100%
Electricity Sector		**45.0%**			**51.8%**
Distillate (Bbl)	1,667,318	9,712,186	775,615	775,615	10%
Hydroelectric		212,768	None	None	None
Landfill Methane		128,511	7,441	7,441	0.1%
MSW (Tons)	492,984	4,929,840	238,008	238,008	3%
Residual (Bbl)	12,250,444	77,018,539	6,625,982	6,625,982	87%
	Subtotal	92,001,844	7,647,046	7,647,046	100%
Transportation Sector		**36.4%**			**40.1%**
Avgas (Bbl)	43,278	218,467	16,495	16,495	0.3%
Diesel (Bbl)	784,724	4,571,017	554,687	554,687	9%
Gasoline (Bbl)	8,841,048	46,442,024	3,511,353	3,511,353	59%
Jet Fuel (Bbl)	4,072,196	23,089,351	1,822,962	1,822,962	31%
LPG (Bbl)	19,857	79,647	5,464	5,464	0.09%
Residual (Bbl)	6,789	42,682	3,409	3,409	0.06%
	Subtotal	74,443,188	5,914,370	5,914,370	100%
	Total	204,477,659	15,714,761	14,751,549	100%

(State of Hawaii, 1997)

3.3.2 Carbon Dioxide Emissions by Fuel

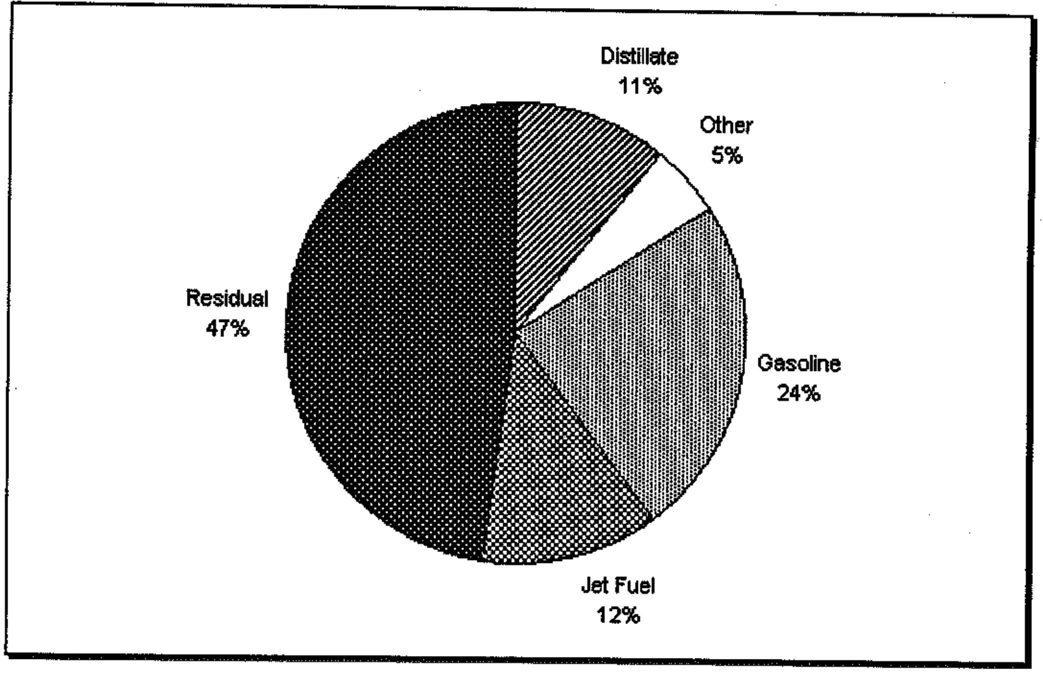
Table 3.4 lists net CO_2 emissions by fuel and Figure 3.3 depicts the percentages of each.

Table 3.4 CO_2 Emissions in Hawaii by Fuel, 1990

Fuel	Quantity	Million Btu	Net Tons CO_2	Percent CO_2
Fossil Fuels				
Avgas (Bbl)	43,278	218,467	16,495	0.1%
Coal (Tons)	24,517	527,116	53,576	0.36%
Distillate (Bbl)	2,994,980	17,697,026	1,582,868	11%
Gasoline (Bbl)	8,875,219	46,621,524	3,525,297	24%
Jet Fuel (BBl)	4,072,196	23,089,351	1,822,962	12%
LPG (Bbl)	875,466	3,511,495	240,912	2%
Residual (Bbl)	13,107,762	82,408,496	7,062,467	48%
SNG		3,480,600	201,522	1%
	Subtotal	177,554,075	14,506,100	
Renewable Energy				
Bagasse (Tons)	1,072,015	17,796,000	Not Included	Not Included
Hydroelectric		1,070,000	None	None
Landfill Methane		128,511	7,441	0.05%
Mac Nuts (Tons)	7,500	84,750	Not Included	Not Included
MSW (Tons)	492,984	4,929,840	238,008	2%
Solar		2,340,000	None	None
Wind		290,000	None	None
Wood Chips (Tons)	16,500	284,483	Not Included	Not Included
	Subtotal	26,923,584	245,449	
	Total	204,477,659	14,751,549	100.0%

(State of Hawaii, 1997)

Figure 3.3 Hawaii CO_2 Emissions by Fuel, 1990



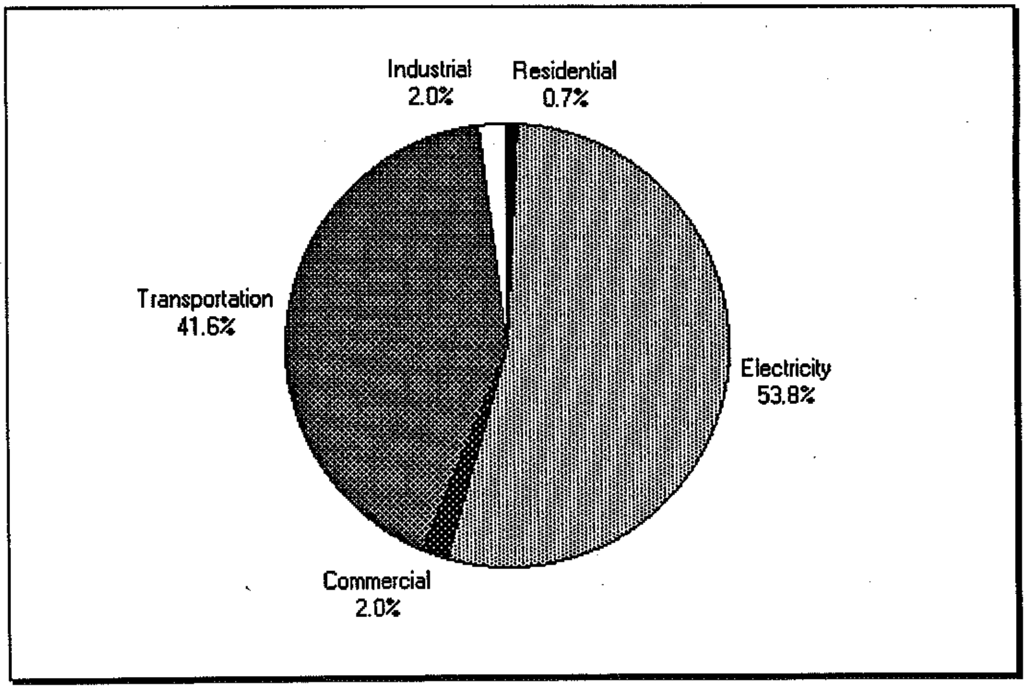
In Table 3.4 and Figure 3.3, residual fuel oil clearly dominated as the main source of net CO_2 emissions at 47% compared to its 40% share of overall energy use

(See Table 3.2). Gasoline followed at 25% with a 23% share of overall energy use. Interisland jet fuel use produced 13% of CO_2 emissions. Distillate fuel use produced 11% of net energy sector CO_2 emissions. All other fuels produced about 5% of 1990 energy sector net CO_2 emissions. As noted above, CO_2 emissions from bagasse, macadamia nut shells, and wood chips used to produce energy were not included as their CO_2 emissions are offset during the growing cycle. Other greenhouse gas emissions produced by the use of these fuels will be included in the inventory as they are not used in the growing cycle.

3.3.3 *Carbon Dioxide Emissions by Energy Use Sector*

Greenhouse and precursor gas emissions were calculated by sector to provide a basis for future evaluation of the relative importance of each sector and the fuel types used in each sector. This detail will help in the development of mitigation measures in Phase II of this project. Sector definitions may be found in Section 1.5 of this report. Figure 3.4 depicts the distribution of Hawaii net energy use CO_2 emissions by economic sector.

Figure 3.4 Percent of Hawaii Net Energy Use CO_2 Emissions by Sector, 1990



Over half of net CO_2 emissions from energy uses (7,647,046 tons or 53.8%) came from the electricity sector, followed by 41.6% (5,914,370 tons) from the transportation sector. The industrial and commercial sectors each contributed about 2% (284,988 tons and 278,767 tons respectively) of Hawaii's net CO_2 emissions from energy. The residential sector produced only 0.7% (94,760 tons).

3.4 Non-Carbon Dioxide Emissions from Energy Use

3.4.1 Summary of Non-Carbon Dioxide Emissions by Fuel

This section presents the non-CO_2 greenhouse and precursor gas emissions from energy use in Hawaii. As depicted on Table 3.5 and 3.7, 18,604 tons of CH_4 were emitted due to energy use Hawaii in 1990. All of the CH_4 emissions were produced by fossil fuel combustion. N_2O emissions totaled 922 tons. NO_x emissions were produced by all fuels and totaled 61,844 tons. CO emissions were 116,247 tons. Finally, NMVOC emissions were 21,589 tons, emitted by all fuels except LPG, SNG, macadamia nuts, and municipal solid waste. Commercial sector and transportation energy uses of residual fuel oil did not emit NMVOCs and bagasse. Coal emissions were extremely small.

Table 3.5 Hawaii Non-CO2 Emissions by Fuel, 1990 (Tons)

Fuel	CH_4	N_20	NO_x	CO	NMVOC
Aviation Gas	0.5	0.2	70	29	4
Bagasse	N/A	N/A	1,326	5	0.1
Coal	1	N/A	345	19	0.4
Distillate	68	352	18,894	4,825	3,049
Jet Fuel	17,746	N/A	7,389	3,117	462
Landfill Methane	1	N/A	25	4	N/A
LPG	6	4	142	113	27
Mac Nuts	N/A	N/A	5	N/A	N/A
Motor Gas	704	557	10,896	106,394	17,746
MSW	N/A	N/A	764	104	N/A
Residual	75	1	21,950	1,393	286
SNG	4	7.2	33	35	N/A
Wood Chips	N/A	N/A	6	210	14
Total	18,604	922	61,844	116,247	21,589

Table 3.6 shows the percentage contribution of each type of fuel to the total of each of the non-CO_2 greenhouse gas emissions. Jet fuel combustion on interisland flights produced 95% of energy use CH_4 emissions; gasoline produced 60% of

N_2O emissions and distillate fuels produced 38%. Residual fuel oil at 36%, produced most of the NO_x emissions, followed by distillate fuel oil (31%), and gasoline (18%). Gasoline use produced 92% of the carbon monoxide and 82% of the NMVOCs.

Table 3.6 Percent Hawaii Non-CO_2 Emissions by Fuel, 1990

Fuel	CH_4	N_2O	NO_x	CO	NMVOC
Aviation Gas	0.003%	0.02%	0.1%	0.02%	0.02%
Bagasse			2%	0.004%	0.0004%
Coal	0.0054%		0.6%	0.02%	0.002%
Distillate	0.4%	38%	31%	4%	14%
Jet Fuel	95%		12%	3%	2%
LPG	0.03%	0.4%	0.2%	0.10%	0.1%
Mac Nuts			0.01%		
Motor Gas	4%	60%	18%	92%	82%
MSW			1.2%	0.09%	
Residual	0.4%	0.1%	35%	1%	1%
SNG	0.02%	0.8%	0.05%	0.03%	
Wood Chips			0.01%	0.2%	0.06%
Total	100%	100%	100%	100%	100%

3.4.2 *Non-Carbon Dioxide Greenhouse Gas Emissions by Sector*

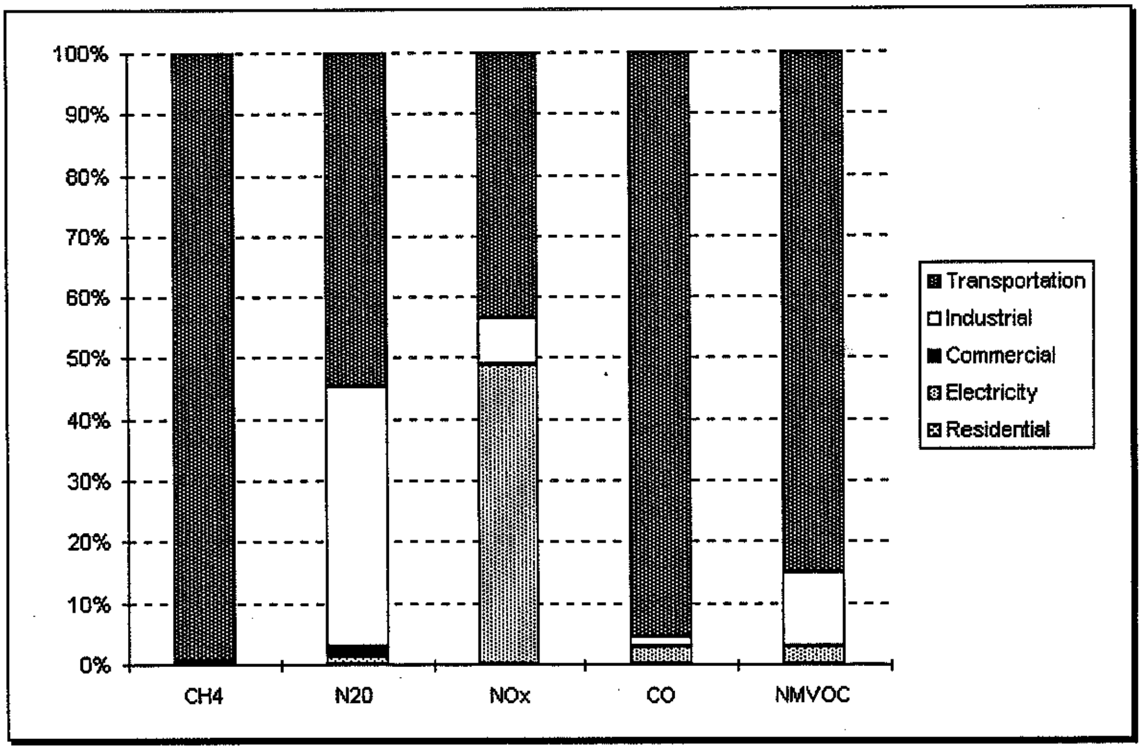
Table 3.7 summarizes non-CO_2 greenhouse and precursor gas emissions by energy sector and fuel. It also reports the percentage contribution to the total of each type of emissions in each energy sector.

Table 3.7 Non-CO_2 Emissions from Energy Use in Hawaii, 1990 (Tons)

Sector/Fuel	CH_4	N_20	NO_x	CO	NMVOC
Residential Sector	**0.01%**	**0%**	**0.1%**	**0.01%**	**0%**
LPG	1	N/A	43	9	N/A
SNG	1	N/A	29	6	N/A
Subtotal	2	N/A	72	15	N/A
Commercial Sector	**0.03%**	**1.4%**	**0.02%**	**0.04%**	**0.002%**
Distillate	0.06	1	10	3	0.4
LPG	2	4	2	15	N/A
Residual	0.03	1	0.03	0.4	N/A
SNG	4	7	3.6	29	N/A
Subtotal	6	13	15	47	0.4
Industrial Sector	**0.1%**	**42%**	**7%**	**2%**	**12%**
Bagasse	N/A	N/A	1,326	5	0.1
Coal	1	N/A	345	19	0.4
Distillate	2	N/A	407	150	39
Diesel (Off-Hwy)	7	332	1,116	1,209	2,223
Gasoline (Off-Hwy)	1	59	3	186	337
LPG	1	N/A	71	18	N/A
LPG (Off-Hwy)	0.0002	0.03	0.001	0.1	0.2
Mac Nuts	N/A	N/A	5	N/A	N/A
Residual	16	N/A	1,293	86	21
Wood Chips	N/A	N/A	6	210	14
Subtotal	27	391	4,570	1,883	2,635
Electricity Sector	**1%**	**1%**	**49%**	**3%**	**3%**
Distillate	50	13	8,914	1,935	361
Landfill Methane	1	N/A	25	4	N/A
MSW	N/A	N/A	764	104	N/A
Residual	58	N/A	20,515	1,304	265
Subtotal	109	13	30,218	3,347	626
Transportation Sector	**99%**	**55%**	**44%**	**95%**	**85%**
Aviation Gasoline	0.5	0.2	70	29	4
Diesel	9	7	8,448	1,528	425
Gasoline	703	498	10,893	106,208	17,409
Jet Fuel	17,746	N/A	7,389	3,117	462
LPG	2	0.03	26	70	27
Residual	N/A	0.04	142	2	N/A
Subtotal	18,460	505	26,968	110,954	18,327
Total	18,604	922	61,844	116,247	21,589

As depicted on Figure 3.5, on the following page, the transportation sector dominated the output of all five of these emissions in 1990. The industrial sector produced significant shares of N_2O and NMVOCs. The electricity sector was responsible for significant NO_x emissions. The residential and commercial sectors produced only small portions of emissions of non-CO_2 greenhouse and precursor gases or none at all. The next section discusses how the greenhouse gas emissions reported above were calculated.

Figure 3.5 Hawaii Non-CO_2 Emissions by Sector, 1990



3.5 General Methodology for Estimating Emissions

3.5.1 *Estimating Carbon Dioxide Emissions*

The methodology used to estimate CO_2 emissions was outlined in the EPA *State Workbook* (USEPA, 1995b). This methodology is described in the following simplified form based on *Wisconsin Greenhouse Gas Emissions; Estimates for 1990* (State of Wisconsin, 1993, 24). The formula for calculating CO_2 emissions can be expressed as:

$$\mathbf{CO_2\ Emissions\ (tons) = (Q_f * EF_f)/2000\ lbs./ton\ *OxFac*44CO_2/12C} \qquad \text{(Equation 3.1)}$$

Where:

Q_f = quantity of fuel type f in millions of Btu

EF_f = emission factor for fuel f (lbs./million Btu)

OxFac = oxidation factor

CO_2 emissions were estimated using Equation 3.1 by the following three-step process.

Step 1. Determine the use of fossil fuel and biomass fuel by type (Q_f) by fossil fuel type.

Most petroleum fuel use data used in this report were obtained from energy statistics compiled by the DBEDT Energy, Resources, and Technology Division from fuel supplier and distributor reports. The reports, required by Chapter 486E, Hawaii Revised Statutes, were submitted to DBEDT by each person or firm who refined, manufactured, produced, sold, exchanged, or utilized fuel in manufacture of products or production of power. Imports and exports of fuel were also reported.

Some bonded fuel used by foreign airlines may not have been reported as it was technically not imported or exported.

Data on fossil fuel and biomass use in the sugar industry were provided by the Hawaii Agricultural Research Center (which was called the Hawaii Sugar Planters' Association in 1990) unpublished data (HSPA, 1991). Additional data on coal use were provided by Hawaiian Cement (Cieslik, 1994), the only coal user outside the sugar industry in 1990. Nathan Yuen (Yuen, 1996) at the Hawaii Resource Recovery Venture provided data on municipal solid waste used for power generation.

Utility fuel use data was obtained from Air Emissions Reports filed by the utilities with the State of Hawaii Department of Health's Clean Air Branch (State of Hawaii, 1991a) and from the Hawaiian Electric Company's Environmental Department.

Air Emissions Reports to the Hawaii Clean Air Branch from commercial and industrial stationary source permit holders provided detailed information on fuel use in these sources and on some non-CO_2 greenhouse and precursor gas emissions. These provided the basis for the stationary source inventories in these two sectors.

Highway use data was provided by the State of Hawaii Department of Transportation Planning Branch (State of Hawaii, 1996a) and data on statewide vehicle registrations came from the City and County of Honolulu Data Services Division (C&C, 1996). This information served as a basis for highway vehicle fuel use estimation and greenhouse gas emission calculation as described Chapter 5.

One category of petroleum product omitted from this report was asphalt and road oil. These products sequester most of the carbon contained within them and do not affect the greenhouse gas inventory. For the record, Hawaii refineries produced 246,142 barrels of asphalt and road oil in 1990 (State of Hawaii, 1997).

It should be noted that the nature of available data resulted in inconsistencies between some sources. In other cases, procedures recommended in the *State Workbook* (USEPA, 1995b) were used to develop estimates. This report used the best data and information available and sought to logically resolve inconsistencies.

Step 2. Multiply use by type (Q_f) by the average carbon emission coefficient of the fuel, EF_f. Divide by 2000 to get tons of total carbon emitted per fuel.

The carbon emission coefficients for each fuel are from Chapter 1 of the EPA *State Workbook* (Table 1-3, 1-11). The carbon emission coefficients are provided in conjunction with the discussion of emissions calculations in Chapters 4 and 5.

This report departs slightly from the *State Workbook* (1-9) methodology by not subtracting international bunker fuels, exports, and, in the case of Hawaii, fuel sold to the armed forces prior to the next step. These amounts were deducted from fuel use prior to Step 1. Emissions from these sources were estimated and reported separately. In addition, since Hawaii is not involved in interstate electricity sales, there were no amounts to report under that category.

Step 3. Multiply by the oxidation factor (OxFac) to calculate total tons of carbon oxidized. Multiply this by 44 tons CO_2/12 tons C to get tons of CO_2 emitted.

The oxidation factor is the fraction of the carbon in the fuel which is oxidized during consumption to form CO_2. Oxidation factors were provided in Chapter 1 of the *State Workbook* (1-13). For biomass (bagasse and MSW) the oxidation factor is 0.90. For synthetic natural gas, it is 0.995. For all other fuels it is 0.99.

3.5.2 Estimating Non-CO_2 Emissions

Calculation of methane (CH_4), nitrous oxide (N_20), nitrogen oxides (NO_x), carbon monoxide (CO), and nonmethane volatile organic compounds (NMVOCs) emissions can be extremely difficult. Emissions of these gases depend upon fuel, combustion process, and pollution controls. They can vary further with size and vintage of combustion technology. Moreover, the amount of non-CO_2 gases from energy use is not considered to be major contributors to climate change (D14-1).

Chapter D-14 of the *State Workbook* provides available emissions factors for a variety of different combustion technologies for each sector. These factors were employed where applicable. The calculations are explained in more detail in Chapter 4 for stationary sources and in Chapter 5 for mobile sources. In the case of stationary sources, NO_x, CO, and NMVOC emissions were based upon the Air Emissions Reports filed by commercial and industrial stationary source permit holders and by the electric utilities with the Hawaii Department of Health (State of Hawaii, 1991a).

Equation 3.2 is the general formula used to calculate non-CO_2 greenhouse and precursor gas emissions:

$$\textbf{Emissions (tons)} = (\mathbf{Q_f} * \mathbf{EF_{fj}})/\mathbf{2000\ lbs./ton} \qquad \text{(Equation 3.2)}$$

Where $\mathbf{Q_f}$ = quantity of fuel type f in million Btu;

$\mathbf{EF_{fj}}$ = emission factor for fuel f in combustion process j (lbs./million Btu); and the product of $Q_f * EF_{fj}$ is divided by 2000 lbs./ton to yield the result in tons.

CHAPTER 4 GREENHOUSE GAS EMISSIONS FROM STATIONARY ENERGY SOURCE FOSSIL AND BIOMASS FUEL COMBUSTION

4.1 Overview

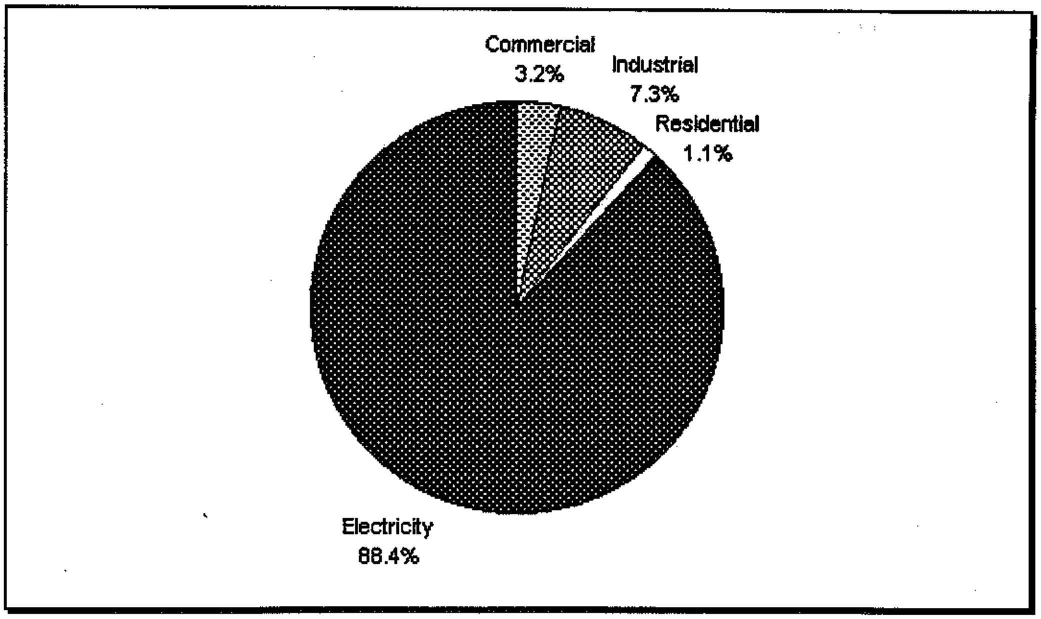
Chapter 4 reports the greenhouse gas emissions produced by combustion of fossil and biomass fuels in stationary energy sources in Hawaii in 1990. Greenhouse gas emissions were calculated by the general methodology described in Chapter 3.

