

Inventory of Oklahoma Greenhouse
Gas Emissions and Sinks:
1990 and 1999

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Executive Summary

Introduction

This report is a statewide greenhouse gas (GHG) emission inventory for Oklahoma and was funded by an Environmental Protection Agency (EPA) grant. Guidance for this inventory was provided by the EIIP Document Series, *Volume VIII: Estimating Greenhouse Gas Emissions*. The guidance document standardizes the methodologies used among the states and was jointly sponsored by the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO) and EPA. The guidance describes sources of data, emission factors for GHGs, calculation methods, sources of uncertainty, and suggestions on reporting.

An emission inventory is an accounting of the amount of air pollutants discharged into the atmosphere. Greenhouse gases refer to a group of chemicals thought to contribute to global warming. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Effects of global warming may impact public health, environment and the economy. Additional details concerning the causes and effects of global warming can be found in the EIIP guidance document and on EPA's website at <http://www.epa.gov/globalwarming>.

The gases being inventoried include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulfur hexafluoride (SF₆) and perfluorocarbons. This inventory identifies the predominant sources of GHG emissions and presents annual emissions from 14 sectors (e.g., fossil fuels, waste disposal, industrial processes), by source (e.g., transportation emissions, manure management), and by gas (e.g., carbon dioxide, methane). Two years were inventoried, 1990 was established as a baseline and 1999 represented the most recent year with complete data available. When possible, state-level data were used, otherwise, nationally collected data were incorporated. This report is comprised of 14 chapters, each representing a specific emissions sector. Each chapter contains the following sections: 1) an overview explaining the GHG source, 2) a method detailing the calculation process, 3) a results outlining the data, 4) a summary compiling the results in tables and figures, and 5) a reference listing the data sources.

This inventory provides a baseline for comparison of future inventories and progress. It may be used by scientists as inputs to air quality models, by policy makers in developing strategies and programs to reduce GHG emissions, and by facilities and regulatory agencies to establish compliance records and technologies. This emission inventory will form the foundation for Oklahoma to address climate change.

Summary

Oklahoma GHG total net emissions exhibited a 22% increase from 1990 to 1999. Net metric tons of carbon equivalent (MTCE) was 23,247,771 for 1990 and 28,318,340 for 1999 (Table E.1.) In 1990 total emission was 33,688,421 MTCE and total sequestration (represented as a negative number) was -10,440,650 MTCE (Figure E.1.) In 1999 total emission was 38,821,143 MTCE and total sequestration was -10,502,803 MTCE.

By Gas

When addressing the inventory results by gas, CO₂ contributed the most to the actual emissions at 72% in 1990 and 70% in 1999. But when including the sectors that sequester carbon, CO₂ comprised 59% in 1990 and 58% in 1999 of GHG net total emissions. CH₄ emissions comprised 28% and 29% of GHG net total emissions in 1990 and 1999 respectively. N₂O contributed a lesser amount of 13% in 1990 and 12% in 1999 to the net total emissions. The remaining gases comprised less than 1% each for either year. In 1999, each gas maintained a similar percentage contribution to the total net emissions as occurred in 1990, even with the 22% increase in totals. More details concerning the changes within each sector can be found in the specific chapters.

CO₂

GHG emission from CO₂ releases was a net positive even though two sectors exhibited negative (sequestration) emissions (Table E.1.) Final MTCE from CO₂ sources was 13,701,109 for 1990 and 16,471,732 for 1999. The largest CO₂ contributor to MTCE was the Fossil Fuel sector at 99% for both years (Figure E.3.) The Municipal Waste Disposal sector sequestered a small portion of MTCE, however, the Forest Management and Land-Use Change sector sequestered a considerable amount of MTCE in the form of CO₂. It totaled -10,208,332 MTCE for both years. Fossil Fuel MTCE increased by 12% from 1990 to 1999, while the Industrial sector CO₂ release increased by 28%. MTCE from CO₂ releases exhibited a net increase of 20% from 1990 to 1999.

CH₄

GHG emission from CH₄ releases was 6,423,654 in 1990 and 8,207,554 in 1999, an increase of 28% (Table E.1.) The largest contributor of MTCE from CH₄ was the Natural Gas and Oil Systems in 1990 at 45% and the Manure Management sector in 1999 at 40% (Figure E.4.) The Coal Mining sector had the largest increase of CH₄ release at 1,500%, however it was less than 0.5% of the total for either year. In 1990, Domesticated Animals and Manure Management sectors each comprised 25% of MTCE from CH₄ respectively. However, in 1999 Domesticated Animals decreased to 21%, while Manure Management increased to 40% of the total MTCE from CH₄.

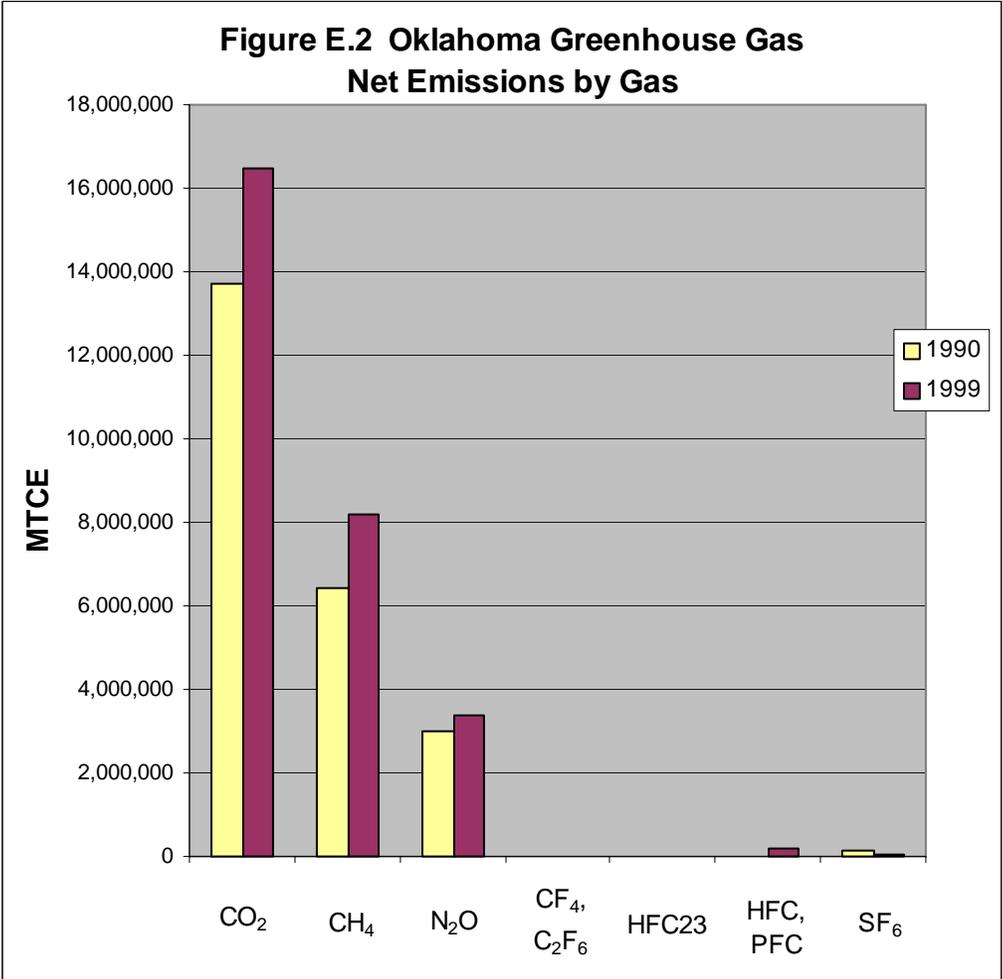
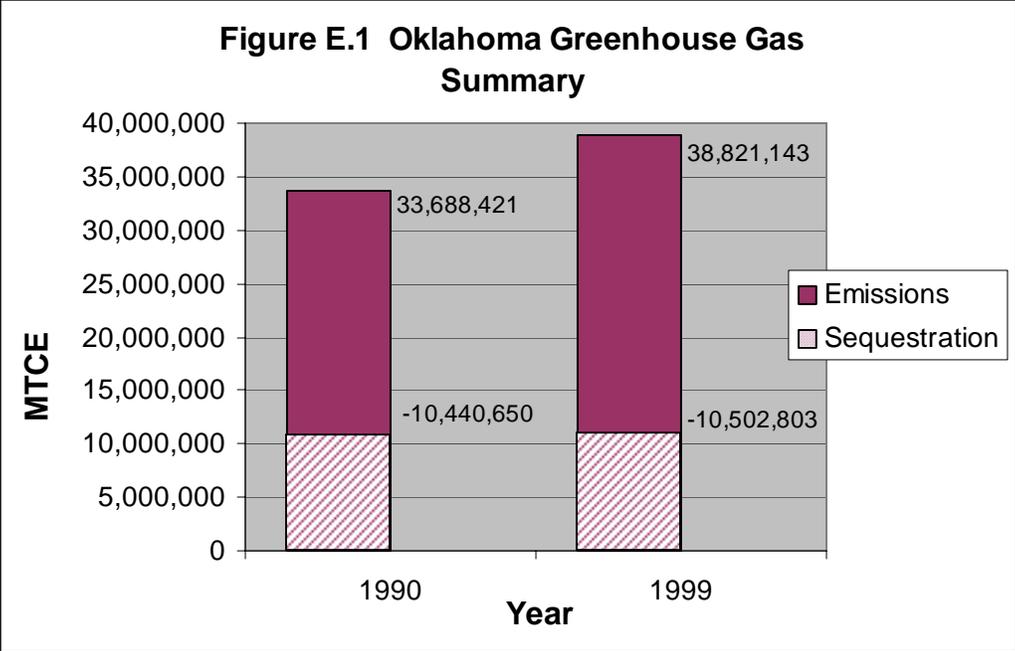
N₂O

Total MTCE from N₂O releases was 2,985,580 in 1990 and 3,403,328 in 1999, an increase of 14% (Table E.1.) The largest contribution to this GHG total was from the Agricultural Soil Management sector at 78% in 1990 and 75% in 1999 (Figure E.5.) The Industrial Processes sector comprised 12% and 13% of N₂O release for 1990 and 1999 respectively, while the Mobile Combustion sector made up 7% and 8% respectively.