This chapter begins with a summary of Hawaii stationary source greenhouse gas emissions. The sections following the summary describe the calculation of greenhouse gas emissions from stationary energy sources in the residential, commercial, industrial, and electricity sectors.

4.2 Summary of Emissions from Stationary Energy Sources

A total of 8,653,644 tons of CO_2 were emitted by stationary energy sources. Figure 4.1 depicts the percentages of stationary source CO_2 emissions produced in each sector. In the residential sector, the various uses of LPG and SNG produced

Figure 4.1 Percent of CO_2 Emissions by Stationary Source Sector in Hawaii, 1990



only 1.1% of CO_2 emissions – the smallest share. Distillate fuel oil, LPG, residual fuel oil, and SNG use in the commercial sector represented 3.2% of total stationary source CO_2 emissions. Industrial sector emissions were 7.3% of the total and were created by combustion of the widest variety of fuels -- bagasse, coal, distillate fuel oil, LPG, macadamia nut shells (Mac Nuts on Table 4.1), residual fuel oil, and wood chips. Bagasse, macadamia nut shells, and wood chips are CO_2 neutral since equivalent amounts of CO_2 are used in growing these fuels. The electricity sector, using distillate and residual fuel oils, landfill methane, and MSW to generate electricity, dominated CO_2 emissions from stationary sources at 88.4 % of the total. Table 4.1 summarizes stationary source CO_2 emissions by sector and by type of fuel.

Table 4.1 Hawaii Stationary Source CO_2 Emissions by Sector and Fuel, 1990

Sector/Fuel	Quantity	Million Btu	Tons CO_2	Percent CO_2
Residential Sector				**1.1%**
LPG (Bbl)	219,711	881,261	60,461	64%
SNG (Btu)		592,400	34,299	36%
	Subtotal	1,473,661	94,760	100%
Commercial Sector				**3.2%**
Distillate (Bbl)	10,512	61,233	4,890	2%
LPG (Bbl)	381,524	1,530,293	104,989	38%
Residual (Bbl)	3,080	19,364	1,666	1%
SNG (Btu)		2,888,200	167,222	60%
	Subtotal	4,499,090	278,767	100%
Industrial Sector				7.3%
Bagasse (Tons)	1,072,015	17,796,000	not included	not included
Coal (Tons)	24,517	527,116	53,576	8.5%
Distillate (Bbl)	167,874	977,866	78,092	12%
LPG (Bbl)	254,349	1,020,194	69,992	11%
Mac Nuts (Tons)	7,500	84,750	not included	not included
Residual (Bbl)	847,449	5,327,911	431,411	68%
Wood Chips (Tons)	16,500	284,483	not included	not included
	Subtotal	26,018,320	633,071	100%
Electricity Sector				**88.4%**
Distillate (Bbl)	1,667,318	9,712,186	775,615	10%
Landfill Methane (Btu)		128,511	7,441	0.1%
MSW (Tons)	492,984	4,929,840	238,008	3%
Residual (Bbl)	12,250,444	77,018,539	6,625,982	87%
	Subtotal	91,789,076	7,647,046	100%
All Sectors	**Total**	123,780,147	8,653,644	

(State of Hawaii, 1997)

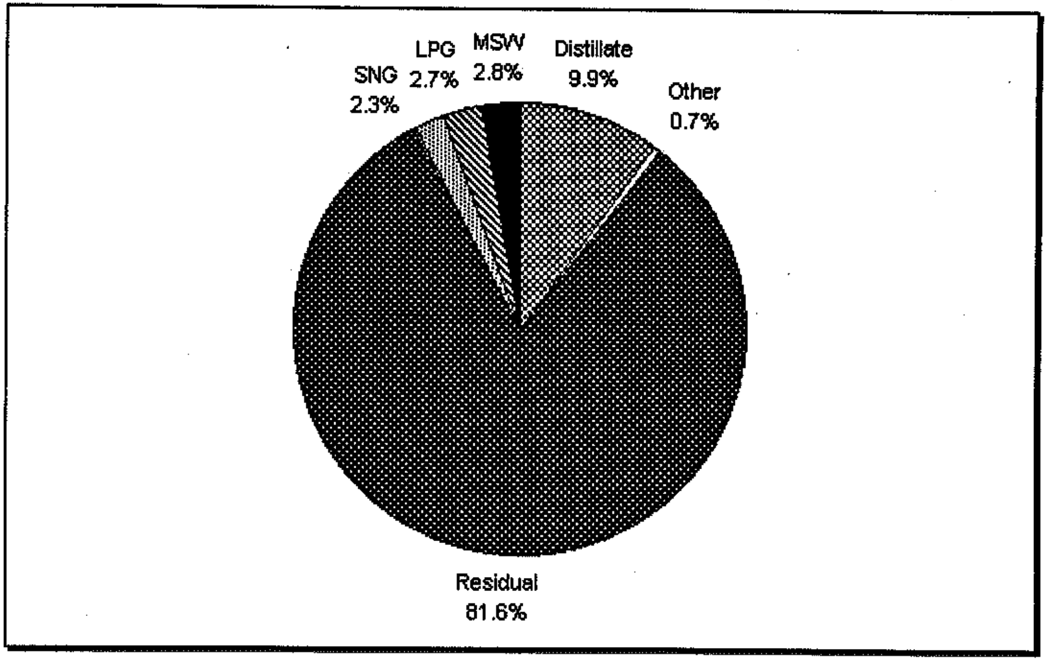
The dominance of the electricity sector is further illustrated when CO_2 emissions by fuel are examined. Table 4.2, on the following page, shows the amounts of each type of fuel combusted by the stationary sources and the tons of CO_2 emissions produced. Residual fuel oil produced 81.6% of total CO_2 emissions -- most of the residual fuel oil was used to produce electricity. Distillate fuel oil was in second place at 9.9%.

Table 4.2 Stationary Source CO_2 Emissions by Fuel

Fuel	Million Btu	Percent Fuel	Tons CO_2	Percent CO_2
Bagasse	17,796,000	14.4%	not included	not included
Coal	527,116	0.4%	53,576	0.6%
Distillate	10,751,285	8.7%	858,597	9.9%
Landfill Methane	128,511	0.1%	7,441	0.1%
LPG	3,431,748	2.8%	235,442	2.7%
Macadamia Nuts	84,750	0.1%	not included	not included
Mun. Solid Waste	4,929,840	4.0%	238,008	2.8%
Residual	82,365,814	66.5%	7,059,059	81.6%
SNG	3,480,600	2.8%	201,521	2.3%
Wood Chips	284,483	0.2%	not included	not included
Total	123,780,147	100.0%	8,653,644	100%

(State of Hawaii, 1997)

Figure 4.2 Percent of CO_2 Emissions from Stationary Sources by Fuel in Hawaii, 1990



Relative percentages of CO_2 emissions from stationary sources fuel use are shown in Figure 4.2. The relatively small amounts of CO_2 emissions from coal and landfill methane are together about 0.7% of the total from stationary sources and are presented as "Other" in the figure. Bagasse, macadamia nut shells, and wood chips are all renewable fuels and are not included in this Figure.

Table 4.3 summarizes the emissions of the non-CO_2 greenhouse and precursor gases -- CH_4, N_2O, NO_x, CO, and NMVOC -- from stationary energy sources by sector and fuel.

Table 4.3 Stationary Source Non-CO_2 Emissions by Sector and Fuel, 1990 (tons)

Sector/Fuel	CH_4	N_2O	NO_x	CO	NMVOC
Residential Sector					
LPG	0.9	N/A	43	9	N/A
SNG	0.6	N/A	29	6	N/A
Subtotal	1.5	N/A	72	15	N/A
Commercial Sector					
Distillate	0.1	1	10	3	0.4
LPG	2	4	2	15	N/A
Residual	0.03	1	0.03	0.4	N/A
SNG	4	7	4	29	N/A
Subtotal	6	13	16	47	0.4
Industrial Sector					
Bagasse	N/A	N/A	1,326	5	0.1
Coal	1	N/A	345	19	0.4
Distillate	2	N/A	407	150	39
LPG	1	N/A	71	18	N/A
Mac Nuts	N/A	N/A	5	N/A	N/A
Residual	16	N/A	1,293	86	21
Wood Chips	N/A	N/A	6	210	14
Subtotal	20	N/A	3,452	488	75
Electricity Sector					
Distillate	50	13	8,914	1,935	361
Landfill CH_4	1	N/A	25	4	N/A
MSW	N/A	N/A	764	104	N/A
Residual	58	N/A	20,515	1,304	265
Subtotal	109	13	30,218	3,347	626
Total	137	26	33,758	3,897	702

Table 4.4 Stationary Source Non-CO_2 Emissions by Fuel, 1990 (tons)

Fuel	CH_4	N_2O	NO_x	CO	NMVOC
Bagasse	N/A	N/A	1,326	5	0.1
Coal	0.84	N/A	345	19	0.4
Distillate	52	14	9,331	2,088	401
Landfill CH_4	1	N/A	25	4	N/A
LPG	4	4	116	43	N/A
Mac Nuts	N/A	N/A	5	N/A	N/A
MSW	N/A	N/A	764	104	N/A
Residual	74	1	21,808	1,391	286
SNG	4	7	33	35	N/A
Wood Chips	N/A	N/A	6	210	14
Total	120	26	33,757	3,897	702

Table 4.4, on the previous page, summarizes estimated non-CO_2 greenhouse and precursor gas emissions from stationary sources by fuel.

4.3 Emissions from Residential Sector Stationary Sources

Hawaii's residential sector stationary sources used non-utility LPG or utility-provided gas. Utility gas included synthetic natural gas or a propane air mixture provided to customers through utility distribution pipelines. For convenience, both types of utility gas will be aggregated and reported as SNG. Table 4.5 shows the amount and heat value of each fuel used in 1990 and their relative percentage of total residential sector fuel use.

Table 4.5 Residential Stationary Source Fuel Use, 1990

Source	Barrels	Million Btu	Percent
LPG	219,711	881,261	60%
SNG	N/A	592,400	40%
Total		1,473,661	100%

(State of Hawaii, 1997)

These factors and the carbon coefficient used to calculate CO_2 emissions, presented in Table 4.6, were used to estimate emissions from all uses which are presented in Table 4.7.

Table 4.6 Residential Stationary Source Emissions Factors (Lbs./Million Btu)

Source	C	CH_4	N_20
LPG	37.8	0.0021	N/A
SNG	31.9	0.0021	N/A
Source	**NO_x**	**CO**	**NMVOC**
LPG	0.098	0.021	N/A
SNG	0.098	0.021	N/A

(USEPA, 1995b, D1-11 and D14-8)

Table 4.7 Residential Stationary Source Emissions, 1990 (Tons)

Source	CO_2	CH_4	N_20
LPG	60,461	0.9	N/A
SNG	34,299	0.6	N/A
Total	94,760	1.5	N/A
Source	**NO_x**	**CO**	**NMVOC**
LPG	43	9	N/A
SNG	29	6	N/A
Total	72	15	N/A

The primary residential uses for these fuels are water heating, cooking, and clothes drying. The *State Workbook* (USEPA, 1995b, D1-11 and D14-8) provided non-CO_2 emissions factors only for gas heaters.

4.4 Emissions from Commercial Sector Stationary Sources

According to Air Emissions Reports made to the State of Hawaii Department of Health (State of Hawaii, 1991b), distillate fuels were used by federal, state, and county governments in boilers and diesel engines. Residual fuel oil was used by county and military facilities in boilers. These are the only uses of fuel purchased by the military that were specifically reported as used within the state and the emissions were included in the inventory. Table 4.8 summarizes fuel use by type of stationary commercial sector energy source in Hawaii in 1990.

Table 4.8 Commercial Stationary Source Fuel Use, 1990

Fuel/Source	Barrels	Million Btu	Percent
Distillate[1]			
Boilers	9,751	56,800	1.3%
Engines	761	4,433	0.1%
LPG[2]			
Various	381,524	1,530,293	34.0%
Residual[1]			
Boilers	3,080	19,364	0.4%
SNG[2]			
Various	N/A	2,888,200	64.2%
Total		4,499,090	100%

[1] State of Hawaii, 1991b

[2] State of Hawaii, 1997

In the commercial sector, LPG and SNG are primarily used for water heating and cooking along with some heating and cooling applications. The emissions factors from the *State Workbook* (USEPA, 1995B, D1-11, D13-2, and D14-9) presented in Table 4.9 were used to calculate the greenhouse gas emissions.

Table 4.9 Commercial Stationary Source Emissions Factors (Lbs./Million Btu)

Source	C	CH_4	N_20
Distillate Boilers	44	0.0013	0.035
Diesel Engines	44	0.009	0.0044
LPG	37.8	0.0025	0.005
Residual	47.4	0.0035	0.103
SNG	31.9	0.0025	0.005
Source	**NO_x**	**CO**	**NMVOC**
Distillate Boilers	0.1	0.035	N/A
Diesel Engines	2.7	0.84	0.2
LPG	0.0025	0.02	N/A
Residual	0.0035	0.038	N/A
SNG	0.0025	0.02	N/A

(USEPA, 1995b, D1-11, D13-2, and D14-9)

Table 4.10 reports total emissions in tons for the commercial sectors by stationary source type.

4.10 Commercial Stationary Source Emissions by Source, 1990 (Tons)

Source	CO_2	CH_4	N_20
Distillate Boilers	4,536	0.04	1
Diesel Engines	354	0.02	0.01
LPG	104,989	2	4
Residual	1,666	0.03	1
SNG	167,222	4	7
Total	278,767	6	13
Source	**NO_x**	**CO**	**NMVOC**
Distillate Boilers	4.0	1	N/A
Diesel Engines	5.9	2	0.44
LPG	1.9	15	N/A
Residual	0.03	0.4	N/A
SNG	3.6	29	N/A
Total	15	47	0.44

The commercial sector stationary source greenhouse and precursor gas emissions by fuel type are summarized in Table 4.11.

4.11 Commercial Stationary Source Emissions by Fuel, 1990 (Tons)

Fuel	CO_2	CH_4	N_20
Distillate	4,890	0.1	1
LPG	104,989	2	4
Residual	1,666	0.03	1
SNG	167,222	4	7
Total	278,767	6	13
Fuel	**NO_x**	**CO**	**NMVOC**
Distillate	10	3	0.4
LPG	2	15	N/A
Residual	0.03	0.4	N/A
SNG	4	29	N/A
Total	16	47	0.4

4.5 Emissions from Industrial Sector Stationary Sources

Both fossil and biomass fuels were used in industrial sector stationary sources to produce mechanical energy for machines, pumps, and other devices, to run electric generators, and to provide steam or process heat. Fossil fuels produced about 25% of the total heat value of the energy used in this sector while biomass fuels produced the remaining 75%. Fossil fuels used included coal, distillate fuel oil, LPG, and residual fuel oil. Residual fuel oil accounted for over two-thirds of fossil fuel use in this sector. The amounts of fossil fuel used by type and stationary source, their heat value, and relative percentage of each used are shown in Table 4.12.

Table 4.12 Industrial Stationary Source Fossil Fuel Use, 1990

Fuel/Source	Quantity	Million Btu	Percent
Coal (Tons)[1]			
Boiler	7,809	167,894	2%
Kiln	16,708	359,222	5%
Distillate (Bbl)[1]			
Boilers	71,020	413,692	5%
Engines	53,329	310,641	4%
Kilns/Process Heat	43,525	253,533	3%
LPG (Bbl)[2]			
Various	254,349	1,020,194	13%
Residual (Bbl)[1]			
Boilers	784,134	4,929,850	63%
Kilns/Process Heat	63,315	398,061	5%
Total		7,853,087	100%

[1] State of Hawaii, 1991b

[2] State of Hawaii, 1997

Table 4.13 summarizes the amounts of biomass fuel used by each type of industrial sector stationary source. Biomass fuels included bagasse, macadamia nut shells, and wood chips. Bagasse was used in the sugar industry to produce steam, process heat, and electricity, accounting for 77% of the heat value of the biomass used. Hawaii's sugar plantations produced 777 million kWh of electricity in 1990 and sold 51% of this output to public utilities. Almost 90% of the electricity generated by the sugar industry was produced by steam boilers that burned bagasse, coal, distillate fuel oil, and/or residual fuel oil. A very small amount of the sugar industry's electricity was produced using diesel generators. Most of the remaining 10% was produced by hydroelectric generators which do not emit greenhouse gases (HSPA, 1991, 11).

Table 4.13 Industrial Stationary Source Biomass Fuel Use, 1990

Fuel/Source	Tons	Million Btu	Percent
Bagasse[1]			
Boilers	1,072,015	17,796,000	98.0%
Macadamia Nut Shells[2]			
Boilers	7,500	84,750	0.5%
Wood Chips[2]			
Boilers	16,500	284,483	1.6%
Total		18,165,233	100%

[1] HSPA, 1991, 7

[2] State of Hawaii, 1991b

Macadamia nut processors on the Island of Hawaii burned macadamia nut shells to provide process heat. Wood chips and other biomass were used to generate electricity on Molokai in 1990, but the facility is no longer in use.

Table 4.14 Industrial Stationary Source Emissions Factors (Lbs./Million Btu)

Source	C	CH_4	N_2O
Bagasse Boilers [1]	0.237	N/A	N/A
Coal Boilers	56.0	0.0053	N/A
Coal Kilns	56.0	0.0022	N/A
Distillate Boilers	44.0	0.0007	N/A
Diesel Engines	44.0	0.009	N/A
Distillate Kilns/PH	44.0	0.0022	N/A
LPG	37.8	0.0029	N/A
Macadamia Nut Boiler	0.47	N/A	N/A
Residual Boilers	47.4	0.0064	N/A
Residual Kilns/PH	47.4	0.0022	N/A
Wood Chip Boilers[2]	0.47	N/A	N/A
Source	**NO_x**	**CO**	**NMVOC**
LPG	0.14	0.036	N/A
Other Fuels/Sources	As reported in DOH Air Emissions Inventory		

[1] Bagasse is 23.7 % carbon by weight (Paturau, 1989)

[2] The coefficient of wood is 0.47 lbs. per pound of wood.. This coefficient is used for macadamina nut shells and wood chips.

(USEPA, 1995b, D1-11, D14-7, and D14-8, and State of Hawaii, 1991b)

The emissions factors for C and CH_4 from the *State Workbook* (USEPA, 1995b, D1-11, D14-7 – D14-8), presented in Table 4.14, were used to calculate CO_2 and CH_4 emissions for all industrial sector fuels and sources. Reports by covered source operators to the State of Hawaii Department of Health (State of Hawaii, 1991b) provided the amounts of fuel used and NO_x, CO, and NMVOC emissions from stationary sources.

NO_x, CO, and NMVOC emissions for municipal solid waste and LPG were also calculated. According to the *State Workbook* (USEPA, 1995b, D14-7 -- D14-8), industrial stationary sources did not produce significant quantities of N_2O.

Table 4.15 displays industrial sector stationary source emissions by source.

Table 4.15 Industrial Stationary Source Emissions, 1990 (tons)

Source	CO_2	CH_4	N_2O
Bagasse Boilers	not included	N/A	N/A
Coal Boilers	17,065	0.44	N/A
Coal Kilns	36,511	0.40	N/A
Distillate Boilers	33,037	0.14	N/A
Diesel Engines	24,807	1.40	N/A
Distillate Kilns/PH	20,247	0.28	N/A
LPG	69,992	1.48	N/A
Macadamia Nut Boiler	not included	N/A	N/A
Residual Boilers	424,120	15.78	N/A
Residual Kilns/PH	7,291	0.09	N/A
Wood Chip Boilers	not included	N/A	N/A
Total	633,071	20	N/A
Source	**NO_x**	**CO**	**NMVOC**
Bagasse Boilers	1,326	5	0.1
Coal Boilers	54	19	0.4
Coal Kilns	291	N/A	N/A
Distillate Boilers	30	8	0.5
Diesel Engines	358	125	27.5
Distillate Kilns/PH	19	17	11.5
LPG	71	18	N/A
Macadamia Nut Boiler	5	N/A	N/A
Residual Boilers	968	79	16.8
Residual Kilns/PH	325	7	4.4
Wood Chip Boilers	6	210	14.0
Total	3,452	488	75

Table 4.16 lists industrial sector stationary source GHG emissions by fuel. Additional industrial energy sector emissions were produced by mobile sources, including agricultural and industrial off-highway vehicles and mobile equipment. The amounts of fuel used and the amounts of greenhouse and precursor gases produced are discussed in Chapter 5.

Table 4.16 Industrial Stationary Source Emissions by Fuel, 1990 (tons)

Fuel	CO_2	CH_4	N_2O
Bagasse	not included	N/A	N/A
Coal	53,576	1	N/A
Distillate	78,092	2	N/A
LPG	69,992	1	N/A
Macadamia Nut Shells	not included	N/A	N/A
Residual	431,411	16	N/A
Wood Chips	not included	N/A	N/A
Total	633,071	20	N/A
Fuel	**NO_x**	**CO**	**NMVOC**
Bagasse	1,326	5	0.1
Coal	345	19	0.4
Distillate	407	150	39
LPG	71	18	N/A
Mac Nut Shells	5	N/A	N/A
Residual	1,293	86	21
Wood Chips	6	210	14
Total	3,452	488	75

4.6 Emissions from Electricity Sector Stationary Sources

Electricity sector fuel use data are the most complete of available Hawaii energy data. Hawaii's four regulated electric utilities, Hawaiian Electric Company, Inc. (HECO); Hawaii Electric Light Company, Inc.; Maui Electric Company; and Kauai Electric Division of Citizens Utilities each reported fuel use and sulfur dioxide, CO, NO_x, and NMVOC emissions by individual generation unit to the State of Hawaii Department of Health's Clean Air Branch in annual Air Emissions Reports (State of Hawaii, 1991b). Table 4.16 summarizes electricity sector fuel use in 1990.

Table 4.17 Electric Utility Fuel Use, 1990

Fuel/Source	Quantity	Million Btu	Percent
Distillate (Bbl.)			
Engines	1,018,544	5,933,076	6.5%
Combustion Turbines	648,774	3,779,110	4.1%
Landfill Methane			
Combustion Turbine		128,511	0.1%
Municipal Solid Waste (Tons)			
Boiler	492,984	4,929,840	5.4%
Residual (Bbl.)			
Boilers	12,250,444	77,018,539	83.9%
Total		91,789,076	100%

(State of Hawaii, 1991b)

As shown in Table 4.17, in 1990, 83.9% of the fuel used in the electricity sector was residual fuel oil burned in boilers used to produce steam to drive generators. About 10.6% was distillate fuel oil used in diesel generators and simple-cycle combustion turbine generators. Finally, MSW was 5.4% of the fuel used to produce electricity and landfill methane 0.1%.

The values reported in this section for 1990 are for generation operated by the four electric utilities and two independent power producer operating in 1990. The independent power producers were the City and County of Honolulu's H-POWER garbage-to-energy plant in the Campbell Industrial Park on Oahu, and Kapaa Generating Partners' landfill methane-fueled combustion turbine cogeneration plant in Kailua, Oahu.

H-POWER, began full operation in 1990 and provided 45 MW of firm capacity. H-POWER generated 339,976 MWh and sold 309,513 MWh to HECO under a power purchase agreement. In addition, the 3.3 MW Kapaa landfill methane combustion turbine generator sold 8,846 MWh of electricity to HECO on an as available basis.

Additional electricity was generated by the cogenerators at the two oil refineries, by wind farms on Oahu, Maui, and the Island of Hawaii, and by small independent hydroelectric plants on the Island of Hawaii. The fuel used by the cogenerators at the refineries was included in the industrial section of this chapter. The sugar industry also produced significant amounts of electricity and sold about

51%, or 413,454 MWh to the electric utilities for resale to utility customers. Figure 4.18 summarizes electricity generation and sales in Hawaii in 1990.

Table 4.18 Electricity Generation and Sales in Hawaii (MWh), 1990

Source	HECO	HELCO	KE	MECO	Total
Electric Utilities					
Steam	6,371,778	476,826	80,724	248,750	7,178,078
Diesel	-	124,866	182,809	484,812	792,487
Hydro	-	23,052			23,052
Wind	-	-		93	93
Other	48,602				48,602
Net Generation	6,420,380	624,744	263,533	733,655	8,042,312
Sold to Utilities					
Landfill Methane	8,846				8,846
MSW	309,513				309,513
Oil Refineries	41,086				41,086
Small Producers	1,261	20,838		17,287	39,386
Sugar Industry[1]	38,420	167,310	111,514	96,210	413,454
Wind	11,548				11,548
Subtotal	410,674	188,148	111,514	113,497	823,833
Disposition of Energy					
Used by Company/Statio	(16,039)	(33,951)	(6,355)	(32,156)	(88,501)
Energy Losses	(344,428)	(63,190)	(25,834)	(30,654)	(464,106)
Subtotal	(360,467)	(97,141)	(32,189)	(62,810)	(552,607)
Total Sold to Customers	6,470,587	715,751	342,858	784,342	8,313,538

[1] The Sugar Industry sold only a portion of power generated to the utilities; about half was used internally.

Sources: HECO Federal Energy Regulatory Commission (FERC) Form 1 for 1990, pp.326-327, 401; HELCO, KE, and MECO FERC Annual Reports, Schedule C for 1990; and Unpublished HSPA data

Electricity is used by residential, commercial, and industrial customers, but the emissions produced in meeting their demands are presented in this section rather than with the end use. Due to a lack of direct correspondence between the rate classifications used by the utilities and the economic sectors, such an apportionment would be extremely difficult in any event. Table 4.19, summarizes utility electricity sales based upon HECO's 1990 Federal Energy Regulatory Commission Form No.1 (401), and Schedules C from the HELCO, KE, and MECO 1990 Annual Reports to the Hawaii Public Utilities Commission.

Table 4.19 Electric Utility Sales in Hawaii by Rate Classification, 1990

			MWh		
Classification of Rates	**HECO**	**HELCO**	**KE**	**MECO**	**Total**
Residential Sales	1,657,105				1,657,105
Residential Comb. Lighting, Heating, and Small Power		273,856	115,188	266,809	655,853
Electric Service for Employees			1,173	2,807	3,980
General Lighting Service		202,322	88,501	235,820	526,643
Heating, Cooking, Refrigeration, Etc.		45,940		27,127	73,067
Comb. Power & Incidental Lighting				243,876	243,876
Small (or Comm)	1,594,707				1,594,707
Government State, Hwy, & Park Lighting	48,297	3,262	2,103	4,756	58,418
Governmental Contract		3,582			3,582
Large (or Ind.)	3,170,478				3,170,478
General Power			132,492		132,492
Primary Power		186,759			186,759
Industrial Contract				147	147
Irrigation			3,400		3,400
Total	6,470,587	715,721	342,857	781,342	8,310,507
Percent of Total	**78%**	**9%**	**4%**	**9%**	**100%**

Table 4.20 Electric Utility Emissions Factors (Lbs./Million Btu)

Source	**C**	**CH_4**	**N_2O**
Distillate			
Engines	44.0	0.009	0.0044
Combustion Turbines	44.0	0.0124	N/A
Landfill Methane			
Combustion Turbine	31.9	0.0124	N/A
Municipal Solid Waste (Tons)			
Boiler	26.6	N/A	N/A
Residual			
Boilers	47.4	0.0015	N/A
Source	**NO_x**	**CO**	**NMVOC**
Distillate			
Engines	As reported in DOH Air Emissions Inventory		
Combustion Turbines	As reported in DOH Air Emissions Inventory		
Landfill Methane			
Combustion Turbine	0.394	0.067	N/A
Municipal Solid Waste (Tons)			
Boiler	0.31	0.042	N/A
Residual			
Boilers	As reported in DOH Air Emissions Inventory		

(USEPA, 1995b, D1-11 and D14-7 and State of Hawaii, 1991b)

State Workbook (USEPA, 1995b, D1-11 and D14-7) emissions factors were used to calculate electricity sector greenhouse gas emissions are listed in Table 4.20.

Table 4.21 displays emissions in tons by fuel type and stationary source.

Table 4.21 Electric Utility Emissions, 1990 (Tons)

Fuel/Source	CO_2	CH_4	N_20
Distillate			
Engines	473,815	27	13
Combustion Turbines	301,800	23	N/A
Landfill Methane			
Combustion Turbine	7,441	1	N/A
Municipal Solid Waste (Tons)			
Boiler	238,008	N/A	N/A
Residual			
Boilers	6,625,982	58	N/A
Total	7,647,045	109	13
Fuel/Source	**NO_x**	**CO**	**NMVOC**
Distillate			
Engines	8,015	1,725	295
Combustion Turbines	899	210	66
Landfill Methane			
Combustion Turbine	25	4	N/A
Municipal Solid Waste (Tons)			
Boiler	764	104	N/A
Residual			
Boilers	20,515	1,304	265
Total	30,218	3,347	626

Finally, Table 4.22 lists electricity sector emissions by fuel type.

Table 4.22 Electric Utility Emissions by Fuel, 1990 (Tons)

Fuel	CO_2	CH_4	N_20
Distillate	775,615	50	13
Landfill Methane	7,441	1	N/A
Municipal Solid Waste	238,008	N/A	N/A
Residual	6,625,982	58	N/A
Total	7,647,046	109	13
Fuel	**NO_x**	**CO**	**NMVOC**
Distillate	8,914	1,935	361
Landfill Methane	25	4	N/A
Municipal Solid Waste	764	104	N/A
Residual	20,515	1,304	265
Total	30,218	3,347	626

CHAPTER 5 GREENHOUSE GAS EMISSIONS FROM MOBILE SOURCE FOSSIL FUEL COMBUSTION

5.1 Overview

This section presents the inventory of greenhouse gas emissions from the combustion of fossil fuels sold or distributed in Hawaii in mobile sources in 1990. Mobile sources include the engines of aircraft, ships and boats, and a variety of highway and non-highway vehicles. Except for emissions from highway vehicles, emissions from mobile sources were calculated using the general methodology described in Chapter 3. Section 5.5 describes the method used to calculate highway vehicle greenhouse gas emissions.

This chapter begins with a summary of the greenhouse gas emissions from mobile sources. The following sections explain the calculation of the greenhouse gas emissions from each of the mobile source uses of fossil fuels.

5.2 Summary of Emissions from Mobile Energy Sources

5.2.1 Carbon Dioxide Emissions from Mobile Sources

Greenhouse gas emissions were calculated for transportation sector mobile sources, industrial sector mobile sources, and non-aviation military mobile sources. Transportation fuels used in Hawaii included aviation gasoline (Avgas), distillate fuel oil (diesel), motor gasoline, jet fuel, LPG, and residual fuel oil.

5.2.1.1 Carbon Dioxide Emissions from Transportation Mobile Sources

Table 5.1 displays estimated transportation sector mobile source fuel use and carbon dioxide emissions in 1990 by category and type of fuel used. These are divided into in-state uses, overseas uses, and military uses. Transportation fuel use and emissions were dominated by jet fuel (57.2%), gasoline (26.2%), distillate

(8.7%), and residual (7.7%), with LPG (0.04%) and aviation gasoline (0.1%) making very small contributions to the total. An estimated 13,417,024 tons of CO_2 were produced from transportation mobile source fuel use.

Table 5.1 Transportation Fuel Use and CO_2 Emissions, 1990

Use/Fuel	Barrels	Million Btu	Tons CO2	Percent CO_2
In-State Aviation Fuel				
Avgas	43,278	218,467	16,495	
Jet Fuel	4,072,196	23,089,351	1,822,962	
	Subtotal	23,307,818	1,839,457	14%
Overseas Aviation Fuel				
Jet Fuel	11,483,568	65,111,831	5,140,742	38%
Military Aviation Fuel				
Avgas	1,546	7,804	589	
Jet Fuel	1,585,532	8,989,966	709,780	
	Subtotal	8,997,770	710,369	5%
In-State Marine Fuel				
Distillate	322,175	1,876,669	149,871	
Gasoline	3,879	20,376	1,238	
Residual	6,789	42,682	3,409	
	Subtotal	1,939,727	154,517	1%
Overseas Marine Fuel				
Distillate	1,735,339	10,108,350	807,253	
Residual	2,056,854	12,931,441	1,032,705	
	Subtotal	23,039,791	1,839,958	14%
Highway Vehicle Fuel				
Distillate	462,549	2,694,348	215,170	
Gasoline	8,837,169	46,421,648	3,511,353	
LPG	19,857	79,547	5,457	
	Subtotal	49,195,543	3,731,980	28%
Total Transportation Sector Fuel Use and CO_2 Emissions				
Avgas	44,824	226,271	17,084	0.1%
Distillate	2,520,063	14,679,367	1,172,294	9%
Gasoline	8,841,048	46,442,024	3,512,591	26%
Jet Fuel	17,141,296	97,191,148	7,673,484	57%
LPG	19,857	79,547	5,457	0.04%
Residual	2,063,643	12,974,123	1,036,114	8%
	Total	171,592,480	13,417,024	100%

(State of Hawaii, 1997)

5.2.1.2 Carbon Dioxide Emissions from Non-Transportation Mobile Sources

Table 5.2 summarizes estimated non-transportation mobile source fuel use and CO_2 emissions of fuel. Distillate fuel use accounted for 93% of industrial mobile source CO_2 emissions, followed by gasoline at slightly less than 3%. LPG use was less than 3/1000 of one percent. Non-aviation military uses of distillate fuel (which were not counted as in-state uses) produced 80% of estimated CO_2 emissions, while residual fuel oil uses emitted 14%, and gasoline 6%.

Table 5.2 Non-Transportation Mobile Source Fuel Use and CO_2 Emissions, 1990

Use/Fuel	Barrels	Million Btu	Tons CO_2	Percent CO_2
Agricultural Mobile Equipment Fuel				
Distillate	221,976	1,293,010	103,260	
Gasoline	29,166	153,209	11,902	
LPG	25	100	7	
	Subtotal	1,446,319	115,168	57%
Industrial Mobile Equipment Fuel				
Distillate	185,702	1,081,714	86,386	
Gasoline	5,005	26,291	2,042	
	Subtotal	1,108,005	88,428	43%
Total Industrial Mobile Source Fuel Use and CO_2 Emissions				
Distillate	407,678	2,374,724	189,646	93%
Gasoline	34,171	179,500	13,944	7%
LPG	25	100	7	0.003%
	Total	2,554,324	203,596	100%
Non-Aviation Military Fuel				
Distillate	834,246	4,859,483	388,078	80%
Gasoline	64,735	340,053	26,416	6%
Residual	128,216	806,094	69,349	14%
	Total	6,005,630	483,843	100%

(State of Hawaii, 1997)

5.2.1.3 Summary of Carbon Dioxide Emissions from Mobile Sources

Figure 5.1 Percentages of CO_2 Emissions from Mobile Sources by End-Use, 1990

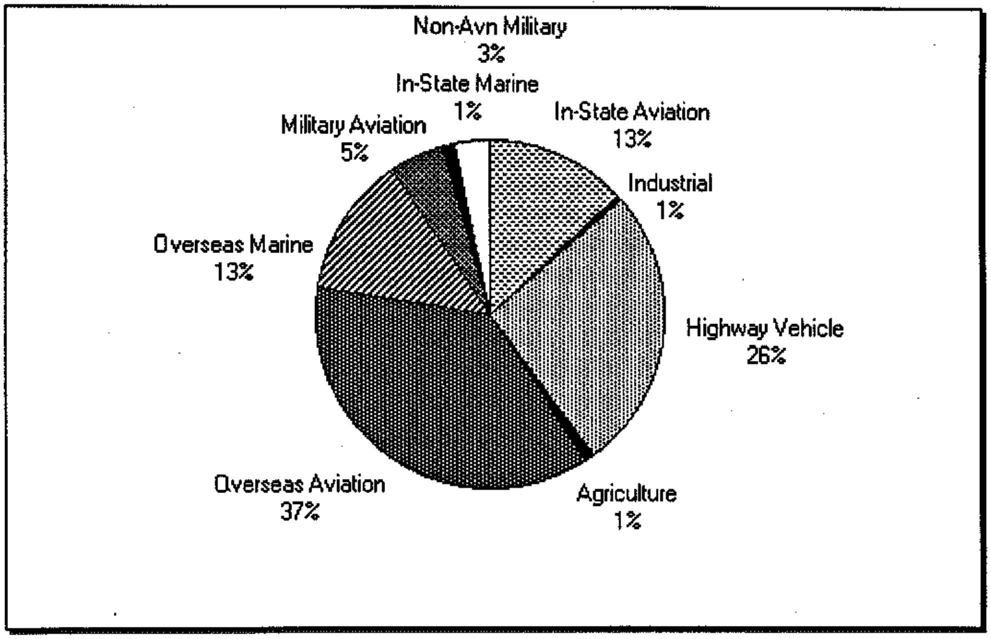


Figure 5.1 depicts the relative share of CO_2 emissions from each end-use of mobile source fuels sold or distributed in Hawaii in 1990.

Table 5.3 summarizes mobile source fuel use and CO_2 emissions by category. The values in the first section, in-state use, were included in the overall Hawaii Greenhouse Gas Inventory. While in-state uses were only 42% of mobile source CO_2 emissions from fuels sold or distributed in Hawaii, only this amount resulted from non-military transportation fuel use in Hawaii. Further rationale for the exclusion of overseas and military fuel use will be presented below.

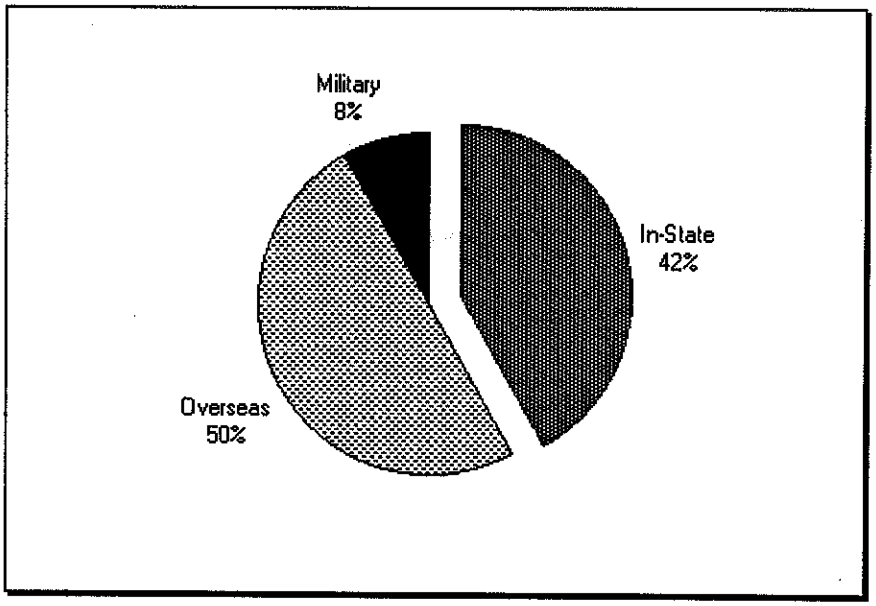
Table 5.3. Mobile Source CO_2 Emissions by Fuel, 1990

Fuel	Barrels	Million Btu	Tons CO_2	Percent CO_2
In-State Use				
Avgas	43,278	218,467	16,495	
Distillate	1,192,402	6,945,741	554,687	
Gasoline	8,875,219	46,621,524	3,526,535	
Jet Fuel	4,072,196	23,089,351	1,822,962	
LPG	19,882	79,647	5,464	
Residual	6,789	42,682	3,409	
	Total	76,997,412	5,929,551	42%
Overseas Use				
Distillate	1,735,339	10,108,350	807,253	
Jet Fuel	11,483,568	65,111,831	5,140,742	
Residual	2,056,854	12,931,441	1,032,705	
	Total	88,151,622	6,980,700	49%
Military Use				
Avgas	1,546	7,804	589	
Distillate	834,246	4,859,483	388,078	
Gasoline	64,735	340,053	26,416	
Jet Fuel	1,585,532	8,989,966	709,780	
Residual	128,216	806,094	69,349	
	Total	15,003,400	1,194,212	8%
Total Mobile Source Use of Fuel Sold/Distributed in Hawaii				
Avgas	44,824	226,271	17,084	0.1%
Distillate	3,761,987	21,913,574	1,750,018	12%
Gasoline	8,939,954	46,961,577	3,552,951	25%
Jet Fuel	17,141,296	97,191,148	7,673,484	54%
LPG	19,882	79,647	5,464	0.04%
Residual	2,191,859	13,780,217	1,105,463	8%
	Total	180,152,434	14,104,463	100%

(State of Hawaii, 1997)

Figure 5.2 displays mobile source fuel use CO_2 emissions by category in graphic form. Overseas uses produced half of mobile source emissions and military uses accounted for 8%. As a result, as stated above, only 42% of mobile source CO_2 emissions, or 5,929,550 tons, were attributed to Hawaii.

Figure 5.2 Percentages of Mobile Source Fuel Use CO_2 Emissions by Category, 1990



5.2.1.4 Overseas Mobile Source Fuel Use

Overseas aviation and marine fuel uses were not included in the overall Hawaii Greenhouse Gas Emissions Inventory presented in Chapter 2 or the summary of in-state energy sector greenhouse gas emissions in Chapter 3. In the case of jet fuel, available data did not discriminate between fuel used for overseas flights to and from the rest of the United States or foreign destinations nor by nationality of air carrier. In addition, based upon guidance from the Environmental Protection Agency (Sibold, 1995), emissions produced by flights between Hawaii and the rest of the United States were not counted as Hawaii emissions. Marine fuels sold as bunker fuel or exported were not included for similar reasons.

5.2.1.5 Military Mobile Source Fuel Use

As noted in Section 3.2.2, fuel purchased by the armed forces was not included in the accounting of Hawaii energy use due to a lack of data on use in Hawaii. Emissions are reported here as a record of emissions from fuels sold to the military by Hawaii refiners or distributors.

5.2.1.6 Summary of Carbon Dioxide Emissions from In-State Mobile Sources

Table 5.4 In-State Mobile Source Fuel Use and CO_2 Emissions, 1990

Use/Fuel	Barrels	Million Btu	Tons CO_2	Percent CO_2
In-State Aviation Fuel				
Avgas	43,278	218,467	16,495	
Jet Fuel	4,072,196	23,089,351	1,822,962	
	Subtotal	23,307,818	1,839,457	31%
In-State Marine Fuel				
Distillate	322,175	1,876,669	149,871	
Gasoline	3,879	20,376	1,238	
Residual	6,789	42,682	3,409	
	Subtotal	1,939,727	154,517	3%
Highway Vehicle Fuel				
Distillate	462,549	2,694,348	215,170	
Gasoline	8,837,169	46,421,648	3,511,353	
LPG	19,832	79,547	5,457	
	Subtotal	49,195,543	3,731,980	63%
Agricultural Mobile Equipment Fuel				
Distillate	221,976	1,293,010	103,260	
Gasoline	29,166	153,209	11,902	
LPG	25	100	7	
	Subtotal	1,446,319	115,168	2%
Industrial Mobile Equipment Fuel				
Distillate	185,702	1,081,714	86,386	
Gasoline	5,005	26,291	2,042	
	Subtotal	1,108,005	88,428	1%
Total Mobile Source Fuel Use				
Avgas	43,278	218,467	16,495	
Distillate	1,192,402	6,945,741	554,687	
Gasoline	8,875,219	46,621,524	3,526,535	
Jet Fuel	4,072,196	23,089,351	1,822,962	
LPG	19,857	79,647	5,464	
Residual	6,789	42,682	3,409	
	Total	76,997,412	5,929,551	100%

(State of Hawaii, 1997)

Table 5.4 summarizes the estimated 5,929,551 tons of CO_2 emissions produced from in-state mobile sources by category and fuel. Highway vehicles produced

63%, a total of 3,731,980 tons. In-state aviation produced 31%, or 1,839,457 tons. The remaining categories, in-state marine (3%), agricultural mobile sources (2%), and industrial mobile sources (1%), together produced 6% of in-state mobile source emissions, a total of 358,113 tons. Figure 5.3 shows the relative shares of estimated mobile source CO_2 emissions produced by each category.

Figure 5.3 CO_2 Emissions from In-State Mobile Sources by Category, 1990

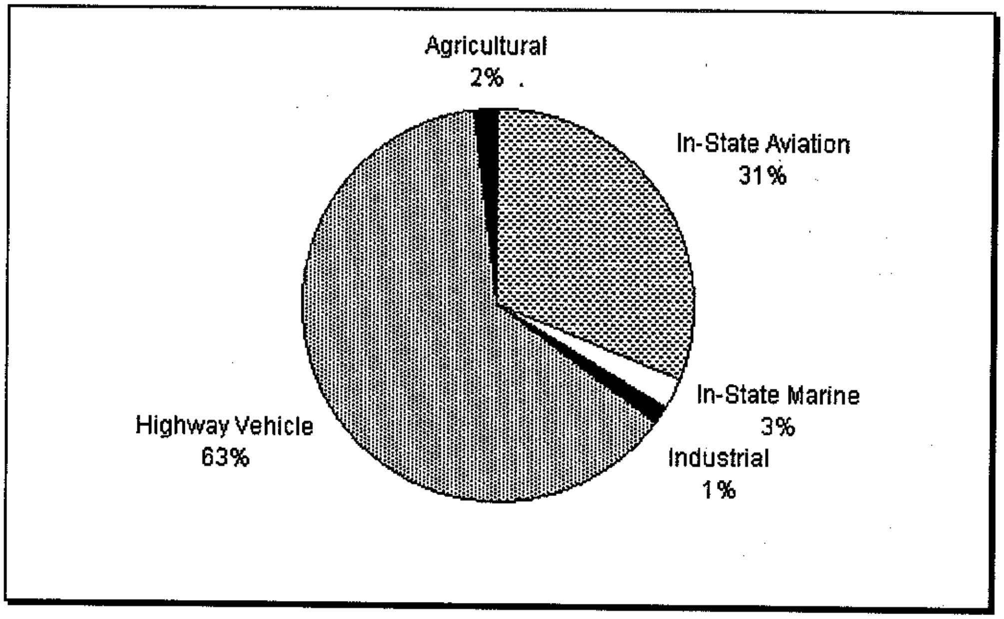


Figure 5.4 CO_2 Emissions from In-State Mobile Sources by Fuel, 1990

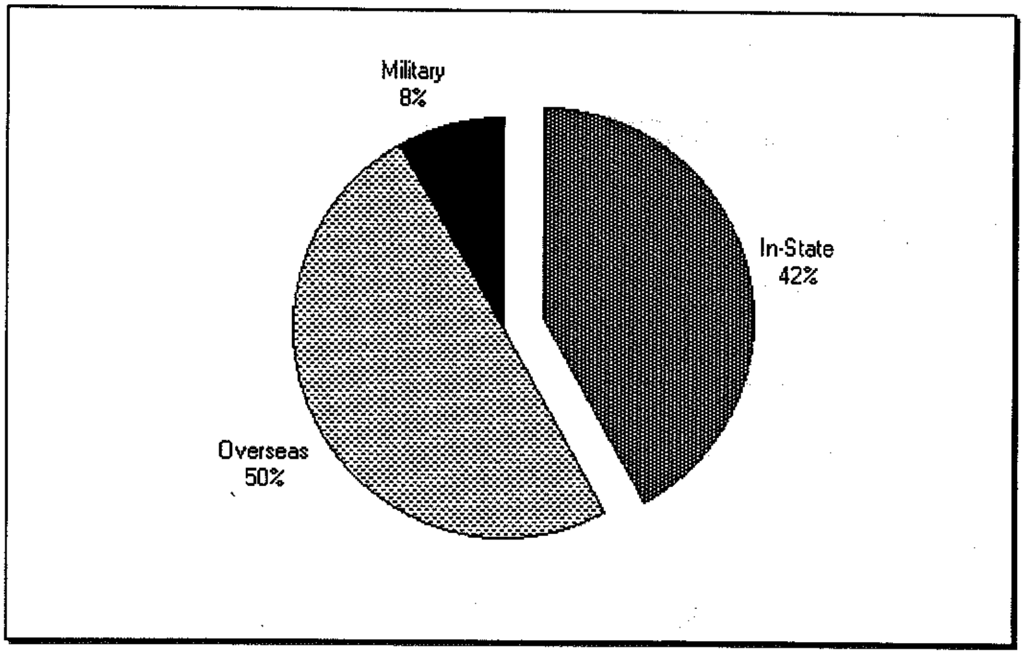


Figure 5.4 summarizes in-state CO_2 emissions from mobile sources by fuel. Gasoline was the primary source of mobile emissions at 59.5%, followed by in-state jet fuel use at 30.7% and distillate at 9.4%. Residual, aviation gasoline, and LPG combined totaled about 0.5%.