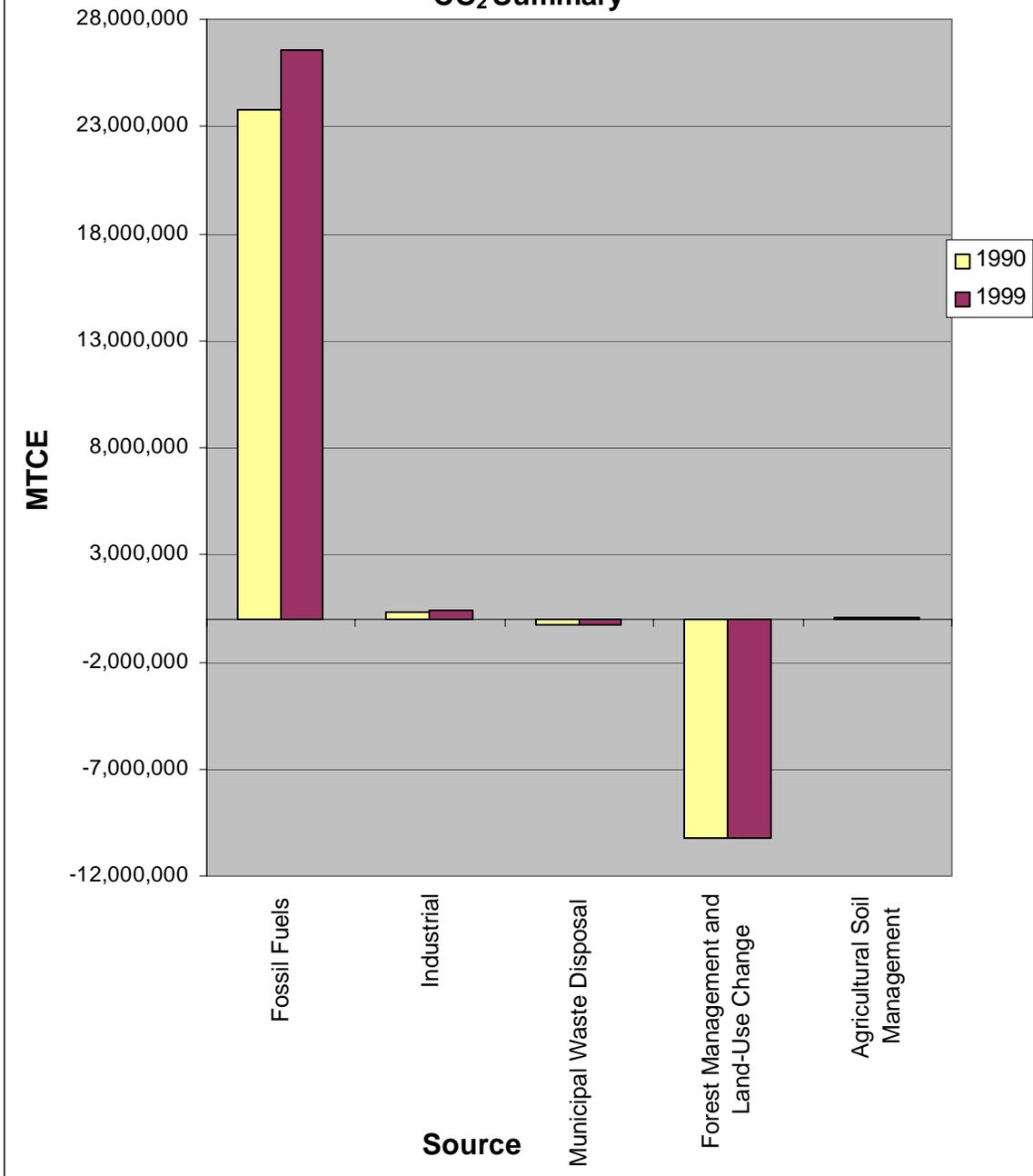
Other Gases

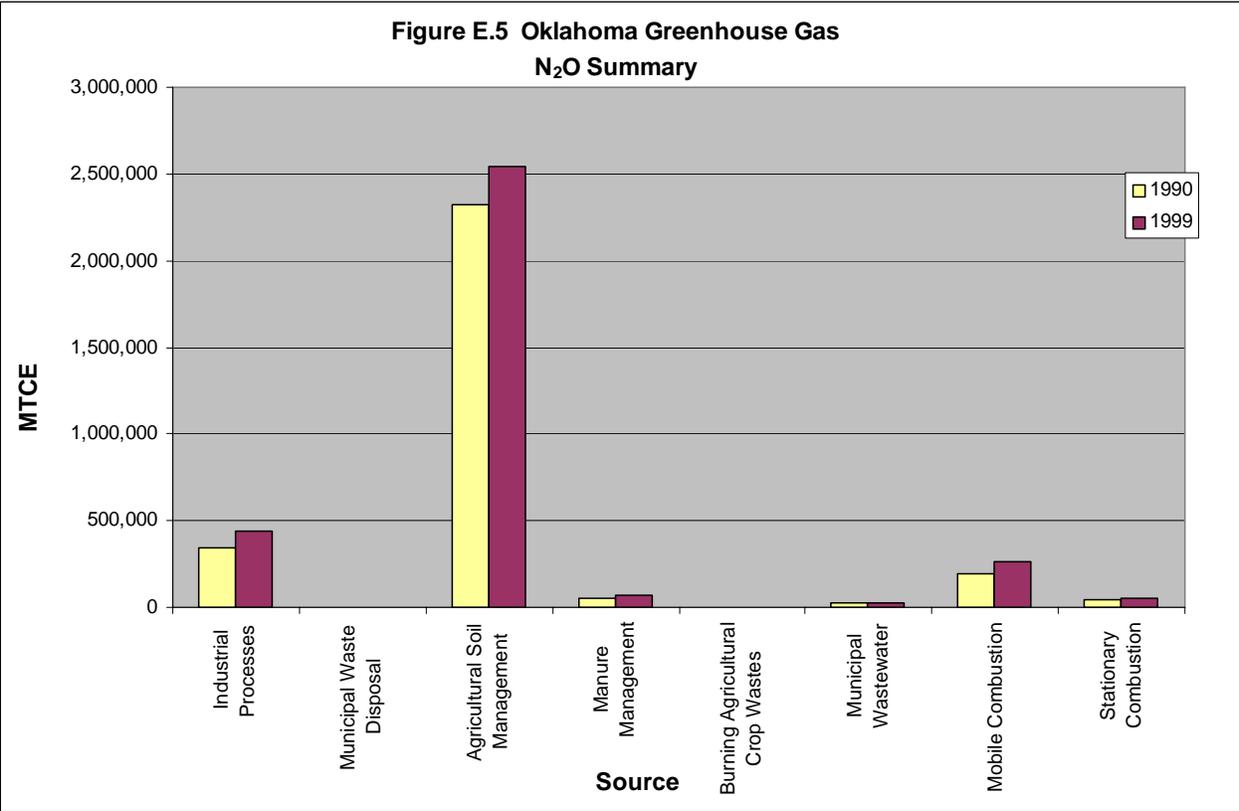
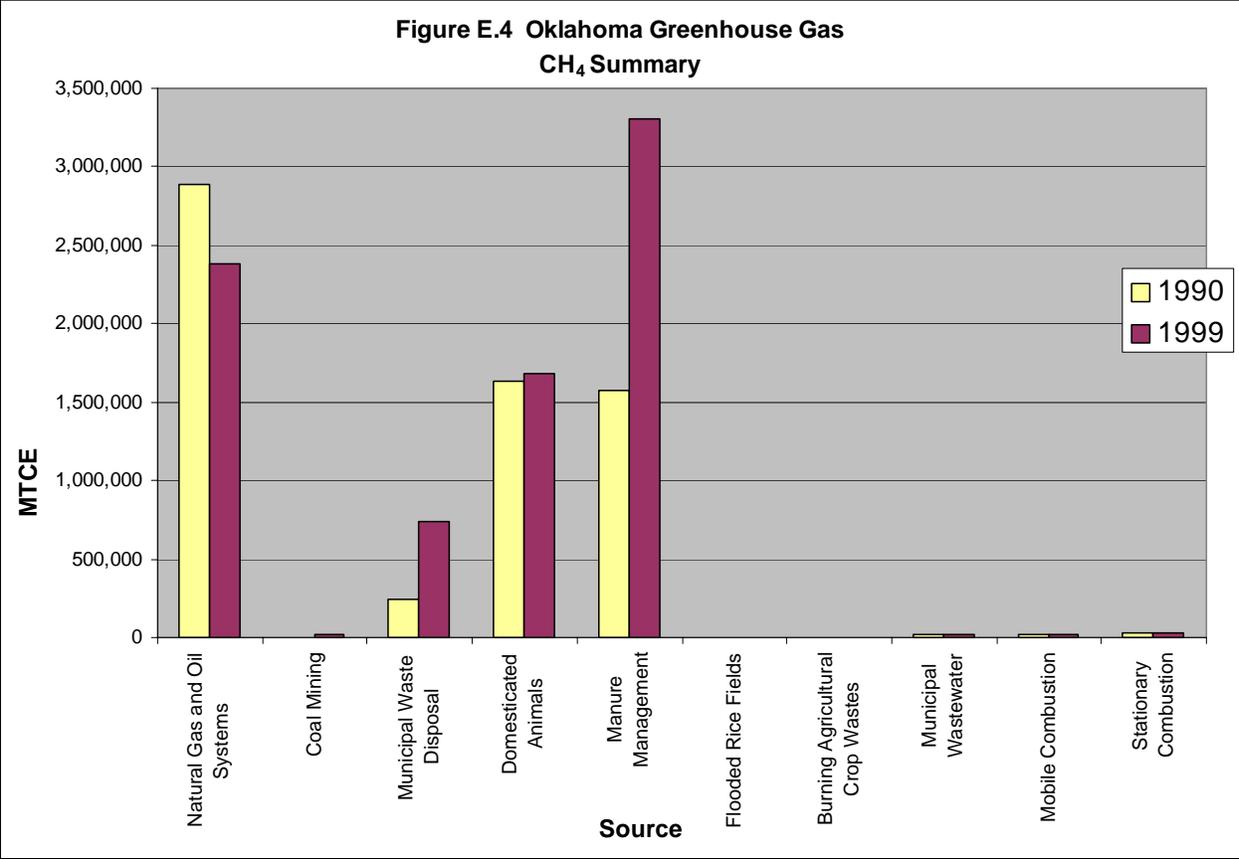
Industrial Processes sector potentially released several other greenhouse gases in smaller quantities. No CF₄, C₂F₆, nor HFC23 were released in either year. HFC and PFC were categorized together. The release of this category was 3,103 MTCE in 1990 and 171,339 MTCE in 1999 (Table E.1.) This was an increase of 5,421%. Release of SF₆ was 134,325 MTCE in 1990 and 64,387 MTCE in 1999 and resulted in a decrease of 52%. These items are further detailed in the Industrial Processes chapter.

Table E.1 Oklahoma Greenhouse Gas Emissions		
by Gas		
Sources	1990	1999
	MTCE	MTCE
CO₂		
Agricultural Soil Management	29,095	26,602
Fossil Fuels	23,810,194	26,562,101
Industrial	302,470	385,832
Municipal Waste Disposal	-232,318	-294,471
Forest Management and Land-Use Change	-10,208,332	-10,208,332
CO₂ Total	13,701,109	16,471,732
CH₄		
Natural Gas and Oil Systems	2,892,016	2,384,406
Coal Mining	1,401	22,418
Municipal Waste Disposal	244,279	742,777
Domesticated Animals	1,629,273	1,681,154
Manure Management	1,578,904	3,308,353
Flooded Rice Fields	4,392	1,538
Burning Agricultural Crop Wastes	2,714	2,059
Municipal Wastewater	19,011	20,773
Mobile Combustion	21,922	19,211
Stationary Combustion	29,742	24,865
CH₄ Total	6,423,654	8,207,554
N₂O		
Industrial Processes	343,964	442,019
Municipal Waste Disposal	3,026	2,761
Agricultural Soil Management	2,321,538	2,545,236
Manure Management	52,229	67,861
Burning Agricultural Crop Wastes	381	316
Municipal Wastewater	26,606	29,072
Mobile Combustion	194,017	262,421
Stationary Combustion	43,819	53,642
N₂O Total	2,985,580	3,403,328
CF₄, C₂F₆		
Industrial Processes	0	0
HFC23		
Industrial Processes	0	0
HFC, PFC		
Industrial Processes	3,103	171,339
SF₆		
Industrial Processes	134,325	64,387
TOTAL Net	23,247,771	28,318,340