5.2.1.7 Non-Carbon-Dioxide Emissions from Mobile Sources

Table 5.5 Transportation Non-CO_2 GHG Emissions (Tons), 1990

Use/Fuel	CH_4	N_2O	NO_x	CO	NMVOC
In-State Aviation Fuel					
Avgas	0.5	0.22	70	29	4
Jet Fuel	50.8	N/A	7,389	3,117	462
Subtotal	51	0.22	7,459	3,146	466
Overseas Aviation Fuel					
Jet Fuel	143	N/A	20,836	8,790	1,302
Military Aviation Fuel					
Avgas	0.02	0.01	3	1	0.2
Jet Fuel	20	N/A	2,877	1,214	180
Subtotal	20	0	2,880	1,215	180
In-State Marine Fuel					
Distillate	N/A	1.88	6,231	94	N/A
Gasoline	N/A	0.02	68	1	N/A
Residual	N/A	0.04	142	2	N/A
Subtotal	N/A	2	6,440	97	N/A
Overseas Marine Fuel					
Distillate	N/A	12	39,790	599	N/A
Residual	N/A	13	43,074	649	N/A
Subtotal	N/A	25	82,864	1,248	N/A
Highway Vehicle Fuel					
Distillate	9	5.39	2,218	1,434	425
Gasoline	702	438.80	10,825	106,207	17,227
LPG	2	N/A	26	70	27
Subtotal	712.57	444.18	13,069	107,711	17,679
Total Transportation Sector Fuel Use and Non-CO_2 GHG Emissions					
Avgas	1	0.2	72	31	5
Distillate	9	19	48,239	2,127	425
Gasoline	702	439	10,893	106,208	17,227
Jet Fuel	214	N/A	31,102	13,121	1,944
LPG	2	N/A	26	70	27
Residual	N/A	13	43,216	651	N/A
Total	927	471	133,547	122,207	19,628

Table 5.5 summarizes the transportation sector mobile source emissions of CH_4, N_20, NO_x, CO, and NMVOCs from transportation sector mobile source fuel use. Non-CO_2 emissions varied significantly with use. Highway vehicles produced the largest quantities of these gases other than NO_x, which was primarily produced by

overseas marine uses. In-state marine fuel use created the most of the NO_x emissions.

Table 5.6 shows non-transportation mobile source non-CO_2 emissions produced by agricultural mobile equipment, industrial mobile equipment, and non-aviation military fuel use.

Table 5.6 Non-Transportation Mobile Source Non-CO_2 Emissions, 1990 (Tons)

Use/Fuel	CH_4	N_2O	NO_x	CO	NMVOC
Agricultural Mobile Equipment Fuel					
Distillate	2.84	329.72	15.52	860	2,140
Gasoline	0.34	39.07	1.84	102	254
LPG	0.0002	0.03	0.001	0.1	0.2
Subtotal	3	369	17	962	2,394
Industrial Mobile Equipment Fuel					
Distillate	4.9	2	1,433.0	454	108
Gasoline	0.1	0	35.0	11	3
Subtotal	5	2	1,468	465	111
Total Industrial Mobile Source Fuel Use and Non-CO_2 GHG Emissions					
Distillate	8	332	1,449	1,314	2,248
Gasoline	0.5	39	37	113	257
LPG	0.0002	0.03	0.001	0.1	0.2
Total	8	371	1,485	1,427	2,505
Non-Aviation Military Fuel					
Distillate	22	11	6,439	2,041	486
Gasoline	2	1	451	143	34
Residual	N/A	1	2,676	40	N/A
Total	24	13	9,566	2,224	520

5.2.1.8 Summary of Non-CO_2 Emissions from Mobile Sources

Table 5.7 summarizes estimated non-CO_2 greenhouse gas emissions from in-state mobile source use by fuel. The largest shares of these emissions come from the use of gasoline.

The values for in-state use are included in the Hawaii inventory for the reasons explained above. The following summarizes the relative contribution of mobile source in-state fuel use to the emissions of each type of non-CO_2 greenhouse and precursor gas. Gasoline use creates the largest quantities emitted.

- **Methane.** Gasoline use dominates in-state CH_4 emissions (91%), followed by in-state jet fuel use (6.5%). Distillate, LPG, and aviation gasoline each contribute less than one percent.

- **Nitrous Oxide.** Gasoline use creates most of the N_2O emissions, 58% of the total, followed by distillate at 41.4%. Aviation gasoline, LPG, and residual fuel oil produce only minor amounts of N_2O.

Table 5.7 Total Mobile Source Non-CO_2 Emissions by Fuel, 1990 (Tons)

Fuel	CH_4	N_2O	NO_x	CO	NMVOC
In-State Use					
Avgas	0.48	0.22	70	29	4
Distillate	16	339	9,897	2,842	2,673
Gasoline	703	478	10,930	106,321	17,484
Jet Fuel	50.80	N/A	7,389	3,117	462
LPG	2	0.03	26	70	27
Residual	N/A	0.04	142	2	N/A
Total	772	818	28,453	112,381	20,650
Overseas Use					
Distillate	N/A	12	39,790	599	N/A
Jet Fuel	143	N/A	20,836	8,790	1,302
Residual	N/A	13	43,074	649	N/A
Total	143	25	103,700	10,038	1,302
Military Use					
Avgas	0.02	0.01	3	1	0.2
Distillate	22	11	6,439	2,041	486
Gasoline	2	1	451	143	34
Jet Fuel	20	N/A	2,877	1,214	180
Residual	N/A	1	2,676	40	N/A
Total	44	13	12,446	3,439	700
Total Mobile Source Use of Fuel Sold/Distributed in Hawaii					
Avgas	1	0.2	72	31	5
Distillate	N/A	362	56,126	5,482	N/A
Gasoline	705	479	11,381	106,464	17,518
Jet Fuel	214	N/A	31,102	13,121	1,944
LPG	2	0.03	26	70	27
Residual	N/A	14	45,892	691	N/A
Total	921	856	144,598	125,858	19,493

- **Oxides of Nitrogen.** All uses create NO_x emissions with gasoline (38.4%), diesel (34.7%), and jet fuel (25.9%) dominating the in-state emissions.

- **Carbon Monoxide.** Gasoline use creates most of the in-state carbon dioxide emissions (94.6%). In-state jet fuel use emissions (2.7%) and diesel use emissions (2.5%) are also significant.

- **Non-Methane Volatile Organic Compounds.** Gasoline use creates 84.6% of the NMVOCs with most of the remainder produced by distillate uses.

5.3 Emissions from Aviation Fuel Use

Table 5.8 summarizes reported aviation fuel sales and distribution in Hawaii in 1990 by category of use. Only 24% of the jet fuel (4,072,196 barrels), but 97% of aviation gasoline (43,278 barrels) was used for in-state flights. Together, they represented 24% of the total heat value of aviation fuels sold or distributed in Hawaii.

Table 5.8 Aviation Fuel Sold or Distributed in Hawaii, 1990

Fuel	In-State	Overseas	Military	Total
Jet Fuel				
Barrels	4,072,196	11,483,568	1,585,532	17,141,296
Btu	23,089,351	65,111,831	8,989,966	97,191,148
Percent	24%	67%	9%	100%
Aviation Gasoline				
Barrels	43,278	0	1,546	44,824
Btu	218,467	0	7,804	226,272
Percent	97%	0%	3%	100%

(State of Hawaii, 1997)

The emission factors from the *State Workbook* (USEPA, 1995b, D1-5 and D13-16) as reproduced in Table 5.9, were used to calculate greenhouse gas emissions from aviation fuels.

Table 5.9 Jet Fuel and Aviation Gasoline Emissions Factors (Lbs./Million Btu)

Fuel	C	CH_4	N_20
Jet Fuel	43.5	0.0044	N/A
Avgas	41.6	0.133	0.002
Fuel	**NO_x**	**CO**	**NMVOC**
Jet Fuel	0.64	0.27	0.04
Avgas	0.18	53.03	1.19

(USEPA, 1995b, D1-5 and D13-16)

Figure 5.5 depicts in-state use of jet fuel which represented 24% of total CO_2 emissions from aviation fuel sold or distributed in Hawaii. Overseas commercial aviation use produced 67%, while military use was 9%.

Figure 5.5 Percentages of Aviation Fuel CO_2 Emissions by Activity, 1990

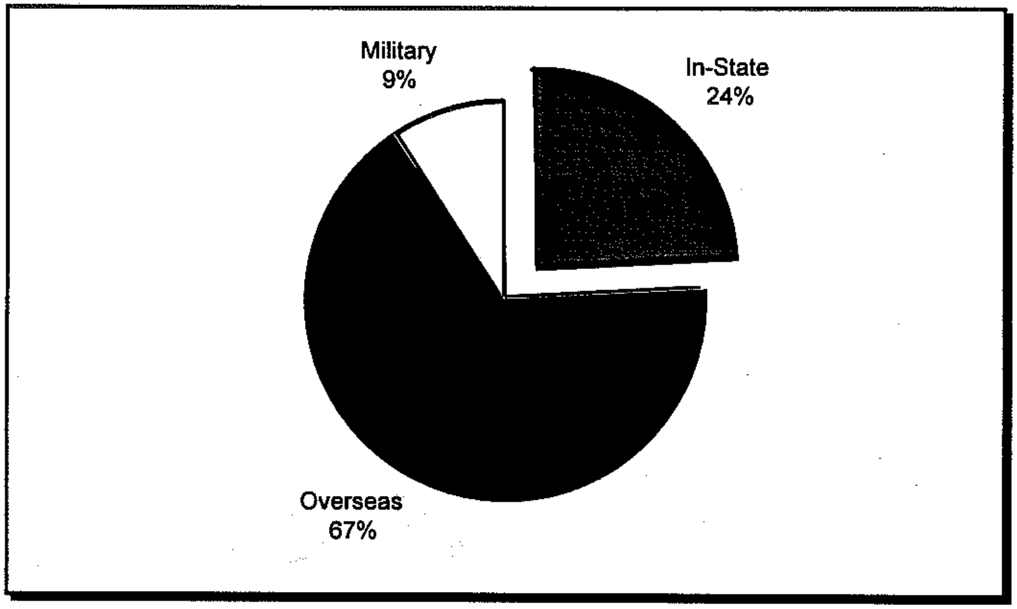


Table 5.10 summarizes calculated greenhouse gas emissions for jet fuel and aviation gasoline by use. In-state use of jet fuel produced 1,822,962 tons of CO_2, 51 tons of CH_4, 7,389 tons of NO_x, 3,117 tons of CO, and 462 tons of NMVOC.

Table 5.10 Emissions from Aviation Fuels Sold or Distributed in Hawaii, 1990 (Tons)

Fuel	In-State	Overseas	Military	Total
Jet Fuel				
CO_2	1,822,962	5,140,742	709,780	7,673,484
CH_4	51	143	20	214
N_20	N/A	N/A	N/A	N/A
NO_x	7,389	20,836	2,877	31,101
CO	3,117	8,790	1,214	13,121
NMVOC	462	1,302	180	1,944
Aviation Gasoline				
CO_2	16,495	N/A	589	17,084
CH_4	0.48	N/A	0.02	0.50
N_20	0.22	N/A	0.01	0.23
NO_x	69.9	N/A	2.5	72.4
CO	29.5	N/A	1.1	30.5
NMVOC	4.37	N/A	0.16	4.53
Aviation Fuels Total				
CO_2	1,839,457	5,140,742	710,370	7,690,569
CH_4	51	143	20	214
N_20	0.22	N/A	0.01	0.23
NO_x	7,459	20,836	2,879	31,174
CO	3,147	8,790	1,215	13,151
NMVOC	466	1,302	180	1,948

5.4 Emissions from Marine Fuel Use

Ships and boats operating in Hawaiian waters used distillate fuel, motor gasoline, and residual fuel oil. Some fuel was used in-state, some was used for overseas bunkers or was exported, and some was sold to the military. As with the aviation fuel discussed in the previous section, only marine fuel used in-state were included in the overall Hawaii Greenhouse Gas Inventory. Some portion of military purchases of 834,246 barrels of diesel fuel, 64,735 barrels of motor gasoline, and 128,216 barrels of residual fuel oil in 1990 may have been used for ships or boats, but data were not available to determine actual use. Emissions from military uses of these fuels are estimated in Section 5.6.3 as non-aviation military fuel uses.

Table 5.11 depicts marine use of distillate fuels, motor gasoline, and residual fuel oil by category. In-state marine use of distillate fuel of 322,175 barrels accounted for 16% of the total. All reported marine motor gasoline use (3,879 barrels) occurred in-state, but only three-tenths of one percent of marine use of residual fuel oil (6,798 barrels) was used by ships in-state.

Table 5.11 Marine Fuel Sold or Distributed in Hawaii, 1990

Fuel	In-State	Overseas	Total
Distillate			
Barrels	322,175	1,735,339	2,057,514
Btu	1,876,669	10,108,350	11,985,019
Percent	16%	84%	100%
Motor Gasoline			
Barrels	3,879	0	3,879
Btu	20,376	0	20,376
Percent	100%	0%	100%
Residual Fuel Oil			
Barrels	6,789	2,056,854	2,063,643
Btu	42,682	12,931,441	12,974,124
Percent	0.3%	99.7%	100%

(State of Hawaii, 1997)

Table 5.12 displays the emission factors from the *State Workbook* (USEPA, 1995b, D1-5, D13-16) used to calculate emissions from marine fuels.

Table 5.12 Marine Fuel Emissions Factors (Lbs./ Million Btu)

Fuel	C	CH_4	N_20
Distillate	44	N/A	0.002
Gasoline	42.8	0.011	0.0044
Residual	47.4	N/A	0.002
Fuel	**NO_x**	**CO**	**NMVOC**
Distillate	6.64	0.1	N/A
Gasoline	3.54	1.1	0.24
Residual	6.64	0.1	N/A

(USEPA, 1995b, D1-5 and D13-16)

As Figure 5.6 shows, only 8% of total CO_2 emissions were from marine fuel use by ships and boats operating in state waters. A total of 154,517 tons of CO_2 was emitted from in-state marine fuel use out of a total of 1,994,475 tons from all marine fuel sold, distributed, or refined in Hawaii. Of these fuel uses, the greatest amount of CO_2 emissions, 149,871 tons, was produced by using distillate fuel.

Residual marine fuel use emitted 3,409 tons, and motor gasoline use on boats emitted 1,238 tons.

Figure 5.6 Percent of Marine Fuel CO_2 Emissions by Activity, 1990

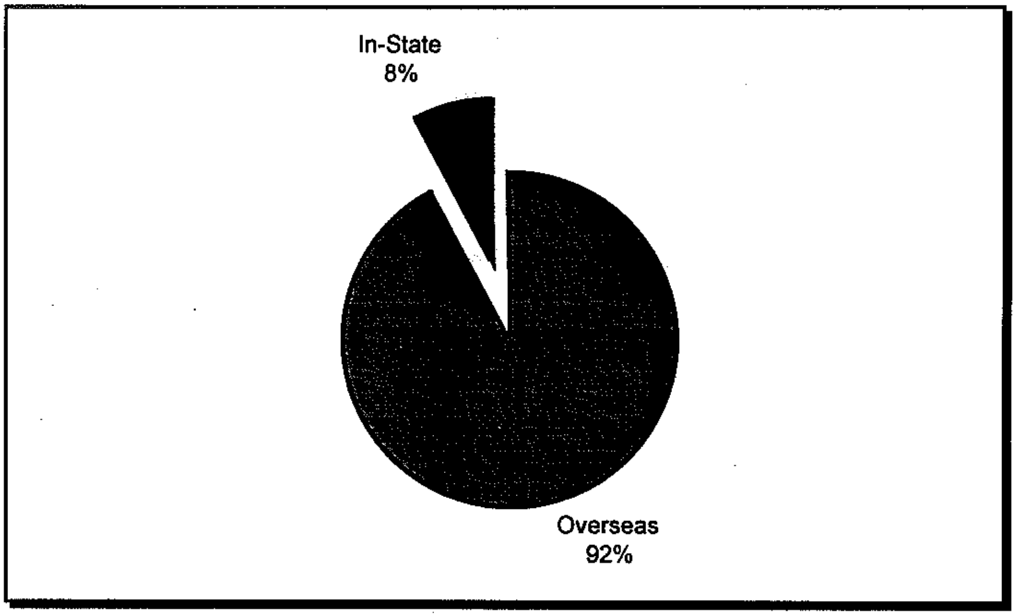


Table 5.13 Marine Fuel Emissions, 1990 (Tons)

Fuel	In-State	Overseas	% In-State	Total
Distillate Fuel				
CO_2	149,871	807,253	16%	957,124
N_2O	2	10	16%	12
NO_x	6,231	33,560	16%	39,790
CO	94	505	16%	599
Motor Gasoline				
CO_2	1,238	N/A	100%	1,238
N_2O	0.02	N/A	100%	0.02
NO_x	68	N/A	100%	68
CO	1	N/A	100%	1
Residual Fuel Oil				
CO_2	3,409	1,032,705	0.3%	1,036,114
N_2O	0.04	13	0.3%	13
NO_x	142	42,932	0.3%	43,074
CO	2	647	0.3%	649
Marine Fuels Total				
CO_2	154,517	1,839,958	8%	1,994,475
N_2O	2	23	8%	25
NO_x	6,440	76,492	8%	82,932
CO	97	1,152	8%	1,249

Table 5.13, on the previous page, summarizes greenhouse gas emissions from marine fuels used in-state and overseas. In-state distillate fuel use represents 16% of marine uses of fuel sold or distributed in-state. It also accounts for the largest emissions of greenhouse and precursor gases from in-state marine uses. Almost 97% of CO_2, over 99% of N_2O, 97% of NO_x, and 97% of CO in the in-state marine category come from diesel combustion. Based upon EPA formulas, no CH_4 or NMVOC emissions were calculated for marine uses.

5.5 Emissions from Highway Vehicle Fuel Use

Highway vehicles include passenger cars, trucks, buses, and motorcycles using diesel, gasoline, or propane as fuel. The methodology described in Chapter 13 of the *State Workbook* (USEPA, 1995b, D13) was applied.

5.5.1 Calculation of Emissions from Highway Diesel and Gasoline Use

Table 5.14 Estimated Vehicle Miles Traveled on Hawaii's Roads, 1990

Type of Road		Annual VMT	Percent
Rural			
Interstate		101,835,000	1%
Other Principal Arterial		96,360,000	1%
Minor Arterial		1,213,625,000	15%
Major Collector		612,835,000	8%
Minor Collector		131,765,000	2%
Local		653,350,000	8%
Urban			
Interstate		1,399,045,000	17%
Other Freeway & Expressway		797,525,000	10%
Other Principal Arterial		885,490,000	11%
Minor Arterial		640,940,000	8%
Collector		479,245,000	6%
Local		1,051,565,000	13%
	Total	8,063,580,000	100%

(State of Hawaii, 1996a)

Table 5.14 shows the estimated vehicle miles traveled on Hawaii's roads in 1990. To calculate these values, first, the State of Hawaii Department of Transportation estimate of daily vehicle miles traveled (VMT) in 1990 by type of roadway (State of Hawaii, 1996a) was converted to an estimate of annual vehicle miles traveled. Daily vehicle miles traveled were multiplied by 365. Based upon this calculation, Hawaii's vehicles traveled 8.063 billion miles in 1990. Given the concentration of population on Oahu, most of this travel (65%) was on urban roadways.

Next, the estimate of the percentage of roadway use by vehicle class, as presented in Table 5.15, was obtained.

Table 5.15 Travel Activity by Roadway Type and Vehicle Class in Hawaii, 1990

Roadway Type	Passenger Cars	Light Trucks	Heavy Vehicles	Motor-cycles
Rural				
Interstate	77.8%	16.3%	5.5%	0.4%
Other Principal Arterial	81.8%	10.2%	7.5%	0.5%
Minor Arterial	86.7%	9.3%	3.6%	0.4%
Major Collector	82.1%	12.1%	5.2%	0.6%
Minor Collector	79.8%	12.5%	7.0%	0.6%
Local	78.2%	18.3%	3.3%	0.2%
Urban				
Interstate	87.0%	10.7%	2.1%	0.2%
Other Freeway	81.0%	15.4%	3.3%	0.4%
Other Principal Arterial	81.0%	12.8%	5.6%	0.6%
Minor Arterial	83.6%	10.5%	5.4%	0.4%
Collector	88.9%	7.5%	3.0%	0.6%
Local	86.6%	11.2%	1.9%	0.3%

(State of Hawaii, 1996a)

Table 5.16, on the following page, displays total annual VMT by vehicle. This value represents the result of multiplying estimated VMT by roadway type (Table 5.14) by the estimated percentage of roadway use by vehicle class (Table 5.15) to produce an estimate of total annual VMT by vehicle.

Registration data for all four counties were obtained from the City and County of Honolulu's Department of Data Services (C&C, 1996). The numbers of vehicles conforming to each of the EPA's seven vehicle types were compared with the vehicle miles traveled by roadway type and class of vehicle data on Table 5.16 to determine VMT by vehicle type and installed emission control technology. A total of 889,426 vehicles was registered in 1990.

Table 5.16 Vehicle Miles Traveled in Hawaii by Roadway Type and Vehicle Class, 1990

Roadway Type	Passenger Cars	Light Trucks	Heavy Vehicles	Motor-cycles	Total VMT
Rural					
Interstate	79,217,447	16,629,757	5,600,925	386,871	101,835,000
Other Principal Arterial	78,861,217	9,790,176	7,188,167	520,440	96,360,000
Minor Arterial	1,051,664,317	112,895,038	44,077,646	4,987,999	1,213,625,000
Major Collector	503,443,340	74,172,646	31,589,193	3,629,822	612,835,000
Minor Collector	105,160,711	16,497,242	9,280,354	826,694	131,765,000
Local	510,905,980	119,549,983	21,324,691	1,569,347	653,350,000
Subtotal	2,329,253,010	349,534,842	119,060,976	11,921,172	2,809,770,000
Urban					
Interstate	1,216,469,628	149,697,815	29,939,563	2,937,995	1,399,045,000
Other Freeway	645,920,283	122,517,386	26,028,026	3,059,306	797,525,000
Other Principal Arterial	716,973,461	113,435,696	49,363,234	5,717,609	885,490,000
Minor Arterial	535,991,843	67,379,458	34,749,844	2,818,854	640,940,000
Collector	426,199,288	35,891,617	14,296,837	2,857,259	479,245,000
Local	910,183,137	118,180,133	20,308,875	2,892,855	1,051,565,000
Subtotal	4,451,737,640	607,102,105	174,686,378	20,283,877	5,253,810,000
Total	6,780,990,650	956,636,946	293,747,354	32,205,050	8,063,580,000

(State of Hawaii, 1996a)

The seven EPA vehicle types were defined as follows:

Light Duty Gasoline Passenger Cars (LDGV). A passenger car is any gasoline-powered vehicle with a rated gross vehicle weight of less than 8,500 pounds, designed primarily to carry 12 or fewer passengers, and not possessing special features such as four-wheel drive for off-road operation. There were 807,624 light duty passenger cars registered in Hawaii in 1990, representing 90.8% of all registered vehicles.

Light Duty Diesel Passenger Cars (LDDV). This is a passenger car as described for LDGV above, but powered by a diesel engine. The 3,075 light duty diesel passenger cars registered in Hawaii in 1990 were but 0.3% of all registered vehicles.

Light Duty Gasoline Trucks (LDGT). An LDGT is a vehicle having gross vehicle weight less than 8,500 pounds, designed primarily for transportation of cargo or more than 11 passengers, or which are equipped with special features for off-road operation. In 1990, 49,488 light duty gasoline trucks were registered in Hawaii, 5.5% of all vehicles.

Light Duty Diesel Trucks (LDDT). A light truck is as described for LDDT, but powered by a diesel engine. Only 1,199 light diesel trucks were registered in 1990; one-tenth of one percent of all vehicles.

Heavy Duty Gasoline Vehicles (HDGV). A heavy duty vehicle has a gross vehicle rating greater than 8,500 pounds. This includes large pickups, large vans, heavy trucks, and buses. The 8,378 heavy duty gasoline vehicles were 0.9 of the total.

Heavy Duty Diesel Vehicles (HDDV). These fit the same criteria as HDGV, but are diesel engine powered. There were 15,266 registered heavy duty diesel vehicles, or 1.7% of all registered vehicles.

Motorcycles (MCYC). Motorcycles include all registered two-wheel and three-wheel powered vehicles. There were 12,754 in 1990, or 1.4% of registered vehicles. (USEPA, 1995b, D13-6 through D13-11)

The fuel economy values cited from the *OECD Estimation of Greenhouse Gas Emissions & Sinks* (August 1991) by the Wisconsin Department of Natural Resources greenhouse gas inventory (State of Wisconsin, 1993, Table D-2) were used in calculating the amount of fuel used by each vehicle type/emission control technology pair. Where registration data were not sufficient to identify emission controls (identified on the tables as "No Data"), those vehicles' emissions were considered to be uncontrolled.

Table 5.17.a Automobile Gasoline and Diesel Use in Hawaii, 1990

LDGV Control Technology	Registrations	Fraction of Automobile Registrations	VMT by Vehicle Type	Fuel Economy (miles/gal)	Barrels Used
Uncontrolled and Non-catalyst Controls (<1975)	67,832	0.084	567,372,252	20.92	645,739
Oxidation Catalyst (1975-1980)	146,736	0.181	1,227,354,858	20.92	1,396,880
Early Three-Way Catalyst (1981-1988)	408,602	0.504	3,417,700,153	22.11	3,680,408
Three-Way Catalyst (1988>)	160,057	0.197	1,338,776,691	27.99	1,138,822
No Data [1]	24,397	0.030	204,065,645	20.92	232,252
Subtotal	807,624	0.996	6,755,269,598		7,094,101
LDDV Control Technology	**Registrations**	**Fraction of Automobile Registrations**	**VMT by Vehicle Type**	**Fuel Economy (miles/gal)**	**Barrels Used**
Uncontrolled (<1982)	1,621	0.002	13,558,651	20.92	15,431
Moderate Controls (1982-1984)	964	0.001	8,063,257	20.92	9,177
Advanced Controls (1985-1990)	479	0.001	4,006,535	24.93	3,826
No Data [1]	11	0.000	92,008	20.92	105
Subtotal	3,075	0.004	25,720,452		28,540
LDV Total	810,699	1.000	6,780,990,050		

Table 5.17.b Light Truck Gasoline and Diesel Use in Hawaii, 1990

LDGT Control Technology	Registrations	Fraction of Light Truck Registrations	VMT by Vehicle Type	Fuel Economy (miles/gal)	Barrels Used
Uncontrolled and Non-catalyst Controls (<1975)					
	5,053	0.100	95,367,382	14.09	161,153
Oxidation Catalyst (1975-1980)					
	10,101	0.199	190,640,397	14.09	322,147
Early Three-Way Catalyst (1981-1988)					
	24,280	0.479	458,246,593	16.28	670,186
Three-Way Catalyst (1988>)					
	9,364	0.185	176,730,688	22.11	190,315
No Data[1]					
	690	0.014	13,022,659	14.09	22,006
Subtotal	49,488	0.976	934,007,718		1,365,808
LDDT Control Technology	**Registrations**	**Fraction of Light Truck Registrations**	**VMT by Vehicle Type**	**Fuel Economy (miles/gal)**	**Barrels Used**
Uncontrolled (<1982)					
	181	0.004	3,416,089	14.09	5,773
Moderate Controls (1982-1984)					
	287	0.006	5,416,671	14.09	9,153
Advanced Controls (1985-1990)					
	721	0.014	13,607,734	18.11	17,890
No Data[1]					
	10	0.000	188,734	14.09	319
Subtotal	1,199	0.024	22,629,228		33,135
LDT Total	50,687	1.000	956,636,946		

Table 5.17.c Heavy Vehicle Gasoline and Diesel Use in Hawaii, 1990

HDGV Control Technology	Registrations	Fraction of Heavy Truck Registrations	VMT by Vehicle Type	Fuel Economy (miles/gal)	Barrels Used
Uncontrolled (<1979)					
	4,236	0.277	81,402,185	10.62	182,500
Non-catalyst Controls (1981-1989)					
	3,299	0.216	63,396,083	10.62	142,131
Three-Way Catalyst (1989>)					
	400	0.026	7,686,703	10.62	17,233
No Data[1]					
	443	0.029	8,513,024	10.62	19,086
Subtotal	8,378	0.548	160,997,994		360,950
HDDV Control Technology	**Registrations**	**Fraction of Heavy Truck Registrations**	**VMT by Vehicle Type**	**Fuel Economy (miles/gal)**	**Barrels Used**
Uncontrolled (<1982)					
	3,372	0.221	64,798,906	6.89	223,923
Moderate Controls (1982-1984)					
	855	0.056	16,430,328	7.25	53,958
Advanced Controls (1985-1990)					
	2,360	0.154	45,351,548	10.62	101,676
No Data[1]					
	321	0.021	6,168,579	6.89	21,317
Subtotal	6,908	0.452	132,749,360		400,874
HDV Total	15,286	1.000	293,747,354		

Table 5.17.d Motorcycle Gasoline Use in Hawaii, 1990

MCYC Control Technology	Registrations	Fraction of Motorcycle Registrations	VMT by Vehicle Type	Fuel Economy (miles/gal)	Barrels Used
Uncontrolled (<1978)	1,074	0.084	2,711,951	30.11	2,144
Non-catalyst Controls (1978-1990)	11,528	0.904	29,109,284	50.00	13,862
No Data [1]	152	0.012	383,814	30.11	304
MCYC Total	12,754	1.000	32,205,050		16,310

Table 5.17.e Summary of Estimated Gasoline and Diesel Use in Hawaii, 1990

Registrations	VMT	Fuel	Barrels
889,426	8,063,579,400	Gasoline	8,837,169
		Diesel	462,549

[1] Where emission control data was not available, the value for a vehicle with uncontrolled emissions was used.

Sources: Registrations: (C&C, 1996); Fuel Economy (USDOT,1991, Table VM-1)

Fuel Economy Values: *OECD Estimation of Greenhouse Gas Emissions & Sinks* (August 1991 Revision)

Methodology, p.2-66 and Emissions Factors, Tables 2-19 through 2-30, from State of Wisconsin, 1993, Table D-2

Table 5.17.e provides total fuel use. Gasoline use in highway vehicles was estimated to be 8,837,169 barrels. Diesel use in highway vehicles was estimated at 462,549 barrels.

With the quantities of 1990 highway gasoline and diesel fuel use estimated as presented in the preceding tables (Tables 5.17.a through e), fuel use was then multiplied by the *State Workbook* greenhouse and precursor gas emission factors for each vehicle class (USEPA, 1995b, D13-7 – D13-12). The greenhouse gas emissions factors for highway gasoline and diesel fuel use by vehicle type and emission control technology are presented in Tables 5.18.a through g. Some portion of military purchases of 834,246 barrels of diesel fuel and 64,735 barrels of motor gasoline in 1990 may have been used for highway vehicles or off-road vehicles. Military uses and emissions are discussed in section 5.5.3.1.

Table 5.18.a Gasoline Automobile Emissions Factors (Lbs./Million Btu)

Technology	C	CH_4	N_2O	CO	NO_x	NMVOC
Uncontrolled and Non-catalyst Controls (<1975) [1]	42.8	0.069	0.002	16.198	0.862	2.519
Oxidation Catalyst (1975-1980)	42.8	0.036	0.011	5.171	0.641	0.707
Early Three-Way Catalyst (1981-1988)	42.8	0.025	0.029	1.945	0.331	0.420
Three-Way Catalyst (1988>)	42.8	0.016	0.015	2.467	0.398	0.530

Table 5.18.b Diesel Automobile Emissions Factors (Lbs./Million Btu)

Technology	C	CH_4	N_2O	CO	NO_x	NMVOC
Uncontrolled (<1982)	44.0	0.002	0.004	0.331	0.309	0.161
Moderate Controls (1982-1984)	44.0	0.004	0.004	0.354	0.376	0.119
Advanced Controls (1985-1990)	44.0	0.007	0.004	0.552	0.420	0.186

Table 5.18.c Gasoline Light Truck Emissions Factors (Lbs./Million Btu)

Technology	C	CH_4	N_2O	CO	NO_x	NMVOC
Uncontrolled and Non-catalyst Controls (<1975)	42.8	0.059	0.002	15.225	0.906	2.917
Oxidation Catalyst (1975-1980)	42.8	0.031	0.011	4.154	0.552	0.663
Early Three-Way Catalyst (1981-1988)	42.8	0.032	0.029	4.199	0.464	0.530
Three-Way Catalyst (1988>)	42.8	0.025	0.015	2.939	0.420	0.464

Table 5.18.d Diesel Light Truck Emissions Factors (Lbs./Million Btu)

Technology	C	CH_4	N_2O	CO	NO_x	NMVOC
Uncontrolled (<1982)	44.0	0.000	0.004	0.420	0.376	0.221
Moderate Controls (1982-1984)	44.0	0.003	0.004	0.309	0.331	0.133
Advanced Controls (1985-1990)	44.0	0.005	0.004	0.464	0.354	0.199

Table 5.18.e Gasoline Heavy Vehicle Emissions Factors (Lbs./Million Btu)

Technology	C	CH_4	N_2O	CO	NO_x	NMVOC
Uncontrolled (<1979)	42.8	0.044	0.001	19.579	0.773	2.475
Non-catalyst Controls (1981-1989)	42.8	0.022	0.001	7.602	0.641	0.398
Three-Way Catalyst (1989>)	42.8	0.022	0.001	1.613	0.508	0.309

Table 5.18.f Diesel Heavy Vehicle Emissions Factors (Lbs./Million Btu)

Technology	C	CH_4	N_2O	CO	NO_x	NMVOC
Uncontrolled (<1982)	44.0	0.002	0.004	1.127	2.232	0.398
Moderate Controls (1982-1984)	44.0	0.022	0.004	1.392	1.989	0.287
Advanced Controls (1985-1990)	44.0	0.011	0.004	1.149	0.840	0.221

Table 5.18.g Gasoline Motorcycle Emissions Factors (Lbs./Million Btu)

Technology	C	CH_4	N_2O	CO	NO_x	NMVOC
Uncontrolled (<1978)	42.8	0.287	0.002	20.33	0.155	5.524
Non-catalyst Controls (1978-1990)	42.8	0.155	0.002	13.038	0.53	2.143

(USEPA, 1995b, D13-7 – D13-12)

Second Edition, 1995, pp. D13-7 through D-13-12.

Emissions from highway gasoline and diesel fuel use in Hawaii for 1990 were then calculated and are summarized by vehicle type in Tables 5.19.a through g.

Table 5.19.a Emissions from Gasoline Automobiles in Hawaii, 1990 (Tons)

Control	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Uncontrolled and Non-catalyst Controls (<1975)	263,503	117	3	1,462	27,472	4,272
Oxidation Catalyst (1975-1980)	570,016	132	40	2,352	18,972	2,594
Early Three-Way Catalyst (1981-1988)	1,501,840	242	280	3,200	18,802	4,060
Three-Way Catalyst (1988>)	464,712	48	45	1,190	7,379	1,585
No Data[1]	94,773	42	1	526	9,881	1,537
LDDG Total	2,800,071	539	369	8,204	72,625	12,511

[1] Values for uncontrolled emissions used

Table 5.19.b Emissions from Diesel Automobiles in Hawaii, 1990 (Tons)

Control	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Uncontrolled (<1982)	7,178	0.09	0.180	13.89	14.9	7.24
Moderate Controls (1982-1984)	4,269	0.11	0.107	10.05	9.5	3.18
Advanced Controls (1985-1990)	1,780	0.08	0.045	4.68	6.2	2.07
No Data[1]	49	0.00	0.001	0.09	0.1	0.05
LDDV Total	13,276	0.3	0.3	29	31	13

[1] Values for uncontrolled emissions used

Table 5.19.c Emissions from Light Gasoline Trucks in Hawaii, 1990 (Tons)

Control	$C0_2$	CH_4	N_2O	NO_x	CO	NMVOC
Uncontrolled and Non-catalyst Controls (<1975)	65,761	25	0.8	383	6,444	1,235
Oxidation Catalyst (1975-1980)	131,457	26	9.3	467	3,515	561
Early Three-Way Catalyst (1981-1988)	273,479	56	51.0	817	7,391	933
Three-Way Catalyst (1988>)	77,661	12	7.5	210	1,469	232
No Data[1]	8,980	3	0.1	52	880	169
LDGT Total	557,337	123	69	1,930	19,699	3,129

[1] Values for uncontrolled emissions used

Table 5.19.d Emissions from Light Diesel Trucks in Hawaii, 1990 (Tons)

Control	$C0_2$	CH_4	N_2O	NO_x	CO	NMVOC
Uncontrolled (<1982)	2,685	-	0.067	6.3	7.1	3.7
Moderate Controls (1982-1984)	4,258	0.08	0.107	8.8	8.2	3.5
Advanced Controls (1985-1990)	8,322	0.26	0.208	18.4	24.2	10.4
No Data[1]	148	-	0.004	0.3	0.4	0.2
LDDT Total	15,414	0.3	0.4	34	40	18

[1] Values for uncontrolled emissions used

Table 5.19.e Emissions from Heavy Gasoline Vehicles in Hawaii, 1990 (Tons)

Control	$C0_2$	CH_4	N_2O	NO_x	CO	NMVOC
Uncontrolled (<1979)	74,471	21	0.48	371	9,385	1,186
Non-catalyst Controls (1981-1989)	57,998	8	0.37	239	2,838	149
Three-Way Catalyst (1989>)	7,032	1	0.05	23	73	14
No Data[1]	7,788	2	0.05	39	981	124
HDGV Total	147,290	33	1	672	13,277	1,473

[1] Values for uncontrolled emissions used

Table 5.19.f Emissions from Heavy Diesel Vehicles in Hawaii, 1990 (Tons)

Control	$C0_2$	CH_4	N_2O	NO_x	CO	NMVOC
Uncontrolled(<1982)	104,166	1.3	2.6	1,456	735	260
Moderate Controls (1982-1984)	25,101	3.5	0.6	313	219	45
Advanced Controls (1985-1990)	47,298	3.3	1.2	249	340	65
No Data[1]	9,916	0.1	0.2	138.57	70	25
HDDV Total	186,480	8	5	2,156	1,364	395

[1] Values for uncontrolled emissions used

Table 5.19.g Emissions from Motorcycles in Hawaii, 1990 (Tons)

Control	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Uncontrolled (<1978)	875	1.6	0.01	0.9	115	31
Non-catalyst Controls (1978-1990)	5,656	5.6	0.07	19.3	475	78
No Data[1]	124	0.2	0.00	0.1	16	4
MCYC Total	6,655	7	0.09	20	605	114

[1] Values for uncontrolled emissions used

Table 5.20 lists total highway gasoline and diesel vehicle greenhouse gas emissions and the overall total for highway vehicle emissions.

Table 5.20 Total Highway Gasoline and Diesel Vehicle Emissions in Hawaii, 1990 (Tons)

Fuel	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Gasoline	3,511,353	702	439	10,825	106,207	17,227
Diesel	215,170	9	5	2,218	1,434	425
Total	3,726,523	711	444	13,044	107,641	17,652

5.5.2 *Calculation of Emissions from Highway LPG Use*

There were numerous propane vehicles on Hawaii's highways in 1990, including school buses, Handi-Van vehicles, cars, trucks (State of Hawaii, 1995a). Available motor vehicle registration data reported all vehicles as either gasoline or diesel fueled and did not provide numbers, types, or vintage necessary to determine emission control technologies of LPG vehicles. However, State of Hawaii Department of Taxation data indicated that 834,000 gallons, or 19,857 barrels of LPG were taxed for highway use in 1990 (State of Hawaii, 1995b, Table 17.17, 425). This value, with a heat value of 79,500 million Btu, was used as a basis for estimated emissions from highway use of LPG.

The *State Workbook* (USEPA, 1995b, D13-14) provided the greenhouse and precursor gas emission factors displayed on Table 5.21 for passenger cars and heavy duty vehicles with advanced emission controls and uncontrolled emissions.

Table 5.21 Emissions Factors for Highway LPG Use

Technology	C	CH_4	N_2O	NO_x	CO	NMVOC
Passenger Car - Advanced Control	37.8	0.022	N/A	0.42	0.243	0.021
Passenger Car - Uncontrolled	37.8	0.066	N/A	0.84	3.204	1.414
Heavy Duty Vehicles - Advanced Control	37.8	0.022	N/A	0.53	0.199	0.155
Heavy Duty Vehicles - Uncontrolled	37.8	0.066	N/A	0.796	3.359	1.127

(USEPA, 1995b, D13-14)

Since the numbers, types, and control technologies of Hawaii's LPG highway vehicles were unknown, each set of the *State Workbook* greenhouse gas emissions factors was used to calculate total estimated emissions for each vehicle type and emission control technology pair. The results are presented in Table 5.22.

Table 5.22 Emissions from Highway LPG Use (Tons)

Technology	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Passenger Car - Advanced Control	5,464	0.88	N/A	17	10	0.84
Passenger Car - Uncontrolled	5,464	2.63	N/A	33	128	56.31
Heavy Duty Vehicles - Advanced Control	5,464	0.88	N/A	21	8	6.17
Heavy Duty Vehicles - Uncontrolled	5,464	2.63	N/A	32	134	44.88

To estimate the greenhouse gas emissions from highway LPG use for inclusion in this inventory, the average of the four emissions values from Table 5.22 was calculated and used as the nominal value for estimated emissions as presented in Table 5.23.

Table 5.23 Nominal Non-Highway LPG Vehicle Emissions in Hawaii, 1990 (Tons)

CO_2	CH_4	N_2O	NO_x	CO	NMVOC
5,464	2	N/A	26	70	27

5.6 Emissions from Other Mobile Sources

In addition to the transportation mobile sources discussed in the preceding sections of this chapter, there were greenhouse and precursor gas emissions from various types of non-highway vehicles and mobile equipment. The estimation of these emissions is reported in this section. These emissions were attributed to the industrial sector in the final accounting of emissions by sector.

Industrial sector non-highway vehicle emissions include agricultural, off-road construction, and other vehicles and equipment used in industrial operations.

5.6.1. Calculation of Emissions from Agricultural Sector Mobile Sources

While Hawaii's agricultural sector includes pineapples, livestock, macadamia nuts, coffee, fruit, and other products, data were not available that detailed agricultural equipment fuel used in producing those products. Detailed data on fuel used in vehicles in support of sugar production were reported by the Hawaii Agricultural Research Center (HSPA, 1991, 12). The greenhouse gas emissions produced by the remainder of the agricultural sector were estimated as part of the mobile source emissions from the overall industrial sector. Hawaii's sugar industry used 221,976 barrels of diesel fuel, 29,166 barrels of gasoline, and 25 barrels of LPG for mechanical equipment and vehicles in 1990. Table 5.24 summarizes agricultural equipment fuel use.

Table 5.24 Agricultural Equipment Fuel Use, 1990

Fuel	Barrels	10^6 Btu	Percent
Diesel	221,976	1,293,010	89.400%
Gasoline	29,166	153,209	10.593%
LPG	25	100	0.007%
Total		1,446,319	100%

(HSPA, 1991, 12)

The emissions factors from the *State Workbook* (USEPA, 1995b) for "farm equipment," cited below in Table 5.25, were used to calculate the emissions from agricultural equipment in the sugar industry. While the carbon factor was differentiated by fuel type, the other emission factors provided were the same for all three fuel types.

Table 5.25 Emissions Factors for Agricultural Equipment Fuel Use (Lbs./Million Btu)

Fuel	CO_2	CH_4	N_20
Diesel	44.0	0.024	0.0044
Gasoline	42.8	0.024	0.0044
LPG	37.8	0.024	0.0044
Fuel	**NO_x**	**CO**	**NMVOC**
Diesel	3.31	1.33	0.51
Gasoline	3.31	1.33	0.51
LPG	3.31	1.33	0.51

(USEPA, 1995b, D1-5 and D13-16)

Using the general methodology, estimated greenhouse and precursor gas emissions from agricultural equipment use were calculated and were presented in Table 5.26.

Table 5.26 Emissions from Agricultural Equipment Fuel Use in Hawaii, 1990 (Tons)

Fuel		CO_2	CH_4	N_20
Diesel		103,260	15.52	2.84
Gasoline		11,902	1.84	0.34
LPG		7	0.00	0.00
	Totals	115,168	17	3
Fuel		**NO_x**	**CO**	**NMVOC**
Diesel		2,140	860	330
Gasoline		254	102	39
LPG		0.2	0.1	0.0
	Totals	2,394	962	369

5.6.2 Calculation of Emissions from Other Industrial Sector Mobile Sources

Mobile equipment fuel uses outside sugar in the agricultural sector, in the construction industry, and in other industrial activities were estimated in the absence of specific data. This was accomplished by subtracting all other reported stationary and mobile uses from the total amounts of distillate fuel and gasoline reported sold and distributed in Hawaii in 1990. This process resulted in an estimate of consumption of 185,702 barrels of diesel fuel and 5,050 barrels of gasoline by mobile equipment in the industrial sector, as presented on Table 5.27.

Table 5.27 Industrial Equipment Fuel Use in Hawaii, 1990

Fuel	Barrels	10^6 Btu	Percent
Diesel	185,702	1,081,714	98%
Gasoline	5,005	26,291	2%
Total		1,108,005	100%

Source: State of Hawaii, DBEDT Estimate

The emissions factors for "construction and industrial equipment" provided by the *State Workbook* (USEPA, 1995b, D1-5 and D13-16) and reproduced in Table 5.28 were used to calculate emissions.

Table 5.28 Emissions Factors for Industrial Equipment Fuel Use (Lbs./Million Btu)

Fuel	C	CH_4	N_20
Diesel	44.0	0.009	0.0044
Gasoline	42.8	0.009	0.0044
Fuel	**NO_x**	**CO**	**NMVOC**
Diesel	2.65	0.84	0.20
Gasoline	2.65	0.84	0.20

(USEPA, 1995b, D1-5 and D13-16)

Use of the standard *State Workbook* calculation methodology yielded the estimated emissions from industrial equipment as indicated on Table 5.29.

Table 5.29 Emissions from Industrial Equipment Fuel Use in Hawaii, 1990 (Tons)

Fuel	CO_2	CH_4	N_20
Diesel	86,386	4.87	2.38
Gasoline	2,042	0.12	0.06
Total	88,428	5	2
Fuel	**NO_x**	**CO**	**NMVOC**
Diesel	1,433	454	108
Gasoline	35	11	3
Total	1,468	465	111

5.6.3 Calculation of Emissions from Military Non-Aviation Mobile Source Fuel Use

As noted in the discussion of marine fuel use in Section 5.3, some portion of military purchases of 834,246 barrels of distillate fuel, 64,735 barrels of motor gasoline, and 128,216 barrels of residual fuel oil in 1990 may have been used for ships or boats, but data were not available to determine actual use.

For the purposes of this inventory, the maximum greenhouse and precursor gas emissions from military non-aviation fuel use were calculated and are reported by possible uses. Distillate and gasoline use were calculated as emissions from military vehicles. Total distillate use was again calculated as emissions from military marine use as was marine use of residual fuel oil. Total military non-aviation mobile source emissions were reported based upon the highest emission values for each respective fuel use. Table 5.30 summarizes military non-aviation fuel purchases and depicts their heat value in millions of Btu.

Table 5.30 Military Non-Aviation Fuel Purchases in Hawaii 1990

Fuel	Barrels	10^6 Btu	Percent
Distillate	834,246	4,859,483	81%
Gasoline	64,735	340,053	6%
Residual	128,216	806,094	13%
Total		6,005,630	100%

Source: State of Hawaii, DBEDT Estimate

5.6.3.1 Fuel Use in Military Vehicles

The military purchased 834,246 barrels of distillate fuel from Hawaii refiners and distributors in 1990. This fuel could have been used for tactical vehicles, off-road equipment, or ships in Hawaii or overseas. Some may have been used in stationary sources overseas. It was likely that most of the fuel was used in mobile sources, and that the mobile source emissions would have been greater than possible stationary source use except for NO_x. In this section, greenhouse gas emissions were calculated as if all of the distillate was used in military vehicles.

Most of the 64,735 barrels of motor gasoline were likely used in non-tactical vehicles and the emissions calculations were based upon that assumption.

The emissions factors from the *State Workbook* (USEPA, 1995b, D1-5 and D13-16) for industrial equipment were used as a proxy for military off-road vehicles and tactical vehicles. These are presented in Table 5.31.

Table 5.31 Emissions Factors for Industrial Equipment Fuel Use (Lbs./Million Btu)

Fuel	C	CH_4	N_20
Distillate	44.0	0.009	0.0044
Gasoline	42.8	0.009	0.0044
Fuel	**NO_x**	**CO**	**NMVOC**
Distillate	2.65	0.84	0.20
Gasoline	2.65	0.84	0.20

(USEPA, 1995b, D1-5 and D13-16)

Using the general methodology, the estimate of greenhouse and precursor gas emissions from military vehicle use was calculated and is presented in Table 5.32.

Table 5.32 Estimated Emissions from Military Vehicle Use of Fuel Purchased in Hawaii, 1990 (Tons)

Fuel		CO_2	CH_4	N_20
Distillate		388,078	22	11
Gasoline		26,416	2	1
	Total	414,494	23	11
Fuel		**NO_x**	**CO**	**NMVOC**
Distillate		6,439	2,041	486
Gasoline		451	143	34
	Total	6,889	2,184	520

5.6.3.2 Fuel Use in Military Ships

At least some of the 834,246 barrels of distillate fuel purchased from Hawaii refiners and distributors in 1990 could have been for marine uses. In this section, the greenhouse gas emissions from the full amount of distillate fuel oil purchases were calculated as if they had been used for marine purposes.

Although some of the 128,216 barrels of residual fuel oil purchased may have been used in stationary sources overseas, it will be assumed that the fuel was used in military ships. Table 5.33 presents the emissions factors from the *State Workbook* (USEPA, 1995b, D1-5 and D13-16) for distillate and residual fuel oil used as marine fuels.

Table 5.33 Marine Fuel Emissions Factors (Lbs./Million Btu)

Fuel	C	CH_4	N_20
Distillate	44	N/A	0.002
Residual	47.4	N/A	0.002
Fuel	**NO_x**	**CO**	**NMVOC**
Distillate	6.64	0.1	N/A
Residual	6.64	0.1	N/A

(USEPA, 1995b, D1-5 and D13-16)

The greenhouse and precursor gas emissions were calculated using the general methodology and are reported in Table 5.34.