**Figure E.3 Oklahoma Greenhouse Gas
CO₂ Summary**





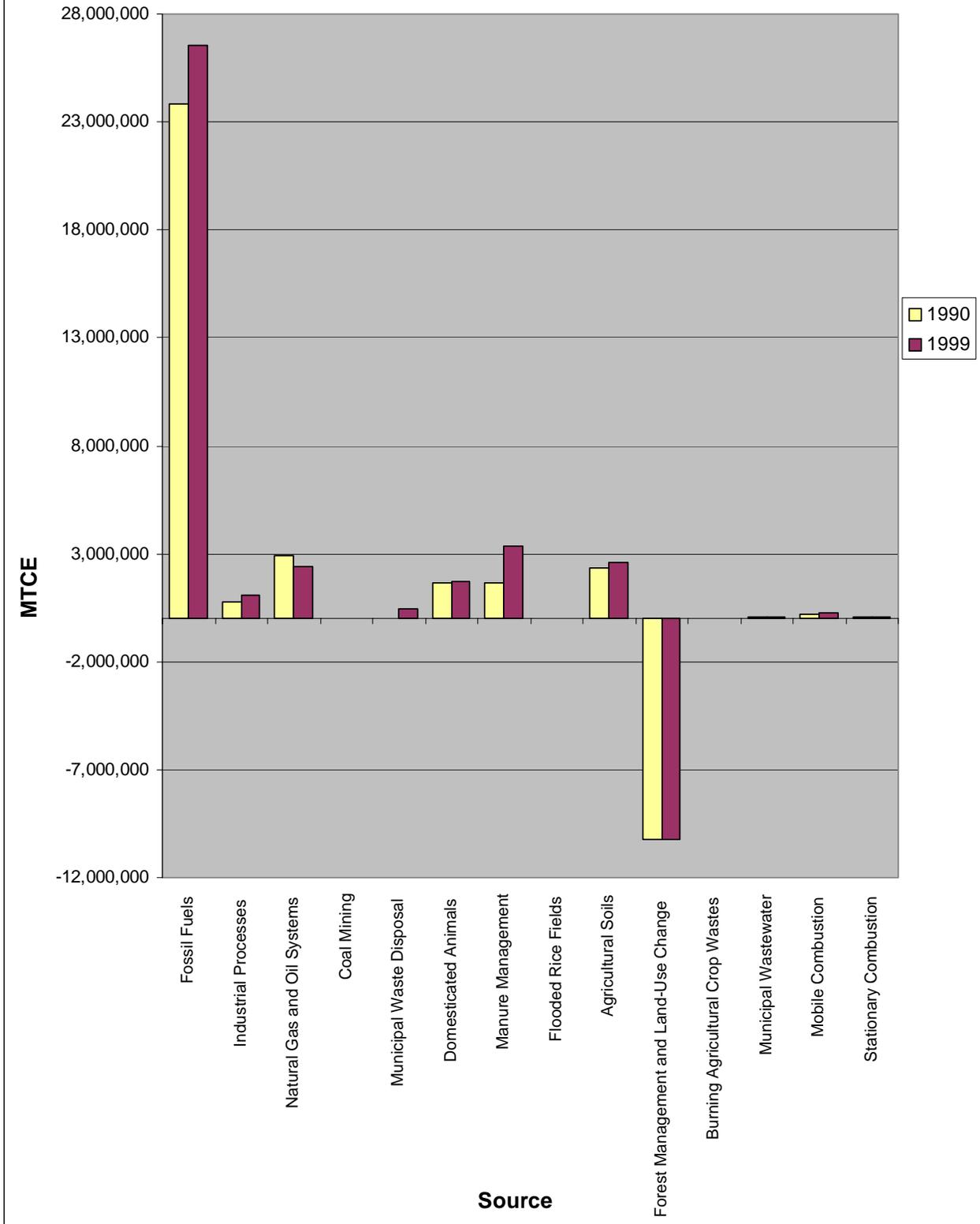
By Source

The Fossil Fuel sector comprised the largest percentage of total MTCE emissions for both 1990 and 1999 at 71% and 68% respectively (Figure E.6.) While this was a slight decrease in total contribution to MTCE, Fossil Fuel emissions actually increased by 12% from 1990 to 1999 (Table E.2.) The second largest contributor in 1990 was Natural Gas and Oil Systems at 9% of total MTCE and Manure Management at 9% in 1999. Agricultural Soils was the third largest contributor for both years.

From 1990 to 1999, Industrial Processes MTCE increased by 36% and comprised less than 3% of total MTCE during both years. While Natural Gas and Oil Systems showed the second highest MTCE in 1990, by 1999 its MTCE input had decreased by 18%. The opposite occurred for Manure Management. From 1990 to 1999, its MTCE had increased by 107%, making it the second highest. Mobile Combustion exhibited a 30% increase during this time frame, yet only comprised 1% of total MTCE for both years.

Table E.2 Oklahoma Greenhouse Gas Emissions		
by Source		
Source	1990	1999
	MTCE	MTCE
Fossil Fuels	23,810,194	26,562,101
Industrial Processes	783,862	1,063,577
Natural Gas and Oil Systems	2,892,016	2,384,406
Coal Mining	1,401	22,418
Municipal Waste Disposal	14,987	451,067
Domesticated Animals	1,629,273	1,681,154
Manure Management	1,631,133	3,376,214
Flooded Rice Fields	4,392	1,538
Agricultural Soils	2,350,633	2,571,838
Forest Management and Land-Use Change	-10,208,332	-10,208,332
Burning Agricultural Crop Wastes	3,095	2,375
Municipal Wastewater	45,617	49,845
Mobile Combustion	215,939	281,632
Stationary Combustion	73,561	78,507
TOTAL Net	23,247,771	28,318,340

Figure E.6 Oklahoma Greenhouse Gas Net Emissions by Source



1. Carbon Dioxide Emissions from Combustion of Fossil Fuels

Overview

Fossil fuel is combusted for many reasons. It is used to provide heat for buildings and homes, generate electricity, and to power cars, trucks, buses and other vehicles. The emissions from fossil fuel combustion produce the majority of energy related emissions. Carbon dioxide (CO₂) is produced when a fossil fuel burns. This is a result of oxidation of the carbon in the fuel. Other gases that are precursors of CO₂ such as carbon monoxide and non-methane volatile organic compounds are emitted as by-products of incomplete combustion. These gases are oxidized to CO₂ over periods ranging from days to years. Emissions of these other gases are counted as CO₂ emissions. All carbon emitted to the atmosphere in fossil fuels is reported by sources as CO₂ emissions.

The amount of CO₂ produced from fossil fuel combustion varies with the type and quantity of fuel consumed, the fraction of the fuel that is oxidized, and the carbon content of the fuel. The amount of carbon contained in the fuel varies for different types of fuel. The carbon content can also vary within the same fuel type, i.e. coal, liquid fuel, natural gas.

Not all carbon in fuel is oxidized to CO₂. There are inefficiencies in the combustion process that leave unburned carbon remaining as soot or ash. Some carbon is not immediately oxidized to CO₂ and is emitted in the form of other hydrocarbons. Some fossil fuels are used for non-energy purposes such as fertilizer, lubricants, and asphalt. In some cases the carbon is oxidized quickly to CO₂ as in the production of fertilizer. Where as in the production of asphalt, the carbon may be sequestered for several centuries.

Methods

Emissions of carbon equivalent from fossil fuels were calculated using the EIIP guidance document. This report addressed the years 1990 and 1999. To calculate CO₂ emissions from fossil fuel combustion, state-level fuel consumption was broken into 5 categories, residential, commercial, industrial, transportation and electric utilities. It was necessary to compile consumption data for each type of fuel consumed because the carbon content of fossil fuels varied by fuel type (i.e. natural gas, coal, kerosene). Emissions from bunker fuels, fuels used in international and interstate transportation, were not addressed in this report. Category-specific consumption data for Oklahoma were obtained from Department of Energy's Energy Information Administration (EIA) *State Energy Data Report 1999*. Fuel statistics were provided on an energy basis rather than weight, because there was considerable variation in the energy content per weight of fossil fuels. All energy data refer to gross caloric values and not net caloric values. This was to provide more accurate emission estimates. Statistics that were originally provided in units such as barrels or short tons were converted to British thermal units (Btu) by factors supplied by the guidance manual.

After conversion to Btu, the total carbon content for each fuel type was calculated by multiplying the fuel type consumption by a carbon content coefficient provided by the guidance manual. It should be noted that these coefficients were national averages based on data obtained in the early 1990's and may not accurately reflect the energy content of fuels combusted in Oklahoma in more recent years. Total carbon content was converted to tons, resulting in tons of carbon potentially emitted from that fuel type. Some fuel types were used in part for non-fuel purposes, resulting in decreased carbon content potential. Thus, the carbon was sequestered, meaning it was either not released or released 20 years or more into the future. To obtain the net carbon available for release, the amount of non-fuel use for the fuel type was determined and then the percentage of stored carbon for that non-fuel use was calculated. This percentage of stored carbon from non-fuel uses was subtracted from total potential carbon resulting in net tons of carbon available.

For any fuel type that had a non-fuel use (i.e. asphalt and road oil) for a specific sector, the percentage of non-fuel use was determined. For each fuel type, this percentage was the ratio of the national non-fuel consumption to national fuel use. When these national consumption numbers were not available by fuel type, the ratio of total energy non-fuel consumption to total energy fuel use was used. Both of these sets of data were queried from the EIA's Annual Energy Review Interactive Data Query System on the Internet. The non-fuel percentage was multiplied by the total tons of carbon content, resulting in total non-fuel use for the fuel type. This total non-fuel use was then multiplied by the percent of carbon stored as provided by the guidance document. This resulted in the amount of carbon stored from non-fuel uses, which was then subtracted from total tons of potential carbon to give the total tons of carbon available to be released from fuel use.

Not all carbon was oxidized during fossil fuel combustion. The amount of carbon that did not oxidize was a small fraction of total carbon. The fraction of carbon oxidized varied by fuel type and was provided by the guidance document. This fraction oxidized was multiplied by the tons of carbon available and resulted in total oxidized carbon or CO₂. Tons of carbon oxidized was converted to metric tons of carbon equivalent (MTCE) which was accomplished by multiplying 0.9072 (metric tons/short ton) by total carbon.

Residential

There was no information available to confirm the origin of coal consumed by the residential category in 1999. It was assumed that the coal was bituminous of Oklahoma origin because it was unlikely that such a small quantity used for residential heating would have been transported any great distance.

Commercial

The data available for the commercial category for 1999, again did not explain the origin of coal combusted. It was assumed this quantity was bituminous of Oklahoma origin. Liquefied petroleum gas and natural gas have some non-fuel commercial uses, resulting in a percentage of stored carbon.

Industrial

There was no available information concerning the origin of coal consumed by the industrial category for either 1990 or 1999. It was assumed the coal was bituminous of Oklahoma origin. It should be noted that the sub-category "other oil" is comprised of 16 petroleum products. It

was assumed that 100% of this oil was used as fuel and 0% of the carbon was stored. All of the carbon in asphalt and road oil was stored. Liquefied petroleum gas, natural gas and lubricants had some non-fuel industrial uses, resulting in a percentage of stored carbon.

Transportation

All calculations for jet fuel consumption were based on national data obtained from EIA and the percentage of use applied to state data.

Electric Utility

All data for coal consumed in both 1990 and 1999 were obtained directly from the utility providers. Distillate fuel oil consumption data were also obtained directly from the utility providers. EIA data for 1990 and 1999 Electric Utilities listed distillate fuel oil consumption in excess of what state data indicated. EIA data listed total oil consumption in 1990 of 86,000 barrels and 1999 consumption of 24,000 barrels. Data gathered from the electric utilities showed consumption in 1990 of 3,450 barrels and 1,665 barrels in 1999.

Results

Residential

Fossil fuels combusted in this category accounted for 4% of the total MTCE for both 1990 and 1999. Fuel consumption in this category increased by 79%, which was accounted for by the increase in LPG.

Commercial

The use of fossil fuels in the commercial category accounted for 3% of total MTCE in 1990 and 2% in 1999. Residual fuel oil and motor gasoline both had decreased use of over 90%, while LPG increased by 80%. Overall, the commercial category had a net MTCE decrease from 1990 to 1999 of 36%.

Industrial

The largest increase in fossil fuel use was LPG at 280% in the industrial category. There were several decreases in fuel use to offset the difference. Distillate fuel oil use dropped 13%, motor gasoline dropped 17%, residual fuel oil dropped 72% and natural gas usage dropped 23%. The use of fossil fuels in the industrial category comprised 26% of total MTCE in 1990 and 21% in 1999, showing a net decrease.

Transportation

Fossil fuel usage in this category comprised 27% of total MTCE in 1990 and 29% in 1999. There was a 64% increase in distillate fuel oil use from 1990 to 1999 and a 13% increase in motor fuel consumption. MTCE for the transportation category increased from 1990 to 1999 by 19%. The amount of naphtha jet fuel consumed dropped 100% between 1990 and 1999.