Table 5.34 Estimated Emissions from Military Marine Use of Fuel Purchased in Hawaii, 1990 (Tons)

Fuel	CO_2	CH_4	N_20
Distillate	388,078	N/A	5
Residual	69,349	N/A	1
Total	457,427	N/A	6
Fuel	**NO_x**	**CO**	**NMVOC**
Distillate	16,133	243	N/A
Residual	2,676	40	N/A
Total	18,810	283	N/A

5.6.3.3 Emissions from Non-Aviation Military Use of Fuel

For the overall inventory, estimated emissions from military vehicles, and from marine uses were combined. Since most emissions from military vehicle use were greater than from marine uses, they were incorporated into the final inventory in Table 5.35 as part of a conservative approach.

Table 5.35 Estimated Emissions from Military Mobile Source Use Use of Fuel Purchased in Hawaii, 1990 (Tons)

Fuel	CO_2	CH_4	N_20
Distillate	388,078	22	11
Gasoline	26,416	2	1
Residual	69,349	N/A	1
Total	483,843	24	13
Fuel	**NO_x**	**CO**	**NMVOC**
Distillate	6,439	2,041	486
Gasoline	451	143	34
Residual	2,676	40	N/A
Total	9,566	2,224	520

CHAPTER 6 GREENHOUSE GAS EMISSIONS FROM NON- ENERGY SOURCES

6.1 Overview

This chapter reports the inventory of non-energy anthropogenic sources of greenhouse and precursor gas emissions which contribute to global warming. The non-energy emissions sources include:

- Industrial Processes
    - Oil Industry
    - Cement Industry
- Municipal Waste Management
    - Municipal Solid Waste Management[1]
    - Municipal Wastewater Treatment
- Agricultural Activities
    - Domesticated Animals
    - Manure Management Systems
    - Agricultural Soil Management
    - Forest Management and Land-Use Change
    - Burning of Agricultural Crop Wastes

The following sections present the summary of emissions from these non-energy activities. Chapter 7 reports the estimation of emissions from industrial processes. Chapter 8 details the calculation of emissions from municipal waste management. Chapter 9 explains the estimation of emissions from agricultural activities.

6.2 Summary of Hawaii Non-Energy Emissions

Hawaii's greenhouse and precursor gas emissions from non-energy activities are

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[1] One element of municipal solid waste management on Oahu since 1990-was the City and County of Honolulu's H-POWER garbage-to-energy plant. While H-POWER's main purpose is to reduce landfill volume, it provides 45 MW of firm capacity to the Hawaiian Electric Company under a power purchase agreement and, in 1990, sold 312,479 MWh of electricity to the utility. H-POWER's greenhouse gas emissions were reported in the energy chapters of this report, but its effect on reducing landfill volume is reported in this chapter.

summarized on Table 6.1. These gases included CH_4, CO_2, N_2O, NO_x, and CO.

Table 6.1 Summary of Greenhouse Gas Emissions from Non-Energy Sources in Hawaii, 1990 (Tons)

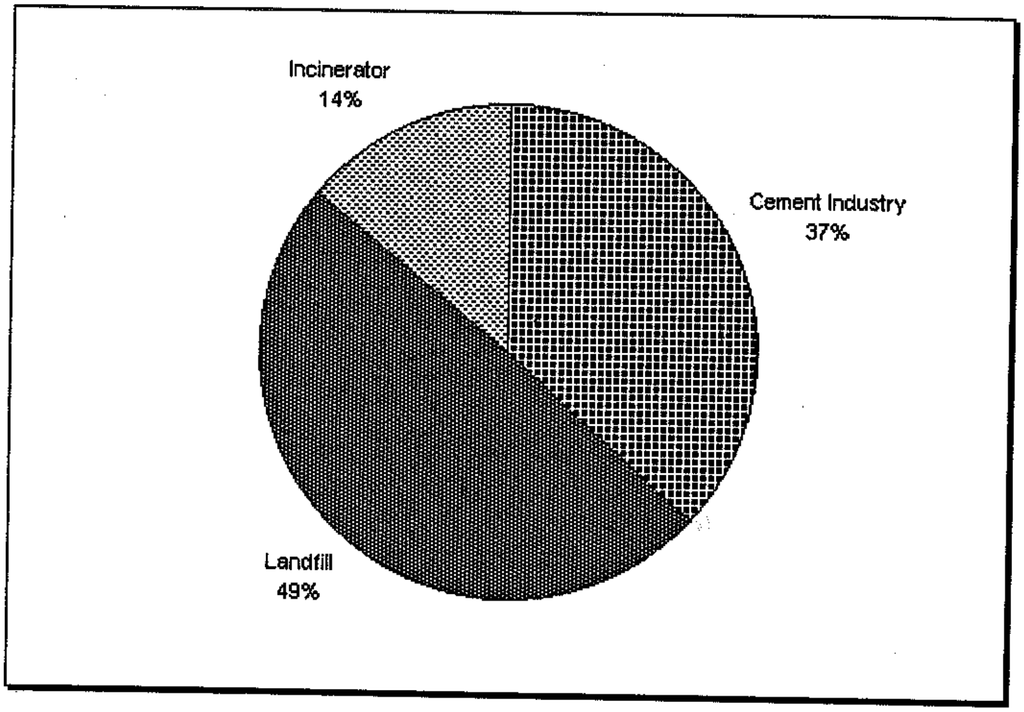
Activity	CO_2	CH_4	N_2O	NO_x	CO
Industrial Processes					
Oil		237			
Cement	109,274				
Municipal Solid Waste Management					
Landfill	147,098	53,490			
Incinerator	42,586				27,101
Municipal Wastewater Treatment					
Treatment		1,027			
Domestic Animals					
		13,368			
Manure Management					
		6,056			
Sugarcane Burning					
		543	8	140	10,857
Fertilizer					
			196		
Changes in Biomass					
Uptake	-415,158				
Abandoned Lands					
Uptake	-519,237				
Total	**-635,437**	**74,721**	**204**	**140**	**37,958**

6.3 Carbon Dioxide Emissions from Non-Energy Sources

Figure 6.1, on the following page, depicts the relative percentage of CO_2 emissions from non-energy sources in Hawaii in 1990. Landfills produced 147,098 tons of CO_2, or 49% of non-energy CO_2 emissions. Cement production produced 109,274 tons, or 37%; and incineration of MSW produced another 42,586 tons, or 14%. While these amounts are significant, they were more than offset by the uptake of 934,395 tons from changes in biomass and abandoned lands. The net uptake of CO_2 in the non-energy sector was 635,437 tons.

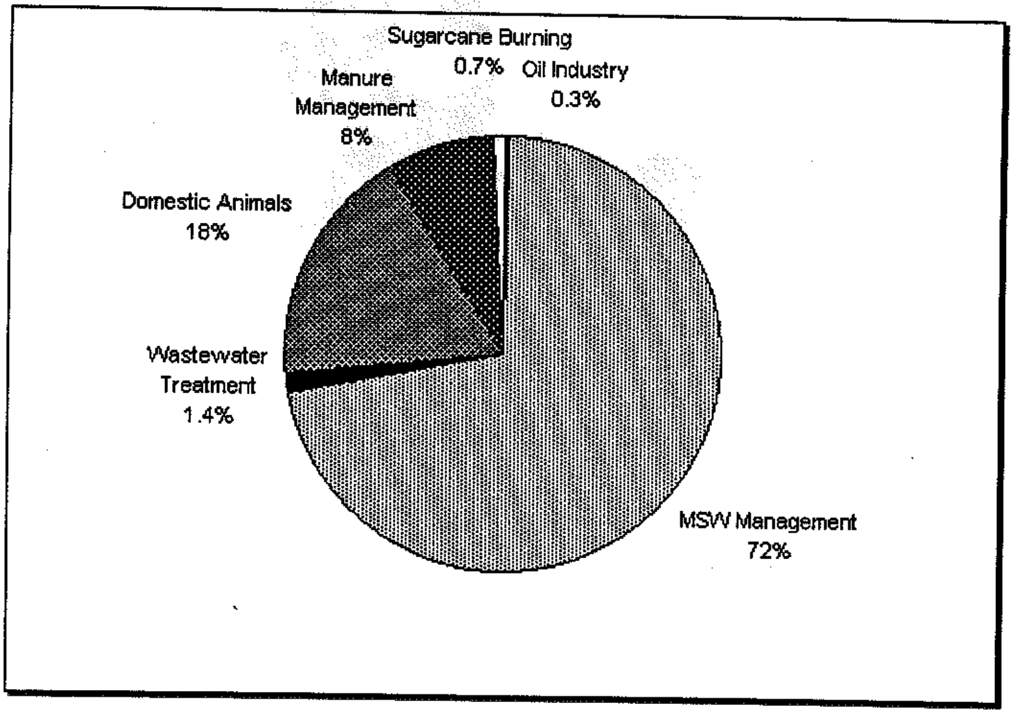
Non-energy activities emitted 74,871 tons of CH_4 in 1990. As depicted in Figure 6.2, on the following page, 72% came from MSW management, particularly landfills. Ruminant domestic animals produced 18% with a further 8% produced by manure management systems. Wastewater treatment and sugarcane burning produced only 1.4% and 0.7% respectively. Transportation and production activities in Hawaii's oil industry emitted only 0.3%.

Figure 6.1 Carbon Dioxide Emissions from Hawaii Non-Energy Sources, 1990



6.4 Methane Emissions from Non-Energy Sources

Figure 6.2 Methane Emissions from Hawaii Non-Energy Sources, 1990



6.5 Other Emissions from Non-Energy Sources

N_2O, NO_x, and CO were also produced by non-energy sources. The emissions are reported in the following sections.

6.5.1 *Nitrous Oxide*

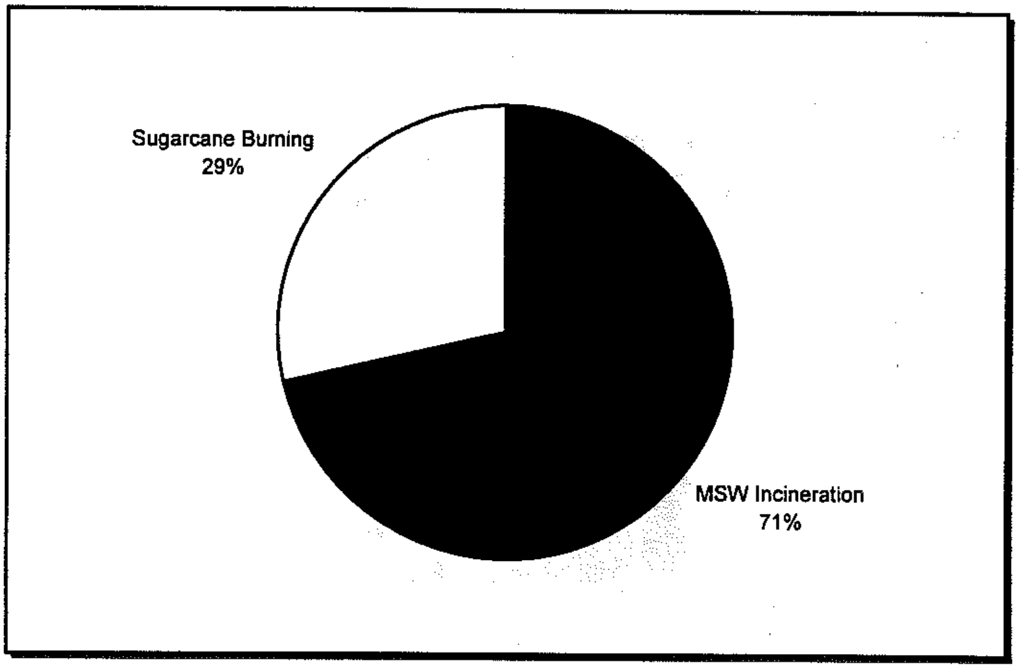
A total of 204 tons of N_2O were emitted by Hawaii non-energy sources in 1990. Fertilizer use produced 196 tons, or 96%, while sugarcane burning produced 8 tons, or 4%.

6.5.2 *Oxides of Nitrogen*

Sugarcane burning also produced 140 tons of NO_x in 1990.

6.5.3 *Carbon Monoxide*

Figure 6.3 Carbon Monoxide Emissions from Hawaii Non-Energy Sources



As Figure 6.3, above, shows 71% of the CO from non-energy sources was produced by municipal solid waste incineration (27,101 tons), while the remaining 29% came from sugar cane burning (10,857).

CHAPTER 7 GREENHOUSE GAS EMISSIONS FROM INDUSTRIAL PROCESSES

7.1 Overview

Hawaii's economy is primarily service-oriented with little major industry. In this section, emissions from the two major greenhouse gas emitting industries -- oil and cement -- are reported. The values reported here include emissions from industrial processes and do not include emissions from energy use in industrial sector for process heat or electricity generation. Emissions from process heat and electricity generation were reported in Chapters 3 and 4.

7.2 Summary of Emissions from Industrial Processes

Table 7.1 summarizes estimated greenhouse gas production from industrial processes in Hawaii in 1990. The sources of these estimates are summarized in the subsequent sections.

Table 7.1 Estimated Greenhouse Gas Emissions from Oil and Cement Industry Processes in Hawaii, 1990 (Tons)

Industry	CO_2	CH_4
Oil		
Transportation, Storage, and Distribution		156
Refining and Processing		81
Subtotal		237
Cement		
Clinker Production	109,005	
Masonry Cement	269	
Subtotal	109,274	
Total	109,274	237

7.3 Emissions from Oil Refining and Utility Gas Industries

Methane is the primary emission from oil and natural gas systems, although smaller quantities of NMVOCs, CO_2, and CO can be emitted. While CH_4 emissions occur throughout the total fuel cycles of oil and natural gas, Hawaii is involved in only the importing, refining, and distribution phases. Emissions occur in marine vessel operation, storage, refining, and from venting and flaring of gas (USEPA, 1995b, D3-1).

While the *State Workbook* (USEPA, 1995b, 3-1 – 3-3) provided a methodology for calculating CH_4 emissions from natural gas processing, transportation, and distribution, there is no natural gas use in Hawaii. However, synthetic natural gas (SNG) and propane-air mixtures are produced for use in utility gas systems. The emissions from this system were included in this report.

Hawaii's non-utility gas needs are met with liquefied petroleum gas (LPG). Emissions from the combustion of these gases were reported in Chapters 3 through 5. LPG production emissions are accounted for with other refinery processing in this chapter.

Leaks or venting of CH_4 vapors can occur during tankering. The amount of leakage is strongly dependent upon the original CH_4 content of the crude oil and its preparation for transport. Crude oil can emit CH_4 from some types of storage tanks. During the refining process, CH_4 may be leaked or vented in some processes. Most of such excess CH_4 is flared, or burned, converting the emissions to CO_2 and other products of combustion. Refined products generally contain negligible amounts of CH_4. Consequently, CH_4 emissions are not estimated for transporting and distributing refined products (USEPA, 1995b, D3-1). CH_4 emissions for Hawaii's refineries were calculated by each of Hawaii's refineries at DBEDT request.

Refinery feedstocks are used to produce synthetic natural gas for use in the main Oahu gas system as utility gas. In the other utility gas service territories, i.e., outlying areas of Oahu and the neighbor islands, propane vapor is the only form of gas distributed. The emissions from the utility gas systems were calculated at DBEDT request by BHP Gas Company.

To preserve the requested confidentiality of individual inputs, the data provided by the two refiners and the gas company are presented in aggregated form on Table 7.2. According to their reports, the two refineries and the utility gas system emitted a reported 237 tons of CH_4 from operations in Hawaii in 1990.

Table 7.2 Reported Methane Emissions from Crude Oil and Synthetic Natural Gas Transportation, Storage, Distribution, Refining, and Processing in Hawaii, 1990

Activity	Pounds CH_4	Tons CH_4
Transportation, Storage, and Distribution	311,721	156
Refining and Processing	162,138	81
Total	473,859	237

(Kusunoki, 1996; Roberts, 1996)

7.3 Emissions from Cement Industry

CO_2 is emitted during the production of cement. CO_2 is produced when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime (calcium oxide or CaO) and CO_2. The lime is then combined with silica-containing materials to form dicalcium or tricalcium silicates, two of the four major compounds in cement clinker. This lime is combined with other materials to produce clinker, an intermediate product from which finished portland and masonry cement are made, while CO_2 is released into the atmosphere. Assuming the average lime fraction of clinker is 64.6% yields an emission factor of 0.507 tons of CO_2 per ton of clinker produced. Masonry cement production requires additional lime and other materials, thus 0.0224 tons of additional CO_2 are emitted for each ton of masonry cement produced (USEPA 1995b, D2-1, 2).

To create Table 7.3, the number of tons of clinker and masonry cement produced were obtained and multiplied by their respective emissions factors to yield the tons of CO_2 produced. A total of 109,274 tons of CO_2 was emitted from cement production in Hawaii in 1990.

Table 7.3 CO_2 Emissions from Cement Production in Hawaii, 1990

Activity	Production (Tons)	Emission Factor[3]	CO_2 (Tons)
Clinker Production[1]	215,000	0.5070	109,005
Masonry Cement[2]	12,000	0.0224	269
Total	227,000		109,274

[1] Cieslik, 1994

[2] Johnson, 1992

[3] USEPA, 1995b, D3-1 – D3-2)

CHAPTER 8 GREENHOUSE GAS EMISSIONS FROM MUNICIPAL WASTE MANAGEMENT

8.1 Overview

This chapter reports the inventory of greenhouse gas emissions produced by municipal solid waste (MSW) management and wastewater treatment in Hawaii.

Landfills are the largest single anthropogenic source of methane emissions in the United States (USEPA, 1993, 80). Although the decomposition of organic waste in landfills occurs in a mainly anaerobic (oxygen free) environment, this process results in the generation of both CH_4 and CO_2. The two major factors that determine the quantity of gas produced are management practices and physical factors. Management practices include type of waste management system, density of refuse, and refuse particle size. Physical factors include waste composition, moisture content, and leachate pH (USEPA, 1995b, D5-1).

As noted above, some MSW was incinerated on Oahu in 1990 and the CO_2 and CO emissions from incineration are reported.

Wastewater treatment can also contribute to methane generation and emissions. Wastewater can be treated aerobically and/or anaerobically and can degrade, untreated, via either mechanism (USEPA, 1995b, D12-1). Methane is generated under anaerobic conditions as the organic matter is degraded.

8.2 Summary of Emissions from Municipal Waste Management

Municipal waste management activities in Hawaii in 1990 emitted 53,490 tons of CH_4, 189,684 tons of CO_2, and 27,101 tons of CO into the atmosphere. The calculation of these estimates is described in the sections which follow.

Table 8.1 Greenhouse and Precursor Gas Emissions from Municipal Waste Management in Hawaii, 1990 (Tons)

Activity	CH_4	CO_2	CO
Municipal Solid Waste			
Landfill	53,490	147,098	
Incinerator		42,586	27,101
Subtotal			
Municipal Wastewater Treatment			
Treatment	1,027		
Municipal Waste Management Total	54,517	189,684	27,101

8.3 Emissions from Municipal Solid Waste Management

Greenhouse gases were emitted from MSW management activities, including landfills, incineration of waste, and use of CH_4 from one landfill to generate electricity and flaring of CH_4 from three others. In addition, 495,000 tons of MSW was burned to produce energy. The emissions from non-energy production aspects of MSW management are covered in this chapter. Emissions from energy production using MSW were reported in Chapters 3 and 4. Greenhouse gas emissions were calculated using the methodology outlined in the *State Workbook* (USEPA, 1995b), with some modifications based upon limited available local data.

8.3.1 Data Collection

Data needed to calculate 1990 greenhouse gas emissions from landfills includes the total amount of waste in place (WIP) in the state, the fraction of waste in large versus small landfills, the number of large landfills, average rainfall, and the quantity of landfill gas flared or recovered for energy purposes. Not all of this information was available, and what was available was obtained with some difficulty.

Hawaii permitting regulations were revised in 1993 to require documentation of waste entering each landfill. As a result, accurate records for individual landfills are available only since then (State of Hawaii, 1993).

As much data as possible were collected from personnel at county landfills (e.g., Rosetti, 1996) and from solid waste personnel in each county (e.g., Namunart, 1996; Baker, 1996). Table 8.2 summarizes these reports and derived data.

Table 8.2 Estimated Hawaii Statewide Waste in Place by Landfill, 1990

Landfill Name	Class	Acres	Years of Operation	MSW per Year (Tons)	Growth Correction Factor	Volume of MSWIP* (Yards^3)	MSWIP (Tons)
Hawaii County							
Hilo Landfill	Nonarid		1970s-Present	**56,314**	67.2		756,860
Puu Anahulu & Kailua LFs	Nonarid	20+18	1970s-Present	**62,571**	51.4		643,735
Maui County							
Central Landfill	Arid		1970-Present	**152,833**	58.2	3,226	1,778,063
Hana Landfill	Nonarid		1965-Present	**1,251**	60.3		19,620
Olowalu & Makani LFs		2 x 15	Closed late 80s		58.2	726,000	435,600
Lanai Landfill **	Arid		1975-Present	**2,190**	75.4		26,420
Kalamaula Landfill	Arid	19	Early '70s-1993			**326,500**	195,900
Honolulu County							
Kapaa Landfill	Nonarid	133	1960s-Present	xxx	xxx	xxx	xxx
Central Site	"	33	1970-1979		82.1	**4,166,667**	**2,500,000**
Site No. 2	"	34	1982-Present	141,333	82.1	**3,540,000**	**2,122,147**
Site No. 3	"	16	1979-1982		82.1	**1,000,000**	600,000
Two Old Landfills	"	40	1950s-1970s		82.1	580,800	348,480
One Old Constr. LF ****	"	10	1950s-1970s		82.1	145,200	145,200
Kalaheo LF, Waimanalo	Nonarid		1987-1990		82.1	2,183,333	**1,310,000**
Waimanalo Gulch Landfill	Nonarid		1989-Present	**300,000**	82.1	**3,500,000**	600,000
Kawailoa LF, Waialua	Nonarid	28	1960s-1986		82.1	1,761,760	1,057,056
Puu Palailai LF, Makakilo	Arid	29	1974-1988		7.5	4,600,000	2,800,000
Waianae Landfill	Arid	20	1971-1984		74.5	774,400	**1,400,000**
Nanakuli Constr. LF ****	Nonarid		1990-Present	**200,000**	82.1	200,000	200,000
Kauai Landfills ***							
Phase I Landfill	Nonarid		1953-1995	62,571	69.0	**763,886**	458,332
Halehaka Landfill	Nonarid		Closed		69.0	363,000	217,800
Total			**MSW/Year**	979,065	**MSWIP Total (tons):**		**17,615,213**

Numbers in Bold were reported, other numbers are estimates or calculations

MSW = Municipal Solid Waste; MSWIP = Municipal Solid Waste-in-Place

* Except where noted, sites are compacted. Assumes 0.6 tons per cubic yard.

** Not compacted. Assumes 0.4 tons per cubic yard.

*** Construction landfills assume 1 ton per cubic yard

Volumes are estimates based on 4840 square yards/acre. If depths are unknown, landfills are assumed 3 yards deep if operating <10 years, 7 yards deep if operating 10-15 years, and 10 yards deep if operating >15 years.

There was no system-wide method for estimating the amount of waste being landfilled at each site, and thus for estimating the amount of waste-in-place (WIP) at each. For example, some landfills recorded only the weight of incoming solid waste, but if the density of the landfill was not recorded as well, volume calculation becomes little more than guesswork. Furthermore, when relevant personnel were asked to estimate the density of solid waste in each landfill, the answers varied over more than a degree of magnitude, bringing all answers into doubt.

The available data were used to develop a preliminary estimate of WIP for each individual landfill. Although estimates of the annual amount of waste presently being landfilled were available for the majority of operating legal landfills, little or no such data were available for most of the closed landfills, some of which were sufficiently large to have a potentially significant impact on methane emission calculations. No data were available for illegal landfills for obvious reasons.

For use in *State Workbook* calculations, this MSW tonnage ideally excludes waste from construction and demolition as well as materials destined for recycling. However, most data available in Hawaii combined construction and demolition waste with regular MSW (for example, Namunart, 1996; Steuteville, 1996). As a result, MSW data included these two types of waste but excluded materials removed from the waste stream for recycling. This may have overstated the amount of methane-producing waste in Hawaii landfills.

In Table 8.2, the volumes and tonnages reported by contacted personnel are shown in bold to distinguish them from those values which were calculated from the area and estimated depth of the landfill. Nevertheless, the 986,887 tons reported to have entered all Hawaii legal landfills in 1990 was essentially equivalent to the total annual tonnage which state officials reported as actually being landfilled (Steuteville, 1996; Harder, 1996; Namunart, 1996) when the 495,000 tons for burning in the H-POWER MSW-to-energy plant and 74,214 tons burned at the Waipahu Incinerator in 1990 are taken into account. As a result of the uncertainty about the accuracy of the data reported above, it was decided to use the *State Workbook* method (USEPA, 1995b, 5-1 - 5-7) for data poor states, supplemented with available Hawaii data. Table 8.2 was thus used only to establish the number of large landfills (over one million tons) for use in estimating waste-in-place when using the *State Workbook* method.

8.3.2 *Estimation of Waste-in-Place (WIP)*

The EPA model for WIP calculation uses data compiled from 85 landfills nationwide (D5-4). It accounts for the fact that methane is released from solid waste for up to 30 years, rather than assuming that the total potential methane production is realized shortly after landfilling.

The basic method required only *de facto* population numbers and the average waste generation rate per capita, supplemented with available data to refine the estimate.

8.3.3 *WIP Calculation*

Equation 8.1 is suggested by the EPA to determine WIP (5-2).

$$\mathbf{WIP} = \frac{\mathbf{30 \times P \times WGR \times L \times GCF}}{\mathbf{2000}} \qquad \text{(Equation 8.1)}$$

Where: **WIP** = waste in place (tons) over the past 30 years;
P = *de facto* population for a given year
WGR = per capita waste generation rate
L = percent landfilled, expressed as a fraction (e.g., 1.0 =100%)
GCF = growth correction factor
2000 = conversion factor for lbs. to tons

The solution of Equation 8.1 required only the *de facto* population trend over the last several years, plus the average per capita waste generation over a period of years. Population figures were obtained from the *Hawaii State Data Book* editions of 1976, 1985, and 1995 (State of Hawaii, 1976, Table 3, 11; 1985, Table 4, 15; 1995b, Table 1.04, 15). **P**, or the 1990 *de facto* population, was 1,257,000 (State of Hawaii, 1995b, Table 1.04, 15). The **WGR**, or waste generation rate, was not as easily obtained.

Data on MSW generation per year were only available for Oahu for the years since 1980. The mean waste generation rate over the period 1980-1990 was 1,588 pounds per capita per year (State of Hawaii, 1991, Table 147, 147). Table 8.3, on the following page, displays the data used in calculation of the WGR.

Table 8.3 Calculation of Average Waste Generation Rate

Year	Oahu Population[1]	Waste[2] (tons)	Tons per Capita	Lbs per Capita
1980	823,400	613,549	0.745	1,490
1981	824,700	714,017	0.866	1,732
1982	837,600	665,276	0.794	1,589
1983	846,300	626,835	0.741	1,481
1984	852,300	611,386	0.717	1,435
1985	854,800	615,574	0.720	1,440
1986	871,000	681,874	0.783	1,566
1987	881,000	678,392	0.770	1,540
1988	888,200	739,820	0.833	1,666
1989	905,900	778,673	0.860	1,719
1990	912,100	825,058	0.905	1,809
		Average Lbs. per Capita		1,588

[1] State of Hawaii, 1995b

[2] State of Hawaii, 1991

Waste generation data for Hawaii's three other counties were not available. Oahu, however, accounted for over 73% of Hawaii's *de facto* population in 1990 and over 75% of its resident population (State of Hawaii, 1995b, Table 1.07, 18). For the purpose of this study, the average waste generation rate from Table 8.3 is assumed to be the same for all counties. This may under-estimate the actual rate, as tourists reportedly generate more waste per capita than residents, and tourists represent a larger percentage of the *de facto* population on the neighbor islands than on Oahu (Namunart, 1996). Thus, the MSW generation rate used should be taken as a minimum estimate for the state.

The *State Workbook* default value for L, or percentage landfilled, was 70%, or 0.7 (USEPA, 1995b, 5-2). However, since the waste generation reported for Oahu did not include materials recycled, it was assumed that all of the waste was either landfilled or burned. Accordingly, the value for L used in this calculation was

100%, or 1.0, as the amount burned was calculated separately and subtracted from the solution of Equation 8.1.

The amount of waste landfilled each year has grown significantly over the past thirty years. If the current, or even the past 11 year average was used to calculate the waste in place over the past thirty years that U.S. landfill waste typically produces methane, the amount would be overstated. Accordingly, a GCF, or growth correction factor was applied. Considering the average *de facto* thirty-year annual population growth rate of 2.22%, a GFC of 0.734 was applied, based upon Table 5.1 in the *State Workbook* (5-3).

Table 8.4. Estimate of Waste-In-Place in Hawaii Landfills, 1990

Year	Oahu *De Facto* Population (July 1)	*De Facto* Population of Neighbor Islands	Total State *De Facto* Population	Calculated WIP on Neighbor Is. (Tons)	WIP on Oahu Before Burning (Tons)	Amount Used for H-POWER (Tons)	Burned (Tons)[2]	Oahu WIP (Tons)[3]	Statewide WIP (Tons)
1960-1980[1]	823,400	232,000	1,055,400	2,592,053	10,416,320	-	2,033,571	8,382,749	10,974,802
		Net WIP on Oahu in 1980:			8,382,749				
1981	824,700	237,900	1,064,581	2,798,024	9,096,766	-	156,429	8,940,337	11,738,362
1982	837,600	247,000	1,086,582	2,994,208	9,605,613	-	156,429	9,449,185	12,443,393
1983	846,300	262,900	1,111,183	3,188,932	10,076,020	-	156,429	9,919,591	13,108,523
1984	852,300	278,200	1,132,484	3,388,495	10,530,977	-	156,429	10,374,549	13,763,043
1985	854,800	283,000	1,139,785	3,592,294	10,990,123	-	156,429	10,833,694	14,425,988
1986	871,000	296,500	1,169,486	3,824,413	11,515,568	-	156,429	11,359,139	15,183,552
1987	881,000	305,500	1,188,487	4,059,656	12,037,531	-	156,429	11,881,103	15,940,758
1988	888,200	312,200	1,202,388	4,319,700	12,620,923	-	156,429	12,464,494	16,784,195
1989	905,900	339,700	1,247,589	4,611,692	13,243,167	-	156,429	13,086,739	17,698,431
1990	912,100	344,900	1,257,000	4,923,678	13,911,797	495,000	78,214	13,338,582	18,262,261

[1] Population numbers in this row as of 1980

[2] Annual Waipahu incinerator tonnage calculated assuming 600 T/day, 5 days/week until 1990, then 300 T/day

[3] Calculated by subtracting the sum of all tonnages burned in previous years which did not go into landfills

Since data waste generation data were not available prior to 1980, the average waste generation rate for 1980 - 1990 was used in Equation 8.1 to calculate WIP in 1980. The results are shown in the first line of Table 8.4. The value for Oahu was reduced by a nominal 156,429 tons per year to account for waste burned at the Waipahu Incinerator between 1967 and 1980. To calculate the WIP for 1980 to 1990, the annual waste generation rate was used in each year. Oahu WIP was reduced by the nominal 156,429 tons burned in the Waipahu Incinerator through 1989 and, the 78,214 tons burned in 1990. An additional 495,000 tons were subtracted to account for the amount burned in the H-POWER plant in 1990 (Yuen, 1996), its first year of operation. The resulting estimate of total waste-in-place in 1990 was 18,262,261 tons. This result is only 3.6% more than the WIP of

17,615,213 tons estimated from available land fill data. For the purposes of estimation of methane emissions, the higher value will be used.

8.3.4 Estimating WIP in Large and Small Landfills

The next step in the process was to determine the fraction of waste in large and small landfills for use in calculating methane emissions from each type. The fraction is important because methane generation rates are different due to a variety of factors related to landfill size, including waste composition, waste age, and ease of moisture movement within the landfill. For this study, the EPA defined a large landfill as one containing more than 1.1 million tons of WIP.

Available data on landfill size indicated there were seven large landfills in 1990, including four which had been closed. Based upon the data reported by Hawaii landfill managers, these held about 63.5% of reported WIP. Although based upon incomplete reporting, it is believed that the reported fraction of large landfills is more accurate than the default value (86%) provided by the *State Workbook* (5-4). The Hawaii estimate was used in the subsequent equations to calculate total CH_4 emissions.

8.3.5 Calculation of Methane Emissions from Landfills

Calculation of methane emissions from landfills also required determination of the overall climate of the landfills (that is, arid or nonarid) for large landfills, yet not for small landfills (U.S. EPA, 1995). $\mathbf{CF_1}$, the conversion factor for tons of waste to cubic foot per day of CH_4 for non-arid areas was used as most landfills in Hawaii are in non-arid areas.

Since the assumed seven large landfills in Hawaii were estimated to contain about 62% of the reported total WIP (18,262,261 tons), as discussed above, these values were used in calculating emissions. Thus, 11,596,536 tons of waste were considered to be in large landfills while 6,665,725 tons were in small landfills.

The first equation, Equation 8.2, calculates M_L, the amount of methane produced from large landfills in tons per year, within a range of plus or minus 15%.

$$M_L = N \times [419{,}000 + (CF_1 \times WIP_L/N)] \times CF_2 \qquad \text{(Equation 8.2)}$$

Where: M_L = methane from large landfills (tons/yr.) ± 15%

N = number of large landfills in the state

419,000 = constant recommended in the *State Workbook* (5-6)

CF_1 = conversion factor for tons of waste to ft^3/day methane (0.26 in non-arid areas)

WIP_L = waste in place in all large landfills statewide (tons)

CF_2 = conversion factor from ft^3/day to tons/yr. methane (0.0077)

Similarly, the second equation, Equation 8.3, calculates M_s, the amount of methane produced from small landfills in tons per year within a range of plus or minus 20%.

$$M_S = WIP_S \times CF_1 \times CF_2 \qquad \text{(Equation 8.3)}$$

Where: M_S = methane from small landfills (tons/yr.) ± 20%

WIP_S = waste in place in all small landfills statewide (tons)

CF_1 = conversion factor for tons of waste to ft^3/day methane (0.35 in non-arid areas)

CF_2 = conversion factor for ft^3/day to tons/yr. methane (0.0077)

The solution of Equation 8.2 resulted in an estimate of 45,800 tons of methane produced from large landfills ($\pm$ 20%) and Equation 8.3's solution was 17,964 tons of methane from small landfills ($\pm$ 15%). The sum of the results of the two equations was 63,764 tons.

8.3.6 Adjustments for Use, Flaring, and Oxidation of Landfill Methane

Not all of the estimated 63,764 tons of CH_4 produced by Hawaii's landfills was emitted into the atmosphere. An estimated 10% was oxidized in the soil of the landfills. Some CH_4 was used to generate electricity at the Kapaa Generating Partners Plant at the Kapaa Landfill in Kailua, Oahu; and some was flared, or burned, at other landfills. While flaring produced CO_2, the resulting CO_2 had less negative effect than if the methane was emitted. In this section, the calculation of these adjustments will be reported.

First, an adjustment was made for the oxidation of methane within the soil layer overlaying the landfilled material. Based upon discussion in the *State Workbook* (USEPA, 1995b, 5-8), it was assumed that 10% of generated methane less the amount used to generate electricity and the amount flared was oxidized by this soil layer. This value was calculated to be 6,376 tons in 1990.

The amount of CH_4 used to produce energy at Kapaa in 1990 was not available. However, available information from the operator indicated that 8,912 MWh electricity were produced (State of Hawaii, 1997). By extrapolating available data on CH_4 used to generate electricity from 1994 and 1996, it was estimated that 2,827 tons of CH_4 were used.

Three other Hawaii landfills flared the methane produced – the Olowalu and Makani Landfills on Maui (435,600 tons WIP), and the Halehaka Landfill on Kauai (217,800 tons WIP). These landfills, which are closed, contained 653,400 tons WIP. By using Equation 8.3, it was estimated that these three landfills produced 1,760 tons of CH_4 in 1990. According to the EPA, a 70 to 80% collection efficiency is generally reported for well-designed and well-operated landfill gas collection systems (USEPA, 1995b). Since collection efficiency data were not available on the three landfills cited above, a 75% collection efficiency was assumed following EPA practice (USEPA, 1993). As a result of flaring, approximately 75% of emitted CH_4, or 1,320 tons, was converted to CO_2 in 1990.

Table 8.5 summarizes the adjustments for oxidation, use, and flaring of landfill methane. The final result is an estimate of 53,490 tons of methane emitted to the atmosphere from Hawaii's landfills in 1990.

Table 8.5 Adjustments for Use and Flaring of Landfill Methane, 1990

	(Tons)
Estimate of Methane Produced	63,764
Oxidized	6,376
Used to Generate Electricity	2,578
Flared	1,320
Methane Emitted to Atmosphere	**53,490**

8.3.7 Calculation of Carbon Dioxide Emissions from Landfills

According to several sources (e.g., Farquhar and Rovers, 1973; Emcon Associates, 1980; State of Wisconsin, 1993), the volume of gas emitted from an average landfill stabilizes at about 50% CH_4 and 50% CO_2 after a period of a few months. An equal volume of the two gases under identical conditions will differ in weight according to their relative molecular weights. Thus, since the weight of methane emitted from landfills in Hawaii was calculated as reported above, the weight of an equivalent volume of CO_2 can be estimated by using the following Equation 8.4.

$$W_{CO2} = W_{CH4} \times CF \qquad \text{(Equation 8.4)}$$

Where: W_{CO2} = weight of emitted CO_2 in tons

W_{CH4} = weight of emitted CH_4 in tons

CF = difference in molecular weights = 44/16.

The solution of Equation 8.4 for Hawaii was an estimate of 147,098 tons of CO_2 emitted directly from landfills in 1990.

CO_2 emissions due to the flaring of methane were calculated using Equation 8.4, but by substituting the weight of the methane burned for W_{CH4}. The result of this calculation produced an estimate that 3,630 tons of CO_2 were emitted by flaring.

In addition, 78,214 tons of refuse were burned at the Waipahu Incinerator in 1990. Since about 50% of wood consists of carbon, the carbon content of MSW burned at this facility would be somewhat less than 50%. If one assumes that (1) 30% of the weight of this refuse consisted of carbon, (2) only about 1% of this carbon was retained as ash, and (3) half of this emitted carbon was converted to CO_2 and half to CO, the necessary equations to calculate these emissions from the Waipahu Incinerator are as follows:

$$W_{CO2} = ((W_{MSW} \times \%C) - \%A \times CF_1)/2 \qquad \text{(Equation 8.5)}$$

Where: W_{CO2} = weight of emitted CO_2 in tons

W_{MSW} = weight of municipal solid waste entering incinerator, in tons

%C = percent of MSW consisting of carbon, expressed as a fraction

%A = percent of carbon left behind as ash

2 = conversion factor accounting for half of emitted gas volume consisting of CO_2

CF_1 = difference in molecular weights between CO_2 and C = 44/12;

and

$$W_{CO} = ((W_{MSW} \times \%C) - \%A \times CF_2)/2 \qquad \text{(Equation 8.6.)}$$

Where: W_{CO} = weight of emitted CO in tons

W_{MSW} = weight of municipal solid waste entering incinerator, in tons

%C = percent of MSW consisting of carbon, expressed as a fraction

%A = percent of carbon left behind as ash

2 = conversion factor accounting for half of emitted volume consisting of CO

CF_2 = difference in molecular weights between CO and C = 28/12;

Based upon the solution of these equations, it was estimated that the incinerator emitted about 42,586 tons of CO_2 and 27,101 tons of CO in 1990.

CO_2 and CO were also produced when CH_4 was burned for power at the Kapaa landfill generator and when refuse was burned for power at the H-POWER Plant

(Jones, 1996). Since the Kapaa and H-POWER plants are energy sources, their emissions were discussed in Chapters 3 and 4.

8.3.8 *Total Emissions from Municipal Solid Waste Management*

Table 8.6 summarizes the estimate of greenhouse and precursor gas emissions from MSW management in Hawaii in 1990.

Table 8.6 Emissions from Municipal Solid Waste Management in Hawaii, 1990 (Tons)

Activity	CH_4	CO_2	CO
Municipal Solid Waste			
Landfill	53,490	147,098	
Incinerator		42,586	27,101
Municipal Solid Waste Management Total	53,490	189,684	27,101

8.3 Emissions from Municipal Wastewater Treatment

To determine the methane emissions from municipal wastewater, the following data were obtained:

- Pounds of BOD_5 per capita (0.1356 lbs./capita/day) were obtained from State Department of Health personnel. BOD is the organic loading or biochemical oxygen demand, a measure of the oxygen required by microorganisms to degrade the organic matter in the waste stream. Therefore, a waste stream with a high BOD will generate more methane than one with a lower BOD. BOD_5 refers to a 5-day BOD test (USEPA, 1995b, D12-1);

- *De facto* state population for 1990 of 1,257,000 from *The State of Hawaii Data Book*, 1995 (Table 1.07, 18); and

- Fraction of wastewater treated anaerobically (The default value of 15% (USEPA, 1995b, 12-2) was used as the exact fraction was not available).

Although Hawaii's counties keep track of the volume of wastewater produced annually and the volume treated, the *State Workbook* unfortunately did not provide a way to use those figures in calculating methane emissions.

Further, many residents are not connected to the municipal sewage treatment plants and instead have a cesspool or septic tank, which also generate methane. Accurate records on the number of cesspools and septic tanks were unavailable, thus the default value listed in the *State Workbook* (12-1) was used.

The following equation was used to determine methane emissions from municipal wastewater treatment in accordance with models developed by the EPA and recommended in the *State Workbook*:

$$\mathbf{E_y = \frac{(P \times B \times 365 \times EF \times A\%)}{2000} - MR} \qquad \text{(Equation 8.7)}$$

Where: $\mathbf{E_y}$ = methane emissions for year "y" (tons)

B = BOD_5 generation rate (0.1356 lbs./capita/day)

P = *de facto* population (1,257,000 in 1990)

365 = conversion factor (days/year)

EF = emissions factor (lbs. CH_4 / LB BOD_5) = 0.22

A% = percentage of wastewater treated anaerobically, expressed as a fraction (default = 0.15)

2000 = conversion factor (lbs./ton)

MR = methane recovered (tons) (none in 1990)

Using Equation 8.7, an estimate of 1,027 tons of methane emissions from municipal wastewater treatment in Hawaii in 1990 was calculated. The values used in the calculation are shown in Table 8.7.

Table 8.7 Calculation of Methane Emissions from Municipal Wastewater Treatment in Hawaii, 1990

Data	Value
Defacto Population (x 1000 persons)	1,257
BOD generated (lbs/day)	170,449
Quantity of BOD anaerobically treated (lbs/yr)	9,332,094
Methane Emissions (lbs/yr)	2,053,061
Methane Emissions (tons/yr)	1,027

It should be fairly easy to continue monitoring methane emissions from wastewater treatment. It is recommended that state or county staff develop a mechanism to accurately include contributions from septic tanks and cesspools and determine accurate percentages for BOD_5 generation and fraction of wastewater treated anaerobically. Such data would provide a better picture of methane emissions from wastewater treatment. These data would also aid any future state decisions about development of additional wastewater treatment systems and/or upgrading of existing facilities to reduce such emissions.

Sewage treatment also emits N_2O and CO_2; however, emission rates for these gases are uncertain (USEPA, 1995b), and are not included here.

CHAPTER 9 GREENHOUSE GAS EMISSIONS FROM AGRICULTURAL ACTIVITIES

9.1 Overview

This chapter reports the inventory of greenhouse and precursor gas emissions produced by agricultural activities in Hawaii. These include emissions from domesticated animals, manure management, agricultural soil management, and burning of agricultural crop waste.

9.2 Emissions from Agricultural Activities

The estimated anthropogenic non-energy greenhouse and precursor gas emissions from agricultural activities in Hawaii in 1990 are summarized in Table 9.1.

Table 9.1 Estimated Anthropogenic Non-Energy Emissions from Hawaii Agriculture, 1990

Land Use	CO_2 Emissions (+) or Uptake (-) (Tons CO_2)	CH_4 Emitted (Tons CH_4)	N_2O Emitted (Tons N_2O)	CO Emitted (Tons CO)	NO_X Emitted (Tons NO_X)
Domestic Animals		13,368			
Manure Management		6,056			
Sugarcane Burning		543	8	10,857	140
Fertilizer			196		
Changes in Biomass	-415,158				
Abandoned Lands	-519,237				
Total	**-934,395**	**19,967**	**204**	**10,857**	**140**

CH_4, CO, and N_2O emissions in 1990 were all positive. However, CO_2 emissions were a *negative* 934,395 tons per year due to uptake by growing plants. The following sections describe the calculation of these values.

9.3 Emissions from Domesticated Animals

This section covers calculations to determine methane emissions from domesticated animals. Two classes of animals are covered here. Ruminants, the first class of animals, produce comparatively greater amounts of methane emissions due to fermentation in their "fore-stomachs." Common ruminants found in Hawaii are cattle, goats, and sheep. The second class, non-ruminants, also produce methane but in far less volume on a per animal basis than ruminants. Non-ruminants include pigs and horses (USEPA, 1995b, 6-1).

To determine methane emissions, calculations were performed following the models developed by the EPA and listed in the *State Workbook* (6-1 - 6-4). Emissions from cattle, sheep, and pigs were quantified for Hawaii. Population data were not available on goats and horses. Cattle were divided into several subcategories, each with distinct emissions factors. Sheep and pigs were not divided into further categories. The following equation was used to determine methane emissions:

$$\mathbf{M_a = P_a \times Ef_{ar}} \qquad \text{(Equation 9.1)}$$

Where: $\mathbf{M_a}$ = Methane emissions for domesticated animal type "a" (tons/yr.)

$\mathbf{P_a}$ = Population of domesticated animal type "a" (head)

$\mathbf{Ef_{ar}}$ = Methane emissions factor for domesticated animal type "a" (lbs. CH_4/head/yr.) for geographic region "r" (r = West)

As seen in Equation 9.1, emissions factors are region-specific. In the case of Hawaii, the "West" region emissions factors were used as recommended by the *State Workbook* (6-4).

Domesticated animal population data were required to determine emissions, as seen in Equation 9.1. All animal population data were obtained from the *Statistics of Hawaiian Agriculture 1993* (State of Hawaii, 1994a). Cattle subcategories in *Statistics of Hawaiian Agriculture 1993* (80) did not correspond directly to those developed by the EPA; however, subcategories were assigned which sought to match the EPA nomenclature as closely as possible. Table 9.2 displays these subcategories for cattle.

Table 9.2 Cattle Subcategories for Determination of Methane Emissions

Categories Suggested by EPA[1]	Definitions Used in This Report[2]
Dairy Cattle	
Mature Cows	Milk cows that have calved
Replacements 12-24 months	Heifers 500 pounds and over ("other") -- prorated based on mature dairy cow fraction of total mature dairy and beef cows
Replacements 0-12 months	Not used
Beef Cattle	
Mature Cows	Beef cows that have calved
Replacements 12-24 months	Heifers 500 pounds and over ("other") -- prorated based on mature beef cow fraction of total mature dairy and beef cows
Replacements 0-12 months	Not used
Yearling Steers and Heifers	Steers 500 lbs and over
Weanling Steers and Heifers	Steers, heifers, and bulls under 500 lbs
Bulls	Bulls 500 lbs and over

[1] USEPA, 1995b, Table D6-2, D6-3

[2] State of Hawaii, 1994b, 80.

Using Equation 9.1, methane emissions were calculated for each animal type and subtype. Cattle were the primary source of methane emissions from domesticated animals. Methane emissions for domesticated animals are displayed in Table 9.3.

Table 9.3 Methane Emissions from Domestic Animals in Hawaii, 1990

Animal Type	1990 Population (Head)[1]	CH_4 Emission Factor (lbs. CH_4/head)	CH_4 Emissions (Tons)
Dairy Cattle			
Mature Cows	11,000	262.5	1,444
Replacements 12-24 months	8,174	134.6	550
Beef Cattle			
Mature Cows	75,000	152.0	5,700
Replacements 12-24 months	30,826	142.7	2,199
Yearling Steers and Heifers	26,000	104.7	1,361
Weanling Steers and Heifers	49,000	51.7	1,267
Bulls	5,000	220	550
Other Domestic Animals			
Sheep	27,000	17.6	238
Swine	36,000	3.3	59
Total	**268,000**		**13,368**

[1] Population data based on January 1, 1990 inventory (State of Hawaii, 1994b, 80)

[2] USEPA, 1995b, Table D6-2, D6-3

9.4 Emissions from Manure Management

In manure management systems, methane is produced by the anaerobic decomposition of organic matter. The key factor in determining the extent to which this process occurs is the type of manure management system employed. Types of systems included in the *State Workbook* (7-1) are pastures, deep pits, liquid slurry, and anaerobic lagoons. Typically, less methane is produced when manure is placed onto pasture and/or range lands, since degradation in these cases occurs aerobically (7-1). All emissions were calculated by animal type and manure management system. For Hawaii, data were available to allow calculation of emissions from manure management systems for cattle, sheep, pigs, and chickens.

Manure management systems produced 6,056 tons of methane emissions in Hawaii in 1990. Table 9.4 summarizes the results.

Table 9.4 Methane Emissions from Manure Management Systems in Hawaii, 1990

Animal Type	Methane (Tons)
Cattle	3,514
Chickens	1,427
Sheep	14
Swine	1,101
Total	6,056

The following steps were used to calculate methane emissions from manure management systems:

- Collection of data on animal populations -- these data were found in the *Statistics of Hawaiian Agriculture 1993* (80-94);
- Determination of the amount of volatile solids (VS) produced by each animal type;
- Use of the appropriate methane conversion factor and other parameters to estimate the amount of methane emissions from each manure management system and animal type; and
- Conversion of all units to tons of methane and summation of emissions over all manure management types (USEPA, 1995b, (7-1 - 7-4).