Electric Utility

The generation of electricity produced the largest amount of CO₂ from fossil fuel use, 39% of total MTCE in 1990 and 44% in 1999. There was a 51% decrease in the use of distillate fuel oil from 1990 to 1999. The largest changes in consumption were in the coal sub-category. The consumption of bituminous coal increased 52% and sub-bituminous coal consumption increased

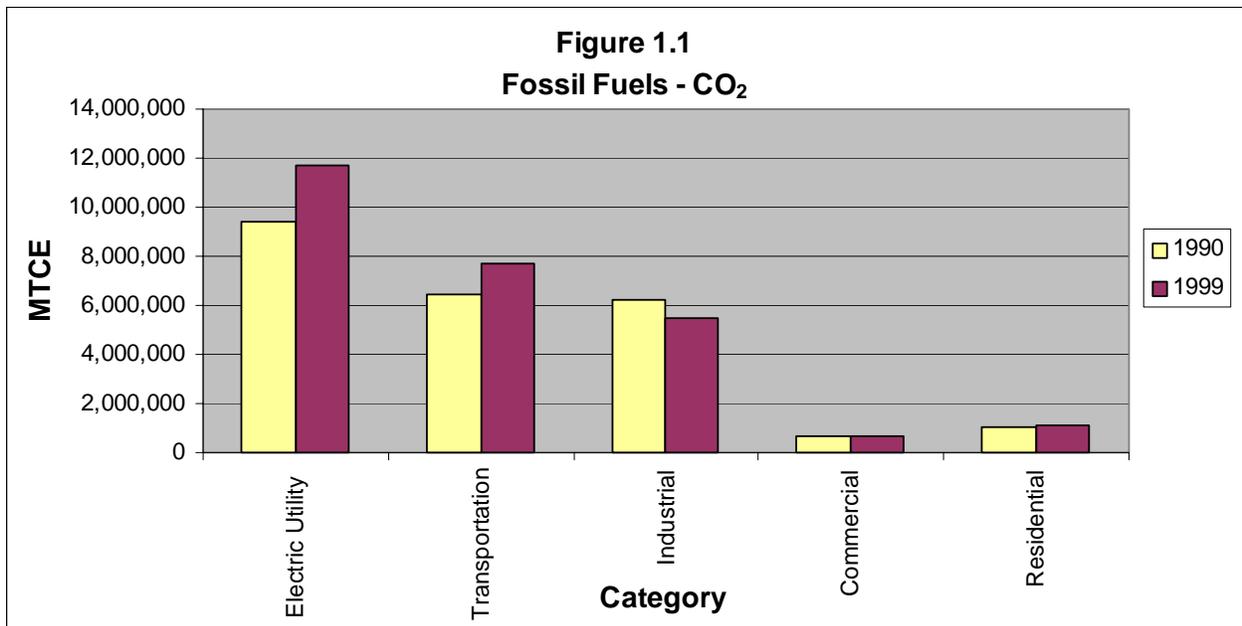
31%. This resulted in a net increase of over 32% for the electric utility category from 1990 to 1999.

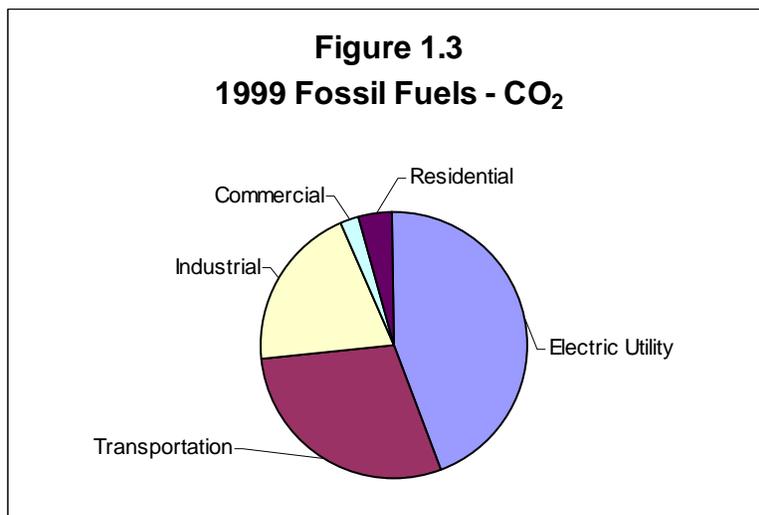
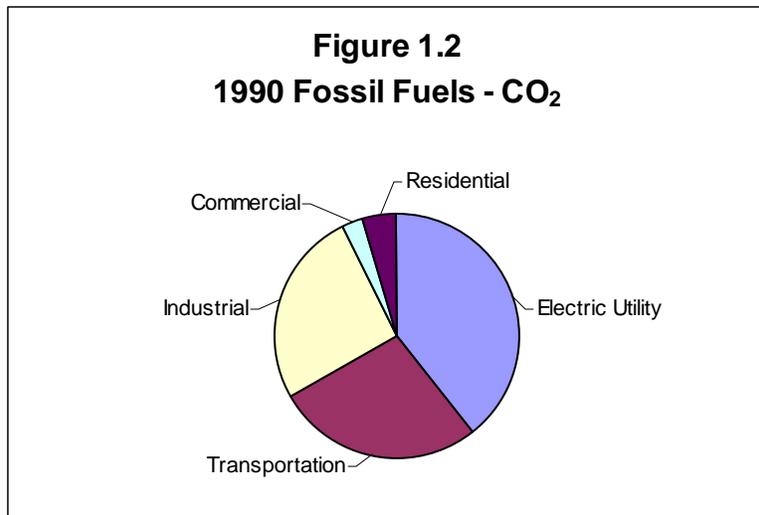
Summary

Table 1.1						
Fossil Fuels - CO ₂						
	1990			1999		
Fuel Type	Consumption (barrels)	Emissions (tons)	MTCE	Consumption (barrels)	Emissions (tons)	MTCE
Electric Utility						
Distillate Fuel Oil	3,450	442	397	1,665	213	192
Bituminous Coal	757,808	506,913	455,273	1,157,809	774,482	695,584
Sub-bituminous Coal	14,454,795	7,172,513	6,441,834	19,038,754	9,447,087	8,484,693
Natural Gas*	169	2,776,417	2,506,171	170	2,792,845	2,521,001
Total	15,216,222	10,456,284	9,403,675	20,198,398	13,014,627	11,701,469
Transportation						
Aviation Gasoline	146,000	15,330	13,768	102,000	10,710	9,619
Distillate Fuel Oil	11,690,000	1,498,074	1,345,462	19,180,000	2,457,917	2,207,524
Jet Fuel: Kerosene	6,892,160	849,958	763,371	6,576,000	810,969	728,354
Jet Fuel: Naphtha	939,840	109,464	98,313	0	0	0
LPG	97,000	7,353	6,604	48,000	3,639	3,268
Lubricants	796,000	53,829	48,346	823,000	55,655	49,985
Motor Gasoline	37,790,000	4,248,133	3,815,367	42,847,000	4,816,611	4,325,933
Natural Gas*	26	427,141	385,565	24	394,284	355,906
Total	58,351,026	7,209,282	6,476,796	69,576,024	8,549,785	7,680,590
Industrial						
Asphalt and Road Oil	3,508,000	0	0	1,719,000	0	0
Distillate Fuel Oil	3,091,000	396,112	355,759	2,660,000	340,879	306,153
Kerosene	16,000	1,973	1,772	25,000	3,083	2,769
LPG	1,693,000	66,160	59,420	6,454,000	239,074	214,719
Lubricants	593,000	40,101	36,016	613,000	41,454	37,231
Motor Gasoline	834,000	93,753	84,203	686,000	77,116	69,260
Other Oil	7,473,000	957,665	860,106	8,622,000	1,104,909	992,350
Residual Fuel Oil	491,000	73,160	65,707	133,000	19,817	17,798
Bituminous Coal	557,000	372,588	334,632	733,000	490,318	440,369
Natural Gas*	307	4,889,408	4,413,493	236	3,755,955	3,390,365
Total	18,256,307	6,890,921	6,211,107	21,645,236	6,072,605	5,471,014

Commercial						
Distillate Fuel Oil	539,000	69,073	62,036	330,000	42,290	37,981
Kerosene	13,000	1,603	1,440	12,000	1,480	1,329
LPG	225,000	8,793	7,897	404,000	14,965	13,441
Motor Gasoline	374,000	42,043	37,760	37,000	4,159	3,736
Residual Fuel Oil	82,000	12,218	10,973	1,000	669	601
Natural Gas*	37	589,277	531,919	40	636,602	574,638
Total	1,233,037	723,007	652,026	784,040	700,165	631,726
Residential						
Distillate Fuel Oil	0	0	0	2,000	256	230
Kerosene	10,000	1,233	1,108	9,000	1,110	997
LPG	1,274,000	96,579	86,741	2,292,000	173,752	156,051
Bituminous Coal	0	0	0	1,000	669	601
Natural Gas*	66	1,084,281	978,741	62	1,018,567	919,424
Total	1,284,066	1,182,093	1,066,590	2,304,062	1,194,354	1,077,303
TOTAL - All Sectors	94,340,658	26,461,588	23,810,194	114,507,760	29,531,536	26,562,101

* Billion ft³





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2. Non-Energy Greenhouse Gas Emissions from Industrial Processes

Overview

Greenhouse gas emissions result from many industrial processes. In some cases, such as cement production, greenhouse gases are released as a byproduct of the manufacturing process. Other gasses may leak to the atmosphere either during a manufacturing process or later, during product use. This chapter covers emissions from the following industrial processes, as recommended by the EIIP protocol:

- Cement Production (CO₂)
- Nitric Acid Production (N₂O)
- Adipic Acid Production (N₂O)
- Lime Manufacture (CO₂)
- Limestone Use (CO₂)
- Soda Ash Manufacture and Consumption (CO₂)
- Aluminum Production (CO₂ and perfluorocarbons)
- HCFC-22 Production (HFC-23)
- HFCs and PFCs from Consumption of Substitutes for Ozone-Depleting Substances (HFCs)
- SF₆ Consumption by electric Utilities (SF₆)
- Magnesium Production (SF₆)
- CO₂ Manufacture (CO₂)

The primary gas (or gasses) evaluated for each process is listed in parentheses. Greenhouse gasses are also emitted when industrial processes consume energy. Energy-related emissions are addressed in other chapters.

Methods

Total greenhouse gas emissions released from each of the listed industrial processes were calculated using the best available estimation method. In most cases, state production (or consumption) data was multiplied by an emission factor per unit of production (provided by EPA), and converted to annual metric tons of carbon equivalent (MTCE). In cases where reliable state production data was not available, national data was used to develop state emissions estimates. Total greenhouse gas emissions, in MTCE, from the various industrial processes in Oklahoma were then tallied for 1990 and 1999. Methods and data for each of the listed processes are discussed in this chapter.

Section 2.1 – CO₂ from Cement Production

Carbon Dioxide (CO₂) is released during the first step in cement production, called calcination. Limestone (primarily calcium carbonate – CaCO₃) is heated in a cement kiln to form lime (calcium oxide – CaO) and CO₂. Silica-containing materials are then combined with the lime

in the kiln to form the intermediate product called clinker. Additional materials are added to the cooled clinker to produce finished Portland cement.

The production of masonry cement from Portland cement generally requires additional lime, which would result in additional CO₂ emissions. However, the actual formulation for masonry cement varies, with other components such as slag, fly ash and ground limestone used in place of some or all of the additional lime. None of the Oklahoma facilities reported to USGS that they produced this lime onsite. Thus, any additional lime production (by Oklahoma facilities) for this purpose would already be accounted for in the Lime Manufacture source category (Section 2.2) in this chapter; therefore, the additional emissions from making masonry cement from clinker were not added to this source category's total.

Oklahoma clinker production data were obtained from 1990 and 1999 Air Emission Inventory Reports (Turn-Around Documents) submitted to DEQ (1990 reports were transferred to DEQ from its predecessor agency, the Oklahoma State Department of Health or OSDH), and from contacts with individual facilities. The emission factor used in this analysis, 0.507 tons of CO₂ released per ton of clinker produced, was the product of the average lime fraction for clinker of 64.6 percent (IPCC 2000) and a constant reflecting the mass of CO₂ released per unit of lime.

During clinker production, some of the feed materials remain in the kiln as cement kiln dust (CKD). The emissions attributable to the calcinated portion of the CKD are not accounted for by the clinker emission factor. IPCC recommends that total cement production emissions be adjusted to account for CKD recycling. However, information provided by USGS and at least one Oklahoma producer indicated that, considering the IPCC-recommended 2% adjustment and manufacturers' practices, the difference in CO₂ emissions attributable to CKD recycling falls within the accuracy of the emission factor.