Two equations were used in these calculations. The first of these, Equation 9.2, was used to calculate pounds of volatile solids produced by each animal type.

$$\mathbf{VS_i\ produced\ per\ animal\ type = Animal\ population\ (head) \times TAM_i \times vs_i} \qquad \text{(Equation 9.2)}$$

Where: $\mathbf{VS_i}$ = Total VS produced (lbs./yr.) for animal type i

$\mathbf{TAM_i}$ = Typical animal mass for animal type I (lbs./head)

$\mathbf{vs_i}$ = Average annual volatile solids production per unit of animal mass of animal type i (VS per pound of animal mass) (7-3)

The values for total animal mass (TAM) and average annual volatile solids (vs) used to calculate total volatile solids (VS) produced by each animal type and the amounts produced are shown in the top rows of Tables 9-5 and 9-6.

The solution of Equation 9.2, total amount of volatile solids, and additional data were then used in Equation 9.3 to calculate total methane emissions.

$$\mathbf{CH_4\ emissions\ for\ animal_i\ on\ system_j =}$$
$$\mathbf{VS_i \times B_i \times MCF_j \times WS\%_{ij} \times 0.0413 / 2000} \qquad \text{(Equation 9.3)}$$

Where: $\mathbf{VS_i}$ = Total VS produced (lbs./yr.) for animal type i

$\mathbf{B_i}$ = Maximum methane producing capacity per pound of VS for animal type i (ft^3/lbs. VS)

$\mathbf{MCF_j}$ = Methane conversion factor for each manure system j

$\mathbf{WS\%_{ij}}$= Percent of animal type i's manure managed in manure system j (%)

0.413 = density of methane (lbs./ft^3) conversion factor to pounds

2000 = pounds/ton

With the exception of MCF_i , all other Hawaii-specific parameters were available from tables in the *State Workbook* (7-2, 7-5 - 7-14). Based upon the *Workbook* discussion of the temperature dependence of MCF_i (D7-3), it was concluded that values provided for Florida would be most appropriate to represent Hawaii. As in the process of calculating methane emissions from domesticated animals, subcategories for cattle were assigned. These subcategories were the same as those in Table 9.2. The calculation of methane emissions from cattle manure management systems in Hawaii is presented in Table 9.5.

Table 9.5 Methane Emissions Produced by Cattle Manure Management Systems in Hawaii, 1990

	Dairy Cattle		Beef Cattle				
	Mature Cows	Replacements	Mature Cows	Replacements	Yearlings	Weanlings	Bulls
Population[1]	11,000	8,174	75,000	30,826	26,000	49,000	5,000
TAM = Typical animal mass (lbs./head)[2]							
Pasture	1,345	903	1,102	794	794	397	1,597
Drylot				915	915		
vs (VS/lb.)[2]	3.65	3.65	2.6	2.6	2.6	2.6	2.6
VS (lbs./yr.)	54,001,750	26,941,095	214,890,000	439,520	370,711	50,577,800	20,761,000
B_0 = maximum methane producing capacity per pound of VS for animal type (ft^3/VS)[3]							
	3.84	3.84	2.72	2.72	2.72	2.72	2.72
MCF = Methane Conversion Factor [4]							
Anaerobic Lagoon	0.900	0.900	-	-	-	-	-
Liquid/Slurry/Pit	0.386	0.386	-	-	-	-	-
Daily Spread	0.006	0.006	-	-	-	-	-
Solid/Drylot	0.024	0.024	0.024	0.024	0.024	0.024	0.024
Pasture/Range	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Other	0.100	0.100					
WS% = Percent of animal type's manure managed in manure system [5]							
Anaerobic Lagoon	0.31	0.31	-	-	-	-	-
Liquid/Slurry/Pit	0.57	0.57	-	-	-	-	-
Daily Spread	0.06	0.06	-	-	-	-	-
Solid/Drylot	-	-	0.10	0.10	0.10	0.10	0.10
Pasture/Range	0.06	0.06	0.90	0.90	0.90	0.90	0.90
Other	0.06	0.100					
Conversion Factor: ft.^{3} CH_4 to lbs. CH_4			0.0413				
CH4 (Tons)							
Anaerobic Lagoon	1,195	596	-	-	-	-	-
Liquid/Slurry/Pit	942	470	-	-	-	-	-
Daily Spread	2	1					
Solid/Drylot	-	-	29	0.06	0.05	7	3
Pasture/Range	4	2	163	0.33	0.28	38	16
Other	26	21					
TOTAL CH_4 (Tons)	2,168	1,090	192	0.4	0.3	45	19
TOTAL CH_4 (Tons) from Cattle		3,514					

[1] *State of Hawaii, 1994b,* 80

[2] USEPA, 1995b, Table 7-10, 7-2

[3] USEPA, 1995b, Table 7-11, 7-12

[4] USEPA, 1995b, Table 7-12, 7-13

[5] USEPA, 1995b; Tables 7-1, 7-2, 7-13; 7-5, 7-6, 7-14

Table 9.6 shows the calculation of methane emissions produced by layer and broiler chickens, sheep, and breeder and market swine.

Table 9.6. Methane Emissions Produced by Chicken, Sheep, and Swine Manure Management Systems in Hawaii, 1990

	Chickens		Other		
	Layers	Broilers	Sheep	Breeder Swine	Market Swine
Population[1]	974,000	1,940,000	27,000	6,000	30,000
TAM = Typical animal mass (lbs./head)[2]	4	2	154	399	101
vs (VS/lb.)[2]	4.40	6.20	3.4	3.1	3.1
VS (lbs./yr.)	14,999,600	18,042,000	13,970,880	7,421,400	9,393,000
B_0 = maximum methane producing capacity per pound of VS for animal type (ft^3/VS)[3]	5.45	4.81	3.04	5.77	7.53
MCF = Methane Conversion Factor [4]					
Anaerobic Lagoon	0.900	-	-	0.90	0.90
Pit <1 mo.	-	-	-	0.19	0.19
Pit >1 mo.	0.193	-	-	0.39	0.39
Solid/Drylot	-	-	-	0.02	0.02
Litter	-	0.015	0.015	-	-
Other	0.100	-	0.0	0.10	0.10
WS% = Percent of animal type's manure managed in manure system [5]					
Anaerobic Lagoon	0.80	-	-	0.32	0.32
Pit <1 mo.	-	-	-	0.17	0.17
Pit >1 mo.	0.10	-	-	0.36	0.36
Solid/Drylot	-	-	-	0.07	0.07
Litter	-	1.00	0.92	-	-
Other	0.90	-	0.08	0.080	0.080
Conversion Factor: $ft.^3$ CH_4 to lbs. CH_4			0.0413		
CH_4 (Tons)					
Anaerobic Lagoon	1,215	-	-	255	421
Liquid/Slurry/Pit	-	-	-	29	48
Daily Spread	33	-	-	123	203
Solid/Drylot	-	-	-	1	2
Litter	-	27	12	-	-
Other	152	-	2	7	12
TOTAL CH_4 (Tons)	1,400	27	14	415	686

[1] *State of Hawaii, 1994b,* 80

[2] USEPA, 1995b, Table 7-10, 7-2

[3] USEPA, 1995b, Table 7-11, 7-12

[4] USEPA, 1995b, Table 7-12, 7-13

[5] USEPA, 1995b; Tables 7-1, 7-2, 7-13; 7-5, 7-6, 7-14

Population data on horses, donkeys, mules, and goats were not available. However, lack of such data did not significantly affect emissions results. Manure from those particular animals would most likely be found in pastures or similarly dispersed, and thus manure management would involve aerobic rather than anaerobic conditions, which reduces the amount of methane produced.

It is also important to note that although poultry is included here, detailed data were only available for laying chickens. Data on the number of broiler chickens were not available, but the number sold in 1990 – 1,940,000 – was provided in *Statistics of Hawaii Agriculture 1993* (94) and was used as a proxy. More detailed information on broiler chickens is expected to be difficult to obtain in the future due to the competitive concerns of the few broiler producers in Hawaii.

9.5 Emissions from Agricultural Soil Management

Greenhouse gas emissions can also result from various agricultural soil management practices. Emissions of N_2O, for example, which occur naturally in soils, can be increased by the application of nitrogen-bearing synthetic and organic fertilizers. Soils are both sources and sinks for CO_2 and CO, sources of N_2O, and sinks for CH_4. Fluxes of such gases can be affected by tillage practices, irrigation, and the non-use, or fallowing, of fields. The *State Workbook* (USEPA, 1995b) methodology endeavors to quantify emissions based on fertilizer use only, since much uncertainty remains about the other management practices and the direction (i.e., source or sink) and magnitude of their effects (9-1).

Fertilizer use data necessary to determine emissions were obtained from the *Fertilizer Summary* (TVA, 1992), published annually by the Tennessee Valley Authority (TVA) National Fertilizer and Environment Research Center. State Department of Agriculture personnel stated that the TVA publication was the only data source. However, it should be kept in mind that TVA data since 1985 were not derived from reports of actual consumption; rather, the data were estimated by TVA as simple proportions of consumption (Hoover, 1997). All emissions calculations were performed in accordance with models developed by the EPA as listed in the *State Workbook* (9-1 - 9-4). The 1989 - 1991 three year average annual consumption of fertilizer was used instead of 1990 data alone in order to avoid unusual annual variations due to economic, climatic, and other variables.

The following equation was used to calculate emissions:

$$E_f = F_f \times N\% \times CF_1 \times CF_2 \qquad \text{(Equation 9.4)}$$

Where:
E_f = annual N_2O emissions from fertilizer "f"
F_f = annual usage of fertilizer "f" (T/yr.)
$N\%$ = percent of nitrogen in fertilizer "f"
CF_1 = conversion factor for nitrogen (T/yr.) to N_2O as N (T/yr.) = 0.0117
CF_2 = conversion factor for N_2O as N to N_2O (T/yr.) = 44/28 = 1.57

Nitrous oxide emissions from the annual average of 22,485 tons of fertilizer applied in Hawaii in the years 1989 - 1991 were 196 tons as depicted on Table 9.7.

Table 9.7 N_2O Emissions from Fertilizer Applications in Hawaii, 1990

Fertilizer	Fertilizer Applied[1] (Tons)	Percent Nitrogen	CF_1: N to N_20 [4] (Tons/Year)	CF_2: N to N_20 [4] (Tons/Year)	N_2O Emitted (Tons)
Ammonium Sulfate	944	21	0.0117	1.571	4
Urea	2,580	46	0.0117	1.571	22
Other: Nitrogen Solutions	18,961	49 [3]	0.0117	1.571	171
Total	**22,485**				**196**

[1] TVA, 1992 – Average for years 1989 - 1991 used per *State Workbook*

[2] USEPA, 1995b, Table 9-1, 9-2

[3] Nitrogen solutions vary between 21 and 49 percent, high value used

[4] USEPA, 1995b, 9-2 – 9-3.

9.6 Emissions from Forest Management and Land-Use Change

Human activities involving forest management and land-use changes affect the net flux of carbon by altering the amount of carbon stored in the biomass and soils of forest ecosystems. For example, intensified forest management can cause an increased growth rate among forest vegetation, which increases biomass density and thus carbon uptake. Similarly, increased carbon uptake and storage in biomass and soils can result when cropland is abandoned, allowing natural regeneration of forest vegetation. Such activities are considered here because they involve a number of greenhouse gases, including CO_2, CH_4, and N_2O; however, CO_2 is the gas of primary concern and the focus of this section.

The *State Workbook* (10-1 – 10-10) provided the models used to determine the magnitude and trends of CO_2 fluxes from forest management practices. The methodology employed was based on the assumption that CO_2 flux to and from the atmosphere is equal to changes in the carbon stocks of existing biomass and soils. Three categories of activity were evaluated:

- Changes in forests and other biomass stocks (logging, planting, restocking, urban forestry, agroforestry, and fuelwood extraction);
- Forest and grassland conversion (permanent forest clearing, conversion of grasslands to cultivated lands, shifting cultivation, urban development, suburban development, and parking lots); and
- Abandonment of managed lands (abandonment of managed pastureland, cropland, etc.) (10-2).

The formula for determining carbon emissions from or uptake by forest management practices is as follows:

$$\mathbf{CO_2\ Flux = A_i \times GR_i \times C\% \times BH_i \times CF} \qquad \text{(Equation 9.5)}$$

Where: **A_i** = area of accumulating biomass for forest of type "i", in acres

GR_i = annual growth rate of tree type "i", in tons of dry matter per acre per year

C% = percent of biomass consisting of carbon (essentially the same for all Hawaiian tree types), expressed as a fraction

Bh_i = biomass of forest type "i" harvested per year

CF = conversion factor for C to CO_2 = 44/12 (D10-5).

This equation ignores emissions from soils (10-2). Equation 9.5 also assumes that trees replaced bare ground, that is, no biomass was replaced. As a result, uptake as calculated here may be less and emissions from soils may be less, so the two may balance out somewhat.

Although models developed by the EPA were detailed, data inventory proved to be difficult. Published data could not be found on changes in forests in Hawaii. Since the data available were minimal and insufficient, calculations were not made; however, discussions with state forestry personnel did result in some information.

The State Division of Forestry and Wildlife (DFW) reported that there are currently 1.99 million acres of forest in Hawaii, of which 97.7% is classified as "native" forest. The remaining 2.3%, comprising 46,000 acres of "managed" forests, is planted with eucalyptus, other hardwoods, and pine. The DFW also indicated that, as of 1990, no harvesting has been carried out in any forest on state land since the late 1970s and early 1980s. Forestry personnel stated that limited harvesting has been carried out on private lands, but no records were available. For these 46,000 acres of "managed" forest, the *State Workbook* (D10-7) provides a table listing the average annual increment in biomass per acre per year for a normally-growing forest plantation. These data have been incorporated into Table 9.8 below. Since annual data for areas under forest management were unavailable, the total tonnage in Table 9.8 is presented as the 1990 uptake.

Table 9.8 Carbon Dioxide Uptake by Managed Forests in Hawaii

Type of Tree	Total Area with Accumulating Biomass[1] (Acres)	Annual Growth Rate[2] (Tons dm/ Acre/Year)	Annual Biomass Increment (Tons dm/ Year)	Carbon Fraction of Dry Matter (Tons C / Tons dm)	Annual Carbon Uptake Increment (Tons C/ Year)	Annual Biomass Harvested (Tons dm/ Year)	Net Annual CO_2 Emissions (+) or Uptake (-) (Tons C/ Year)
Eucalyptus	27,500	6.5	178,750	0.5	89,375	0.0	-327,708
Hardwoods	12,000	3.0	36,000	0.5	18,000	0.0	-66,000
Pines	6,500	1.8	11,700	0.5	5,850	0.0	-21,450
Total	**46,000**		**226,450**		**113,225**	**0.0**	**-415,158**

[1] State of Hawaii, 1995b, Table 20.01, 509 and discussions with DFW officials

[2] USEPA, 1995b, Table 10-1, 10-5

dm = dry matter.

As can be seen in this table, use of Equation 9.5 for the 46,000 acres of "managed" forest on state lands in Hawaii shows a substantial uptake of carbon by forests in these managed plantations. Indeed, this uptake is sufficient to more than offset the total tonnage of all greenhouse gases emitted by all other land use practices described in this report. However, mere tonnages are misleading and, in spite of this large negative figure, Hawaii's anthropogenic non-energy greenhouse gas emissions still have a significant positive climate warming capability.

Detailed data as required in the *State Workbook* (10-4) were not available on forest and grassland conversion from state or private sources. The most likely conversion to have occurred in Hawaii over the past 20 years would be from agricultural lands to urban; however, no published statistics could be found. While little or no conversion of forest land was found to have occurred, some of Hawaii's former sugar cane lands have been converted to other crops such as macadamia nut and coffee.

Data on abandoned lands, also required to use the *State Workbook* (10-4) methodology, could not be found. In recent years, several large sugar plantations have closed in Hawaii and left thousands of acres of former sugarcane fields fallow, converted to other crops, or rezoned for urban uses (residential, resort, commercial, or industrial). Although this loss of cane fields may continue if additional sugar growing and processing operations are closed, it is not expected that those lands which have been "abandoned" will remain so for long enough to develop significant tree growth, unless planted for forestry. However, at the present time, 59,500 acres have been temporarily abandoned across four islands (Hawaii, Maui, Oahu, and Kauai). Accordingly, the current carbon uptake by these lands was calculated according to the following formula from the *State Workbook* (D10-6).

$$\mathbf{CO_2\ Flux = A \times GR \times US \times C\% \times CF} \qquad \text{(Equation 9.6)}$$

Where: **A** = 20-year (or less) total area of land abandoned and regrowing, in acres

GR = annual rate of aboveground biomass growth, in tons of dry matter per acre per year

US = annual rate of carbon uptake by soils, in tons per acre

C% = percent of biomass consisting of carbon (essentially the same for all Hawaiian tree types), expressed as fraction

CF = conversion factor for C to CO_2 = 44/12.

Since no values are available in the *State Workbook* for carbon uptake by tropical or semitropical soils, the value of US for temperate soils, 0.58, was used in Equation 9.6 (Table D10-7, D10-15). The resulting calculation is presented in Table 9.9.

Table 9.9 Estimated Carbon Uptake by Abandoned Lands in Hawaii, 1990

20 Year Total Area Abandoned and Regrowing[1]	Annual Rate of Above-ground Biomass Growth[2]	Annual Above-ground Biomass Growth	Carbon Fraction of Above-ground Biomass	Annual Carbon Uptake in Above-ground Biomass, < 20 years	Annual Uptake of Carbon in Soils	Total Annual Carbon Uptake in Soils < 20 yrs	Total Carbon Dioxide Emission (+) or Uptake (-)
(Acres)	(Tons dm/ Acre/Year)	(Tons dm)	(Tons C/ Ton dm)	(Tons C/ Year)	(Tons C/ Acre/Year)	(Tons C/ Year)	(Tons CO_2/ Year)
59,500	3.6	214,200	0.5	107,100	0.58	34,510	-519,237

[1] Discussions with DFW officials

[2] USEPA, 1995b, Table 10-5, 10-12

dm = dry matter.

The current trend of abandonment of agricultural lands in Hawaii induces a carbon uptake similar to that of forest management practices discussed above. This trend will likely taper off in the future, as these lands are brought into new types of cultivation or are developed for other uses. However, current plans to convert much of this acreage to crops of macadamia, coffee, eucalyptus and other trees should maintain most of the land as carbon sinks. Unfortunately, the lack of annual data reporting for this sector in Hawaii makes it impossible to produce tables specifically for 1990 emissions from abandoned agricultural lands. As a result, the total reported here is used for the 1990 value.

There are many uncertainties about emissions from forest and land-use changes. Considering the massive carbon uptake capability of Hawaii's forests, shrublands and abandoned agricultural fields, a mechanism should be developed to monitor forest and agricultural activity to determine how these changes affect greenhouse gas emissions.

9.7 Emissions from Burning Agricultural Crop Waste

Sugarcane growers in Hawaii burn their crops prior to harvest to reduce the mass of material that must be transported to sugar mills. Sugarcane crop burning is not practiced annually but rather on a two-year cycle for any given field. Burning of crop matter is included here since it results in the release of several greenhouse gases including CO_2, CH_4, NO_x, and CO. The practice, however, is not considered a net source of CO_2 because the released CO_2 is normally reabsorbed by crop regrowth during the next growing season.

To determine the emissions of the above greenhouse gases, the following steps were accomplished:

- Collection of data on sugarcane and pineapple crop annual production;
- Conversion of data into pounds of biomass produced to determine emissions;
- As per the models listed in the *State Workbook*, determination of the annual greenhouse gas emissions for each crop; and
- Plotting of results and evaluation for any trends.

Statewide sugarcane production data were obtained from the Hawaiian Agricultural Research Center (formerly Hawaiian Sugar Planters' Association) (HSPA, 1991). Unfortunately, although pineapple crop waste has been burned in Hawaii for several years, data on this crop could not be obtained. Although records were maintained by the Clean Air Branch of the State Department of Health, all records for years prior to 1993 were recently discarded (Tam, 1996). In addition, the *State Workbook* does not contain any emissions factors for pineapple, factors which were necessary parameters for any emissions equations. Thus, calculations for pineapple crop waste were not performed.

The following five equations were used to determine greenhouse gas emissions for sugarcane. Equation 9.7 was used to calculate the amount of dry matter burned in pounds.

$$\mathbf{DM = CP \times R{:}C \times RB\% \times DM\% \times B\%} \qquad \text{(Equation 9.7)}$$

Where: **DM** = dry matter burned (lbs.)
CP = crop production (lbs.)
R:C = residue/crop ratio = 0.8
RB% = percent of residue burned, expressed as a fraction = 0.1 (EPA default value)
DM% = percent of residue consisting of dry matter, expressed as a fraction = 0.90 (EPA default value)
B% = "fraction burned," = 0.93 (EPA default value)

Using the result of Equation 9.7, Equation 9.8 was used to calculate the total carbon oxidized.

$$\mathbf{TCO = DM \times C\% \times C_{OX}\%} \qquad \text{(Equation 9.8)}$$

Where: **TCO** = total carbon oxidized (lbs. CO_2 as C)
DM = dry matter burned (lbs.)
C% = percent of dry matter consisting of carbon, expressed as a fraction = 0.4695
C_{OX}% = percent of carbon oxidized, expressed as a fraction = 0.88

Next, Equation 9.9 was used to calculate total nitrogen released in pounds.

$$\mathbf{TNR = TCO \times N{:}C} \qquad \text{(Equation 9.9)}$$

Where: **TNR** = total nitrogen released (lbs. N)
TCO = total carbon oxidized (lbs. CO_2 as C)
N:C = nitrogen:carbon ratio = 0.0064

Equation 9.10 was used to determine tons of carbon gas emitted.

$$\mathbf{CG = TCO \times CFC/2000} \qquad \text{(Equation 9.10)}$$

Where: **CG** = carbon gas (CO or CH_4) emissions (tons)
TCO = total carbon oxidized (lbs. CO_2 as C)
CFC = conversion factors for carbon gases: CO = 0.06; CH_4 = 0.003

Finally, Equation 9.11 was used to calculate nitrogen gas emissions in tons.

$$\mathbf{NG = TNR \times CFN/2000} \qquad \text{(Equation 9.11)}$$

Where: **NG** = nitrogen gas (N_2O or NOx) emissions (tons)
TNR = total nitrogen released (lbs. N)
CFN = conversion factor for nitrogen gases: N_2O = 0.007; NOx = 0.121 (USEPA, 1995b, 11-2 – 11-4)

Some of the variables in Equations 9.7 - 9.11 have questionable merit, especially those in Equation 9.7. For example, the term "fraction burned" is never explained in the *State Workbook*, and seems superfluous since a fraction for "residue burned" is already included. Furthermore, the EPA has provided default values for sugarcane (but not pineapple) in the *State Workbook* -- values which may not be applicable to Hawaii. In particular, the suggestion that only 10% of sugarcane "residue" is burned seems to be far too low. However, since local records on these variables are not available, the EPA default values were used. Using Equations 9.7 - 9.11, greenhouse gas emissions were calculated for sugarcane crop burning. Table 9.10 displays the results.

Table 9.10 Emissions from Agricultural Field (Sugarcane) Burning in Hawaii, 1990

Total Crop Produc-tion (Tons/ Year)	Dry Matter (Tons)	Total Carbon Oxidized (Tons)	Total Nitrogen Released (Tons)	CH_4 Emitted (Tons)	N_2O Emitted (Tons)	NO_x Emitted (Tons)	CO Emitted (Tons)	Total Emissions (Tons)
6,540,925	437,980	180,956	1,158	543	8.1	140	10,857	**11,548**

CO was the primary greenhouse gas emitted by agricultural field burning. This is not surprising, since CO emission is typically a result of oxygen starvation during fires, which is common in field burning of carbonaceous matter on this scale. The estimates may also understate actual emissions. Some reasoning for this assertion has already been explained above, but this does not exhaust the arguments. For example, in 1972, the State of Hawaii estimated that agricultural field burning produced 57,200 tons of carbon monoxide and 1,140 tons of nitrogen oxides per year (quoted in American Lung Association, 1974). Furthermore, Daniels (1979) found through field experiments that previous small-scale measurements of CO emissions from both sugarcane and pineapple waste burning had grossly underestimated CO emissions per ton of biomass. Daniels concluded that sugarcane produced a surprising 5,000 lbs. of CO per ton of biomass, versus 70.6 lbs./ton as measured in previous burn tower experiments. This discrepancy was attributed by Daniels to accumulation of dried leaves and other material on the ground surface, which restricted airflow near the ground (Daniels, 1979). Thus, the numbers in Table 9.10 might be considered minimum values for emissions of the various greenhouse gases.

Although emissions were calculated for sugarcane, at least from the standpoint of the *State Workbook*, it may benefit the state to develop a method for determining the contribution of greenhouse gas emissions from pineapple crop residue. This would result in a more accurate analysis of greenhouse gas contributions from agricultural crop burning. It may be useful to develop Hawaii-specific emissions factors, as discussed above. As pointed out both here and in the workbook, the models developed by the EPA are crude and possess a fairly large degree of uncertainty. Research may be needed to determine specific emission ratios based on type of biomass and burn conditions. Also ignored in the EPA model is the effect of previous burns on soil carbon content, which may influence emissions from current or future burns.

APPENDIX A ACKNOWLEDGEMENTS

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