Results

Total clinker production in Oklahoma increased by approximately 34% from 1990 to 1999. Thus, total CO₂ emissions from cement production increased by 34% during the same period – from 780,610 tons in 1990 to 1,049,099 tons in 1999 or 193,137 metric tons of carbon equivalent (MTCE) in 1990 to 259,566 MTCE in 1999.

The primary uncertainties associated with these estimates were the lime content of clinker, the amount of lime added to masonry cement, and the percentage of CKD recycled inside the clinker kiln. According to EPA, the lime content of clinker typically varied from 64 to 66 percent. CKD recycling varied depending upon plant specifications. Additionally, some amount of CO₂ was reabsorbed when the cement was used for construction. Because the amount of CO₂ reabsorbed was thought to be minimal, it was not estimated.

Section 2.2 – CO₂ from Lime Production

Lime Production releases a significant amount of CO₂. Major uses for lime are construction, water purification, steel making, flue gas desulfurization (FGD) at coal-fired electric power plants, and pulp and paper manufacturing. While some facilities produce lime onsite, the majority of lime is purchased from lime manufacturing facilities. Crushed limestone, composed mostly of calcium carbonate (CaCO₃), is calcined, or roasted at high temperatures in a kiln, to

produce CO₂ and calcium oxide (CaO), or high-calcium quicklime. The CO₂ produced during calcining is normally emitted to the atmosphere. Quicklime is then hydrated to form the final lime product. Although some U.S. facilities recover CO₂ generated during the calcination step for other industrial and commercial uses, none of the Oklahoma lime manufacturing was known to do so. In some cases, a portion of the CO₂ emitted during lime manufacture will actually be reabsorbed when the lime is consumed. A detailed accounting of lime use in Oklahoma and further research into the associated processes are required to quantify the amount of CO₂ that is reabsorbed.

Oklahoma lime production data were obtained from 1990 and 1999 Air Emission Inventory Reports, and from contacts with individual facilities. (In one case, 1990 report was unavailable, so 1989 production data was used in its place.) Research was conducted on the degree to which paper mills, carbide plants, and water treatment plants in Oklahoma practice onsite lime production and lime recycling. The resulting data was included in the totals, but was not broken down separately, due to the limited number of facilities in the research pool. The emission factor used in this analysis – 0.75 tons of CO₂ released per ton of lime produced – was obtained from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2000). The emission factor was the product of a constant (0.785), reflecting the mass of CO₂ released per unit of lime, times the average CaO content for lime (95 percent).

Results

Total lime production in Oklahoma decreased by approximately 20% from 1990 to 1999, resulting in a 20% reduction in total CO₂ emissions from lime production during the same period – from 263,563 tons in 1990 to 211,777 tons in 1999 or 65,210 MTCE in 1990 to 52,398 MTCE in 1999.

Uncertainties in the emission estimate were attributed to slight differences in the chemical composition of these products. Although the methodology accounted for various formulations of lime, it did not account for the trace impurities found in lime, such as iron oxide, alumina, and silica. Due to differences in the limestone used as a raw material, a rigid specification of lime material was impossible. As a result, few plants manufactured lime with exactly the same properties.

Section 2.3 – CO₂ from Limestone Use

In addition to agricultural and construction uses, limestone is used as a flux or purifier in metallurgical furnaces, as a sorbent in flue gas desulfurization (FGD) systems for utility and industrial plants (e.g., at certain coal-fired power plants), as a raw material in glass manufacturing, and in magnesium production. In these applications, limestone is sufficiently heated during the process to generate CO₂ as a by-product. In Oklahoma, limestone is used in glass manufacturing and FGD systems. There is apparently no primary magnesium production in Oklahoma.

Oklahoma limestone consumption data was obtained from 1990 and 1999 Air Emission Inventory Reports, and from contacts with individual facilities. In several cases where 1990 data was not available, 1999 data was used. CO₂ emissions were estimated by multiplying the

amount of limestone consumed by an emission factor of 0.12 tons of carbon (C) per ton of limestone times the 44/12 ratio of CO₂ to C.

Results

Total limestone consumption in Oklahoma increased by approximately 151% from 1990 to 1999, resulting in a 151% increase in total CO₂ emissions from limestone consumption during the same period – from 79,958 tons in 1990 to 200,896 tons in 1999 or 19,783 MTCE in 1990 to 49,705 MTCE in 1999.

Uncertainties in this estimate were due in part, to variations in the chemical composition of limestone. In addition to calcite, limestone may contain smaller amounts of magnesia, silica, and sulfur. The quality of the limestone used for glass manufacturing depended on the type of glass being manufactured. In addition, limestone (calcite – CaCO₃) and dolomite (CaCO₃MgCO₃) were collectively referred to as limestone by the industry, and intermediate varieties were seldom distinguished. A breakdown of calcite versus dolomite consumption was not available from state sources. Therefore, CO₂ emissions were estimated using two methods. The first method, reflected above, assumed that all the limestone consumed was calcite. The second method used the proportions of calcite and dolomite consumption for 1990 and 1999 reflected in Table 3-12 Limestone and Dolomite Consumption of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2000), along with the emission factor for dolomite (0.13 tons of carbon (C) per ton of dolomite). The second method resulted in a slightly higher estimate of CO₂ emissions – 19,916 MTCE in 1990 and 50,165 MTCE in 1999.

Uncertainties also existed in the activity data. Much of the limestone consumed in the United States was reported as “other unspecified uses;” therefore, it was difficult to determine if there were other Oklahoma industrial facilities that accounted for a portion of this unspecified quantity. Additionally, there was some uncertainty of the estimates for limestone used in glass making. Several such facilities did not have limestone usage data available for 1990, so estimates were made based on best estimates of 1990 production and glass raw materials formulas.

Section 2.4 – CO₂ from Soda Ash Manufacture and Use

Soda ash (sodium carbonate, Na₂CO₃) is a white crystalline solid that is readily soluble in water and strongly alkaline. Most soda ash is consumed in glass and chemical production, with minor amounts in soap and detergents, pulp and paper, flue gas desulfurization and water treatment. CO₂ may be generated as a by-product of soda ash production, and eventually emitted into the atmosphere. No soda ash was manufactured in Oklahoma.

CO₂ may also be released when soda ash was consumed. Consumption of soda ash in Oklahoma was primarily in the glass manufacturing sector. Contacts with Oklahoma facilities indicated no significant soda ash consumption for pulp and paper production or flue gas desulfurization. Oklahoma soda ash consumption data was obtained from 1990 and 1999 Air Emission Inventory Reports, and from contacts with individual facilities. In several cases where 1990 data was not available, 1999 data was used. In these applications, it was assumed that one mole of carbon was released for every mole of soda ash used. Thus, CO₂ emissions were estimated using an

emission factor of 0.113 tons of carbon (C) per ton of soda ash consumed, times the 44/12 ratio of CO₂ to C (or 0.415 tons of CO₂ per ton of soda ash consumed).

Results

Total soda ash consumption in Oklahoma declined by approximately 8% from 1990 to 1999, resulting in an 8% decrease in total CO₂ emissions from soda ash consumption during the same period – from 87,223 tons in 1990 to 80,079 tons in 1999 or 21,581 MTCE in 1990 to 19,813 MTCE in 1999.

Emissions from soda ash consumption were dependent upon the type of processing employed by each end-use. Specific information characterizing the emissions from each end-use was limited. Therefore, uncertainty existed as to the accuracy of the emission factors. In addition, accurate information on soda ash consumption by other facilities (e.g., food processing, soap manufacturing, or water treatment) would be extremely difficult to obtain, although consumption in these sectors was believed to be minor in comparison to consumption in the glass manufacturing sector. There was some uncertainty of the estimates for soda ash used in glass making. Several such facilities did not have soda ash usage data available for 1990, so estimates were made based on best estimates of 1990 production and glass raw materials formulas.

Section 2.5 – Carbon Dioxide Manufacture and Consumption

The major emission sources for manufactured CO₂ accounted for in this analysis are from carbonated beverages and food processing. Other industrial applications include chemical production and enhanced oil recovery (EOR). EOR injects CO₂ into the ground to increase reservoir pressure, and is therefore considered sequestered. CO₂ used for purposes other than EOR will ultimately be released to the atmosphere. CO₂ produced as a by-product of other processes (e.g., ammonia production) is already included in the CO₂ emission estimates from fossil fuel consumption (either during combustion or from non-fuel uses) and, therefore, is not included here. Carbon dioxide emission estimates were based on CO₂ consumption with the assumption that the end-use applications, except EOR, eventually release 100 percent of the CO₂ into the atmosphere.

Because CO₂ production and consumption are widespread throughout the U.S., the recommended estimation method uses national emissions, prorated based on state population. In its *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2000), EPA reported national CO₂ consumption for uses other than EOR was about 4,000,000 metric tons in 1990 and 6,512,000 metric tons in 1999, with approximately 80 percent assumed to be already accounted for in the CO₂ emission estimates from other categories (the most important being Fossil Fuel Combustion). Thus, national emissions were equal to 20 percent of CO₂ consumption, or 800,000 metric tons in 1990 and 1,302,400 metric tons in 1999.

Results

National and state populations increased from 248,790,925 and 3,145,576 in 1990, to 272,690,800 and 3,339,500 for 1999, respectively. As a result, estimated total CO₂ emissions from CO₂ manufacturing and consumption in Oklahoma increased by approximately 58% from

1990 to 1999 – from 10,115 metric tons in 1990 to 15,950 metric tons in 1999 or 2,759 MTCE in 1990 to 4,350 MTCE in 1999.

Uncertainty existed in the assumptions made by EPA, including allocation of CO₂ produced from fossil fuel by-products (80 percent) and CO₂ produced from wells (20 percent). In addition, information was not readily available on the quantity, if any, of CO₂ that was recovered by particular end-use sectors.

Section 2.6 – N₂O from Nitric Acid Production

Nitrous Oxide (N₂O) is formed as a by-product of nitric acid (HNO₃) production. Nitric acid, an inorganic compound manufactured almost exclusively in the United States by the catalytic oxidation of ammonia, is used primarily to make synthetic commercial fertilizers. It is also a major component in the production of adipic acid (see Section 2.10) – a feedstock for nylon – and explosives. Currently, the nitric acid industry uses pollution control to reduce emission of NO and NO₂, (i.e., NO_x). However, N₂O is generally released from reactor vents into the atmosphere because the controls used by the vast majority of facilities do not remove N₂O.

Several commercial fertilizer manufacturers in Oklahoma produced nitric acid. There was no known nitric acid production associated with explosives manufacturing in Oklahoma. Nitric acid production data for Oklahoma was obtained from 1990 and 1999 Air Emission Inventory Reports, and from contacts with individual facilities. N₂O emissions were estimated using an emission factor of 0.0061 tons of N₂O per ton of nitric acid produced.

Results

Total nitric acid production in Oklahoma increased by approximately 29% from 1990 to 1999, resulting in a 29% increase in total N₂O emissions from nitric acid production during the same period – from 4,485 tons in 1990 to 5,763 tons in 1999 or 343,964 MTCE in 1990 to 442,019 MTCE in 1999.

Uncertainty was fairly high for N₂O emissions estimates. Nitric acid plants were often part of larger production facilities, such as fertilizer or explosive manufacturing, with only a small amount of nitric acid sold on the market. Therefore, it was difficult to ascertain that the nitric acid production figures obtained were comprehensive. Emission factors were also difficult to determine because the different emission control technologies used by the industry varied considerably in destruction efficiency for N₂O.

Section 2.7 – HFCs and PFCs from Consumption of Substitutes for Ozone-Depleting Substances

During the 1990's, a process began to phase out the manufacture and use of several gasses that are believed to be adversely affecting the stratospheric ozone layer. Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), which have been developed as substitutes for these ozone-depleting substances (ODSs), are potent greenhouse gases. Use of ODS substitutes is growing in a variety of industrial applications that must phase out ODSs under the terms of the *Montreal Protocol* and the Clean Air Act Amendments of 1990 – including air conditioning and

refrigeration equipment, solvent cleaning, foam production, sterilization, fire extinguishing, and aerosols.

EPA detailed their modeling efforts to estimate national emissions of HFCs and PFCs in Chapter 3 (Industrial Processes) and Appendix I of their report, *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2000). The model used by EPA predicts ODS and ODS substitute use in the U.S. based on estimates of the quantity of equipment or products sold each year containing these chemicals, and the amount of the chemical required to manufacture and/or maintain equipment and products over time. State-specific emission data for these substances was not available. For this analysis, Oklahoma emissions were estimated by pro-rating EPA's national emission estimates based on state and national population data.

Results

The use and subsequent emissions of HFCs and PFCs as ODS substitutes has been increasing from small amounts (estimated 0.9 Tg CO₂ Equivalent or 245,000 MTCE) in 1990 to 51.3 Tg CO₂ Eq. (15.5 MMTCE) in 1999 nationwide. Adjusting these amounts to state population, consumption of substitutes for ozone-depleting substances in Oklahoma increased total estimated HFC and PFC emissions from 3,103 MTCE in 1990 to 171,339 MTCE in 1999. The "Uncertainty" discussion for this source category in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (page 105, U.S. EPA 2000) states, "Given that emissions of ODS substitutes occur from thousands of different kinds of equipment and from millions of point and mobile sources throughout the United States, emission estimates must be made using analytical tools such as the Vintaging Model or the methods outlined in IPCC/UNEP/OECD/IEA (1997). Though the model is more comprehensive than the IPCC default methodology, significant uncertainties still exist with regard to the levels of equipment sales, equipment characteristics, and end-use emissions profiles that were used to estimate annual emissions for the various compounds." Estimating state emissions by adjusting the national emissions estimates to state population clearly added additional uncertainty.

Section 2.8 – SF₆ Emissions from Electric Utilities

Sulfur hexafluoride (SF₆) is used by the electric power industry as an insulator gas in electrical transmission and distribution equipment. SF₆ can escape from gas-insulated substations and switch gear through leaking seals, and during equipment installation, servicing, and disposal. The relatively high cost of the gas and increased awareness have combined to reduce the past industry practice of venting SF₆ to the atmosphere during servicing and disposal. The SF₆ Emissions Reduction Partnership for Electric Power Systems is a voluntary partnership established by EPA and many electric power systems to help reduce SF₆ emissions.

State-specific emission data for SF₆ was not available. For this analysis, Oklahoma emissions were estimated by pro-rating EPA's national emissions estimates based on state and national electrical consumption data. EPA developed estimated national SF₆ emissions for 1990 and 1999, based primarily on information reported by utilities participating in EPA's SF₆ Emissions Reduction Partnership for Electric Power Systems ("Partnership") beginning in 1999 and information provided by EPA's Global Programs Division. State and national electrical consumption data were obtained from the Energy Information Agency (EIA), part of the U.S. Department of Energy (DOE).

Results

Using this data and estimation method, total SF₆ emissions from electric utilities in Oklahoma were estimated to decrease by approximately 52% – from 22 tons in 1990 to 11 tons in 1999, or from 132,755 MTCE in 1990 to 64,387 MTCE in 1999.

Using emissions data reported by Partnership participants to extrapolate total U.S. emissions and to estimate past emissions (i.e., 1990) introduced a significant level of uncertainty. Global sales of SF₆, a factor used in EPA's analysis, appeared to closely reflect global emissions – global sales declined by 24 percent between 1995 and 1998, while atmospheric measurements indicate that world emissions of SF₆ declined by 27 percent during the same period. However, U.S. and Oklahoma emission patterns may have differed from global emission patterns. Estimating state emissions by adjusting the national emissions estimates to state electrical consumption added additional uncertainty.

Section 2.10 – GHG Emissions from Additional Industrial Processes

EPA has identified a number of other industrial processes that, on a national basis, are or may be significant sources of greenhouse gas emissions. These emission sources include CO₂ and perfluorocarbons (CF₄ and C₂F₆) emissions from primary aluminum production, nitrous oxide (N₂O) from adipic acid production, HFC-23 from HCFC-22 production, and SF₆ from magnesium production and processing. Estimates for these processes were not included in this analysis for various reasons. There was no known primary aluminum, adipic acid, HCFC-22, or primary magnesium production in Oklahoma. Accurate information on the level of magnesium processing in Oklahoma would have been extremely difficult or impossible to obtain. In addition, discussions with EPA staff indicated that the impacts of the sector's GHG emissions were believed to be minor in comparison to impacts from other sectors.

Summary

Table 2.1						
Industrial Processes						
	1990			1999		
	Cons./Prod.	Emissions(tons)	MTCE	Cons./Prod.	Emissions(tons)	MTCE
CO₂						
Cement Production	1,539,665	780,610	193,137	2,069,229	1,049,099	259,566
Lime Production	353,420	263,563	65,210	283,979	211,777	52,398
Limestone Use	181,723	79,958	19,783	456,581	200,896	49,705
Soda Ash Manufacture/Consumption	210,177	87,223	21,581	192,962	80,079	19,813
Aluminum Production	0	0	0	0	0	0
CO ₂ Manufacture	11,149	11,149	2,759	17,581	17,581	4,350
Total	2,296,134	1,222,503	302,470	3,020,332	1,559,432	385,832
N₂O						
Nitric Acid Production	735,174	4,485	343,964	944,751	5,763	442,019
Adipic Acid Production	0	0	0	0	0	0
Total	735,174	4,485	343,964	944,751	5,763	442,019
CF₄, C₂F₆						
Aluminum Production	0	0	0	0	0	0
HFC23						
HCFC-22 Production	0	0	0	0	0	0
HFC, PFC						
Substitutes for Ozone-Depleting Substances	*		3,103	*		171,339
SF₆						
Electric Utilities	*	22	132,755	*	11	64,387
Magnesium Production and Processing	*	0	1,570	N/A	N/A	N/A
Total		23	134,325		11	64,387
TOTAL - All Processes	3,031,308	1,227,011	783,862	3,965,083	1,565,206	1,063,576

* Used National data

**Figure 2.1
Industrial Processes**

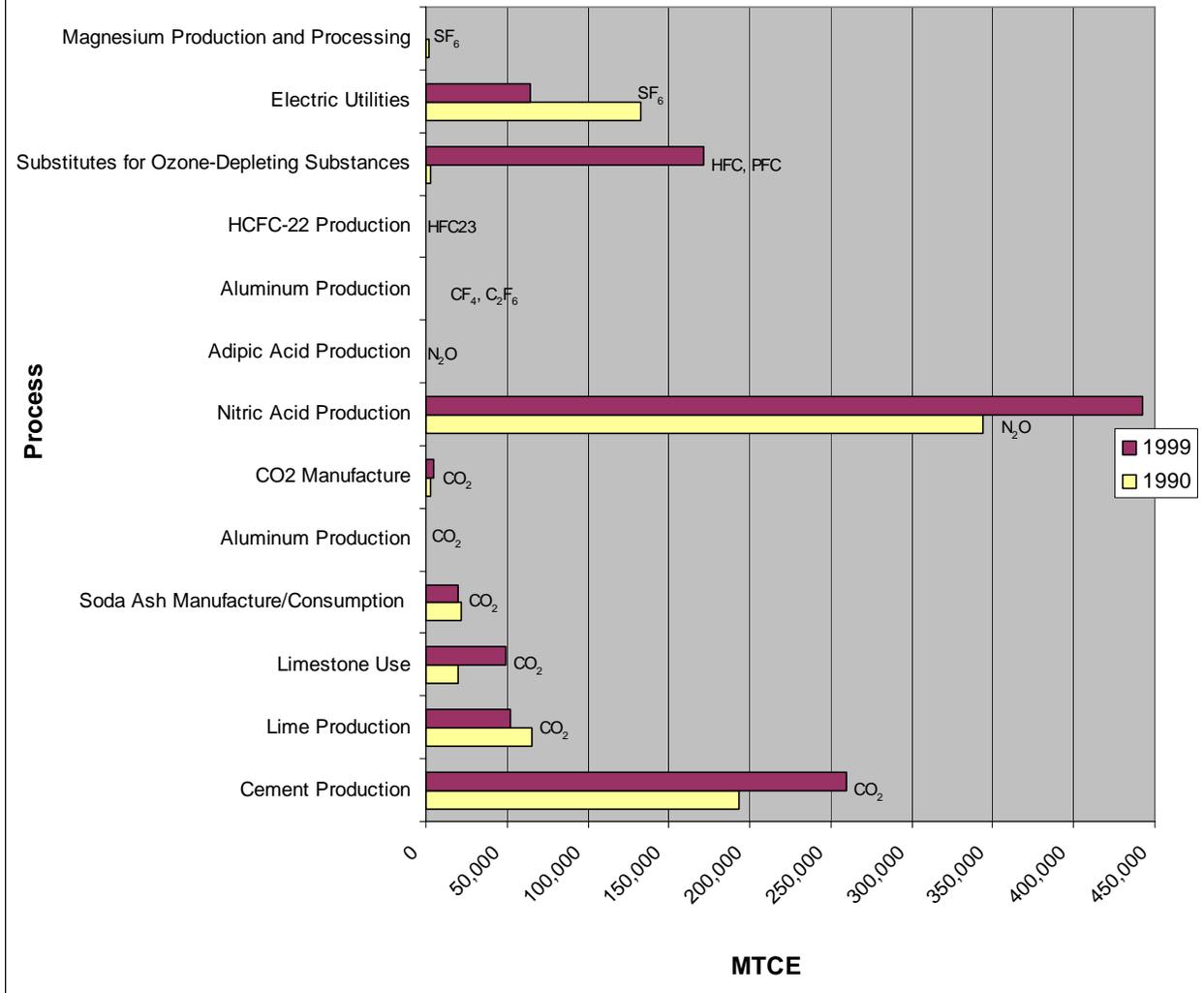


Figure 2.2
1990 Industrial Processes

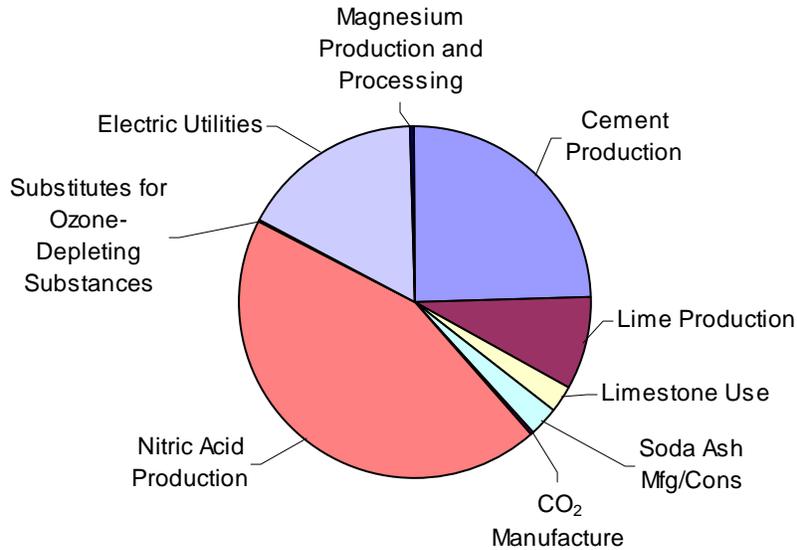
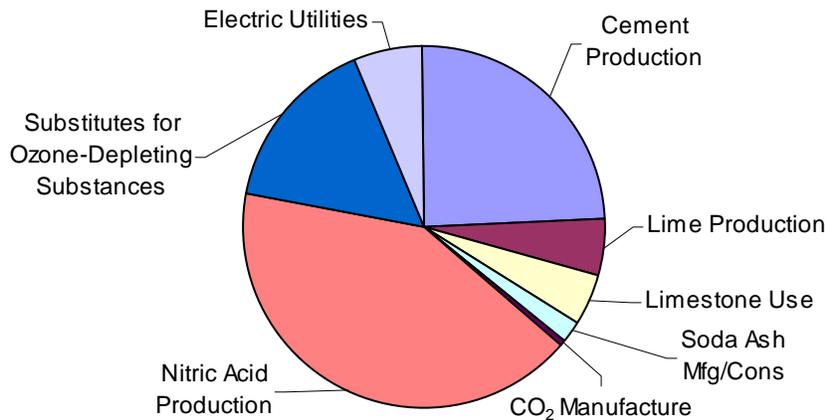


Figure 2.3
1999 Industrial Processes



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3. Methane Emissions from Natural Gas and Oil Systems

Overview

The oil and gas industry is a significant part of Oklahoma's economy. Methane (CH₄), a greenhouse gas with a Global Warming Potential (GWP) of 21, is emitted from both the natural gas segment and the oil segment. According to EPA, oil and natural gas systems currently rank third nationally among sources of CH₄ emissions. In Oklahoma, natural gas and oil systems was the largest contributor to CH₄ emissions in 1990 and second largest in 1999.

Natural Gas Systems

The natural gas system in Oklahoma includes thousands of wells, dozens of processing facilities, and thousands of miles of transmission and distribution pipelines. The four primary stages of the natural gas system are field production, processing, transmission and storage, and distribution. Methane emissions result from normal operations, routine maintenance, and system upsets. Emissions from normal operations include exhaust from natural gas-fired engines and turbines, bleed and discharge emissions from pneumatic devices, and fugitive emissions from system components. Repair and maintenance activities on pipelines, equipment, and wells also contribute to CH₄ emissions. Pressure-relief systems and accidents can lead to emissions during system upsets. Each of the stages of the natural gas system includes equipment with the potential for these emissions.

Field Production

Raw gas is extracted from underground formations through wells. Emissions arise from the wells themselves, gathering pipelines, and well-site gas treatment facilities such as dehydration units and separators. The majority of these are fugitive emissions and emissions from pneumatic devices.

Processing

The produced raw gas is transported to natural gas processing plants, where natural gas liquids and various other constituents are removed. The resulting "pipeline quality" gas is injected into the transmission system. Fugitive emissions from compressors, including compressor seals, are the primary emission sources from this stage.

Transmission and Storage

Under high pressure, large-diameter transmission pipelines transport natural gas long distances, from field production and processing areas to distribution systems. Transmission pipelines also deliver gas to large volume customers, such as power plants and chemical manufacturers. Large compressors, powered by reciprocating engines and turbines, are used to move the gas through the transmission system. These compressor stations, along with metering and regulating stations, produce fugitive emissions – the major source of emissions from the transmission stage. Pneumatic devices and engine exhaust at transmission facilities also contribute emissions.

During periods of low demand (e.g., summer), natural gas may be injected and stored in underground formations. It is then withdrawn, processed, and distributed during periods of high demand (e.g., winter.) The primary contributors to emissions from these storage facilities are compressors and dehydrators. However, emissions attributable to storage facilities were believed to be minimal (less than one percent) compared to other components of the natural gas system.

Distribution

The gas from the transmission system is reduced in pressure and distributed through mains and service lines to individual end users. Emissions from the distribution system result mainly from fugitive emissions from gate stations and non-plastic piping (e.g., cast iron, steel, and copper.)

Oil Systems

CH₄ emissions from oil systems are associated primarily with crude oil production, transportation, and refining operations. CH₄ is released to the atmosphere from these activities as fugitive emissions, vented emissions, emissions from operational upsets, and fuel combustion emissions.

Production Field Operations

CH₄ entrained in crude oil under high pressure is released when the crude oil is pumped into storage tanks at atmospheric pressure. Chemical injection pumps and vessel blowdown are also significant sources of vented emissions, in addition to fugitive and combustion emissions.

Crude Oil Transportation

The majority of CH₄ emissions from crude oil transportation are a result of venting from tanks and loading operations. The rest of emissions from transportation are fugitive emissions, comprised almost entirely of floating roof tank emissions.

Crude Oil Refining

Most of the CH₄ in crude oil escapes or is removed before it is delivered to the refineries. Vented emissions typically account for about 87 percent of the emissions within refineries, while approximately six percent each result from combustion and fugitive emissions. The primary contributors of vented emissions are the process of hardening asphalt by blowing it with air, and blowdown of refinery systems for maintenance. Fuel-gas system leaks account for most of the fugitive emissions from refineries. Refinery combustion emissions include small amounts of unburned CH₄ in process heater stacks, engine exhausts, and flares.

Methods

Natural Gas

Estimates of CH₄ emissions from the natural gas industry were based on EIIP's recommended protocol (EPA 1999), as described in Chapter 3, Methods for Estimating Methane Emissions From Natural Gas and Oil Systems. The protocol included emission factors based on activity factors from the various operating stages of the natural gas system. The protocol also provided default methods of estimating several activity factors for which accurate data was difficult to obtain. Using the emission factors, estimates of emissions from the natural gas production stage were based on the number of non-associated (gas only) and associated (oil and gas) wells, and

the miles of gathering pipeline. Processing emissions were based on the number of natural gas processing plants that operated in Oklahoma during 1990 and 1999. Estimates of emissions associated with natural gas transmission were based on the number of miles of transmission pipeline in the state, the number of gas transmission stations, and the number of gas storage stations. EIIP provided a default method for estimating the number of transmission stations and gas storage stations, based on the number of miles of transmission pipeline. Estimates of emissions from the natural gas distribution stage were based on the number of miles of various kinds of distribution pipe, and the number of service connections (i.e., customers). EIIP default methods were used to estimate the miles of each type of pipe, and the number of each type of service connection. In addition, Section 5 of the EIIP guide provided an Alternative Method for Estimating Emissions from Natural Gas Systems, based on the state's levels of oil and gas production and natural gas consumption.

Activity factor data were obtained from the following sources: American Gas Association's *Gas Facts* (AGA 1991 and 2000); U.S. Department of Energy's (DOE) *Natural Gas Annual* (DOE 1999), *State Energy Data Report 1999 for Oklahoma* (DOE 1999), and *Petroleum Supply Annual, Volume 1* (DOE 1990 and 1999), *Oil and Gas Journal* (PennWell 1990 and 1999), and Oklahoma Corporation Commission's *2000 Report on Crude Oil and Natural Gas Activity Within the State of Oklahoma* (Claxton 2001). OCC staff provided additional data.

Oil Systems

The EIIP guidance provided a method for estimating emissions from oil systems, based on the state's oil and gas production, and the amount of oil transported, stored, and refined. EPA developed emission factors for representing low, high, and median estimates of emissions from normal operation, such as discharges from process vents and chronic leaks, and flaring. Also considered in the factors were emissions resulting from routine maintenance operations, system upsets, and accidents.

Oklahoma Corporation Commission data were used for the amount of crude oil produced in Oklahoma during 1999 and 1990. The amount of oil refined in Oklahoma was estimated based on the amount refined in PAD (Petroleum Administration for Defense) District II, times the ratio of state refining capacity to PAD District II refining capacity, a method recommended by EPA consultant ICF Consulting (Aggarwal 2002). US Energy Information Agency data (DOE 1990 and DOE 1999) was used as inputs for these estimates. Due to a lack of more specific data on amounts of crude oil transported and stored in Oklahoma during the years of interest, estimated amounts of oil refined in Oklahoma were used as a surrogate for these data, as recommended by ICF Consulting (Aggarwal 2002) and the EIIP guidance, respectively.

Results

Natural Gas

Overall, natural gas systems emitted an estimated 2,274,612 MTCE of CH₄ in 1999 and 2,737,817 MTCE in 1990, a decrease of approximately 17%. These changes reflected an overall decrease in natural gas production, processing, and transmission.

Field Production

Emissions from field production and gathering accounted for over 50% of CH₄ emissions from natural gas systems during 1990 and 1999. Estimated emissions from natural gas production decreased by approximately 13% from 1990 to 1999 – from 249,446 metric tons to 218,020 metric tons.

Processing

Processing plants accounted for about 20% of CH₄ emissions from natural gas systems in 1990 and 16% in 1999. Estimated emissions from natural gas processing decreased by approximately 33% – from 97,644 metric tons in 1990 to 65,412 metric tons in 1999.

Transmission and Storage

Approximately 20% of the CH₄ emissions from natural gas systems in 1990 and 1999 were from transmission. Estimated emissions from natural gas transmission decreased by approximately 21% from 1990 to 1999 – from 96,266 metric tons to 76,345 metric tons.

Distribution

The total miles of distribution mains in Oklahoma increased from approximately 23,400 miles in 1990 to approximately 26,000 miles in 1999 (Fothergill 2002). Emissions from the distribution system accounted for less than 10% of emissions from Oklahoma's natural gas system in both years. Distribution system emissions increased by approximately 8% – from 34,676 metric tons in 1990 to 37,378 metric tons in 1999.

Alternative Method

The alternative method for estimating emissions from natural gas systems, which provided a high, median, and low estimate, gave emissions estimates 28% to 56% lower than the preferred method, and showed a decline of approximately 26% from 1990 to 1999.

Uncertainties

The diverse nature of the natural gas industry introduces uncertainty into EIIP's estimating protocol, for which EPA scaled up sampling data from facilities that were selected to be representative of the entire industry. In addition, variability in emission rates measured among system components increased uncertainty in the calculated average emission rates. EPA believes that the uncertainty in the total estimated emissions from this source, on a national basis, is on the order of ±40% (EPA 2002).

Oil Systems

Estimating CH₄ emissions from oil systems using the EIIP-recommended method gave a high, median, and low estimate of emissions of 109,794 MTCE, 66,476 MTCE, and 23,400 MTCE, respectively for 1999, and 154,199 MTCE, 92,818 MTCE, and 31,565 MTCE, respectively for 1990. Using the high estimate as the most conservative, this represented a decline in CH₄ emissions of approximately 29% from 1990 to 1999. These changes reflected a decrease of approximately 37% in Oklahoma's crude oil production. During the same period, refining increased by approximately 17%.

Production Field Operations

Production field operations accounted for approximately 88% of total CH₄ emissions from oil systems in 1999, compared to 93% in 1990. Field storage tanks and natural gas-powered pneumatic devices were the largest sources of CH₄ emissions from production, with related production field processing equipment accounting for additional emissions.

Crude Oil Transportation

Approximately four percent of total CH₄ emissions from the oil industry were from crude transportation activities in 1999, compared to two percent during 1990.

Crude Oil Refining

Crude oil refining processes and systems accounted for only about seven percent of total CH₄ emissions from the oil industry in 1999 and four percent of these emissions in 1990.

Uncertainties

Utilizing the same emission factors for 1999 and 1990 activities introduced an element of uncertainty into estimates, since changes in oil industry practices and variation were not accounted. For instance, a census of tanks and other tank battery equipment, such as separators and pneumatic devices, were not available to EPA for each year considered. This increased uncertainty associated with the estimate of annual venting emissions in production field operations. Since, according to EPA, storage tanks and pneumatic devices accounted for 85% of CH₄ emissions from oil systems, these uncertainties were significant. Emission rates could also vary widely due to the variation in oil composition from reservoir to reservoir and well to well. A single average emission factor could not reflect this disparity.

Summary

Table 3.1					
Natural Gas Systems - CH ₄					
		1990		1999	
		Emissions	MTCE	Emissions	MTCE
		(metric tons)		(metric tons)	
Production					
	Associated Wells	549	3,143	620	3,548
	Non-Associated Wells	244,714	1,401,542	216,009	1,237,144
	Off-Shore Platforms	0	0	0	0
	Gathering Pipeline	4,183	23,958	1,391	7,968
	Total	249,446	1,428,644	218,020	1,248,660
Processing					
	Processing Plants	97,644	559,234	65,412	374,632
	Total	97,644	559,234	65,412	374,632
Transmission					
	Transmission Stations	70,747	405,187	56,107	321,339
	Storage Stations	16,482	94,399	13,072	74,864
	Transmission Pipeline	9,037	51,755	7,167	41,045
	LNG Storage Stations	0	0	0	0
	Total	96,266	551,341	76,345	437,247
Distribution					
	Cast Iron Pipeline	7,163	41,025	7,940	45,472
	Unprotected Steel Pipeline	4,962	28,419	5,500	31,499
	Protected Steel Pipeline	1,367	7,827	1,515	8,675
	Plastic Pipeline	2,954	16,916	3,274	18,750
	Total Services	14,431	82,652	15,146	86,746
	Unprotected Steel Services	2,035	11,654	2,165	12,401
	Protected Steel Services	1,765	10,106	1,838	10,529
	Total	34,676	198,598	37,378	214,072
TOTAL - Natural Gas Systems		478,031	2,737,817	397,154	2,274,612

Figure 3.1
Natural Gas Systems - CH₄

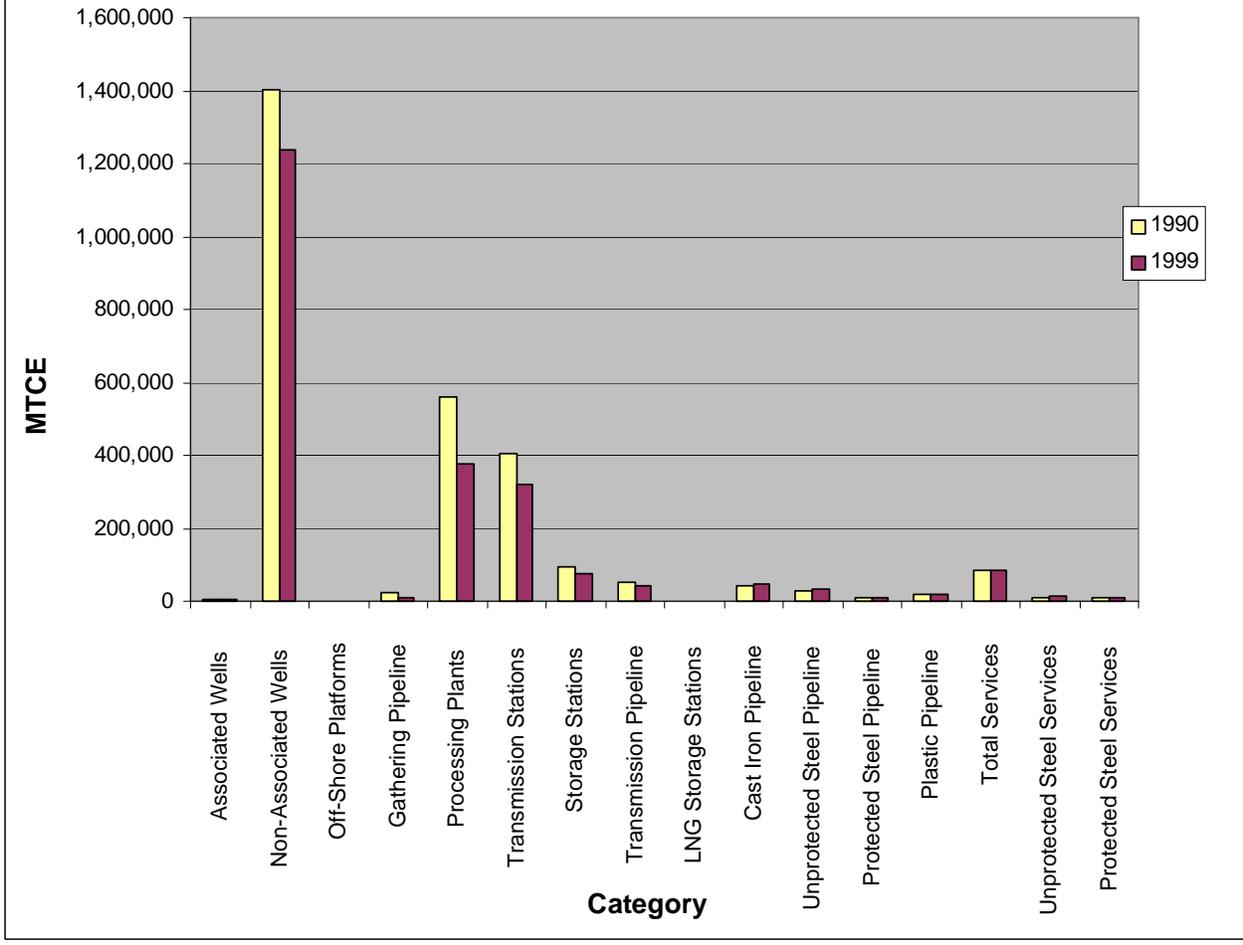


Table 3.2					
Oil Systems - CH ₄					
		1990		1999	
		Emissions	MTCE	Emissions	MTCE
		(metric tons)		(metric tons)	
Production					
Oil Production					
	Low	456,024	1,185	288,452	749
	High	7,556,961	19,632	4,780,069	12,418
	Median	4,039,065	10,493	2,554,865	6,637
Venting and Flaring					
	Low	10,202,328	26,505	6,970,252	18,108
	High	47,513,699	123,435	32,461,457	84,331
	Median	28,858,014	74,970	19,715,854	51,220
Crude Oil Transportation and Refining					
Transportation					
	Low	1,300,773	3,379	1,524,307	3,960
	High	1,300,773	3,379	1,524,307	3,960
	Median	1,300,773	3,379	1,524,307	3,960
Refining					
	Low	153,032	398	179,330	466
	High	2,525,030	6,560	2,958,949	7,687
	Median	1,300,773	3,379	1,524,307	3,960
Storage Tanks					
	Low	38,258	99	44,833	116
	High	459,096	1,193	537,991	1,398
	Median	229,548	596	268,995	699
TOTAL - Low		12,150,415	31,565	9,007,174	23,400
TOTAL - High		59,355,559	154,199	42,262,773	109,794
TOTAL - Median		35,728,173	92,818	25,588,328	66,476

Figure 3.2
Oil Systems - CH₄

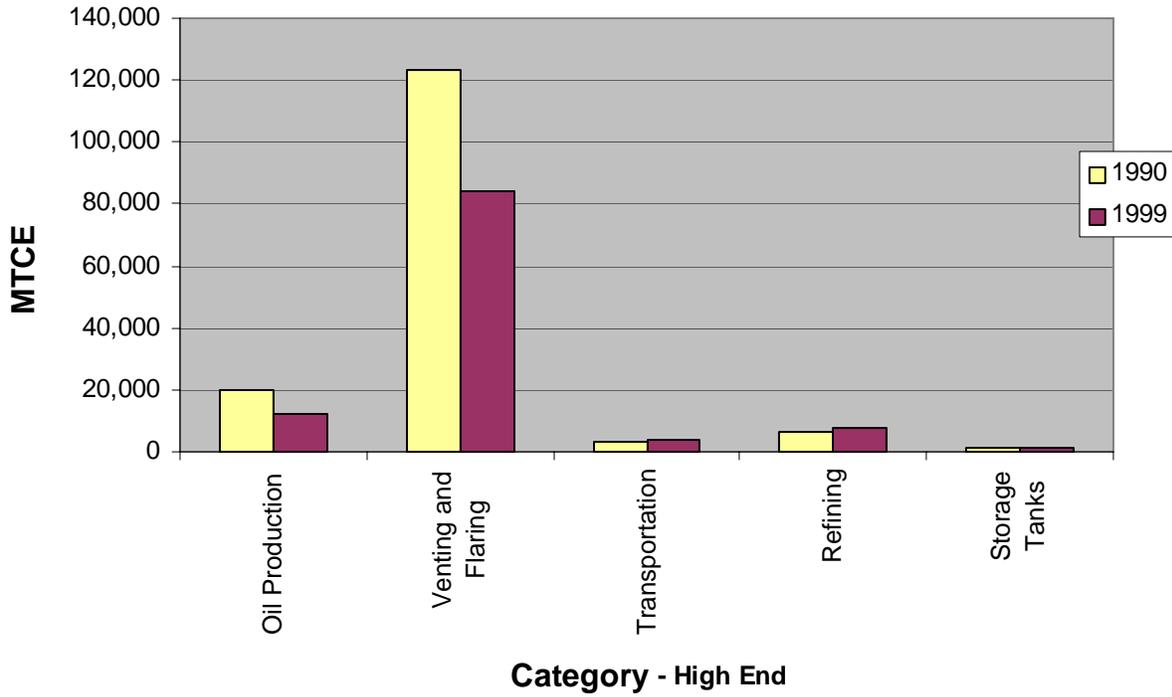
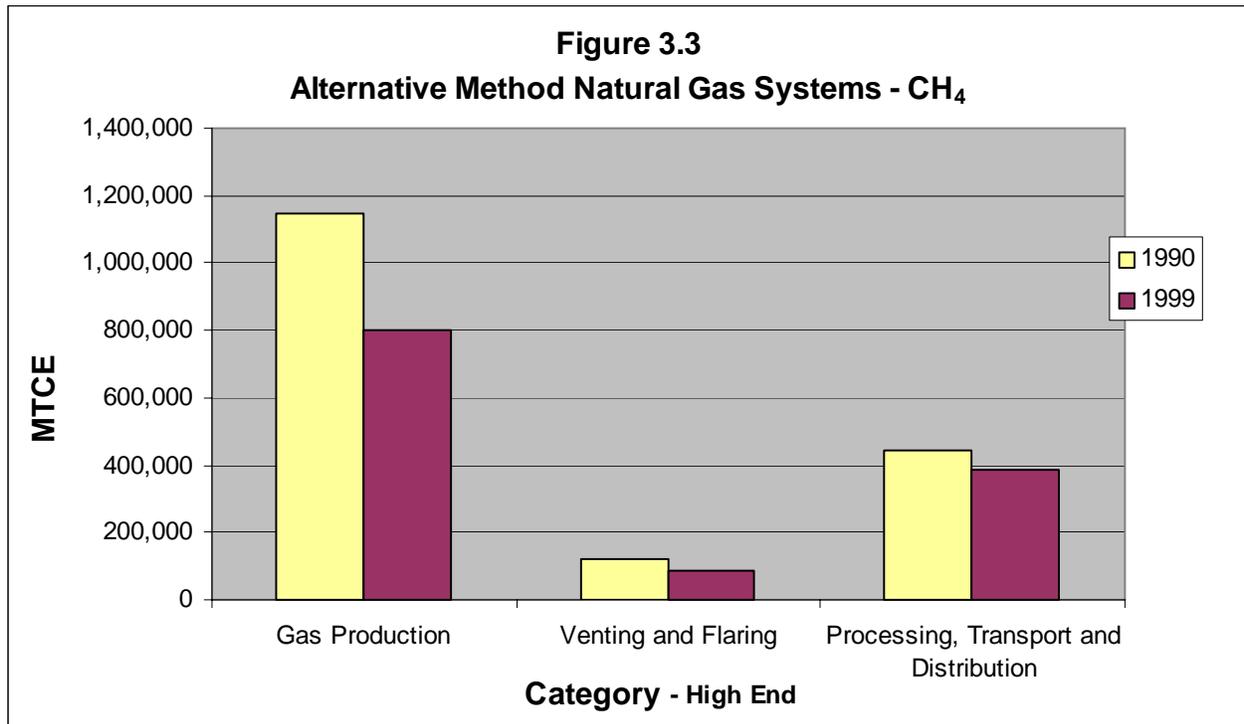
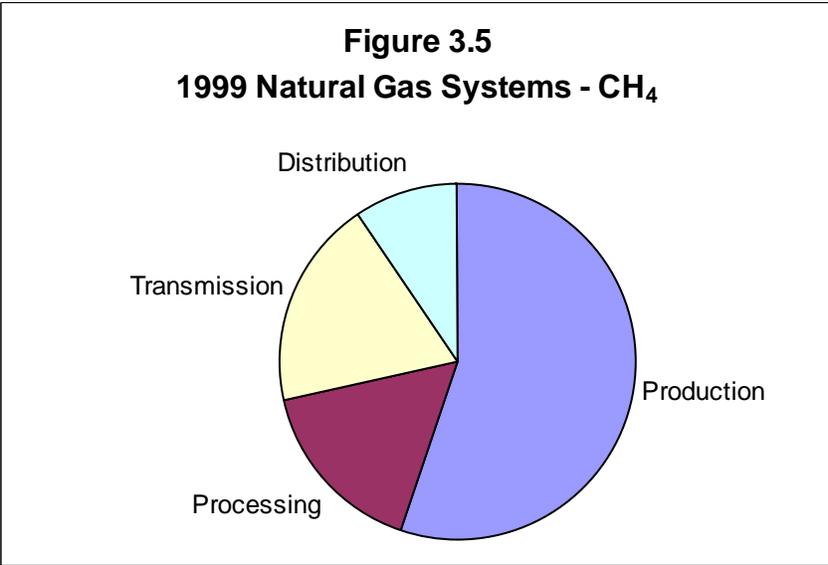
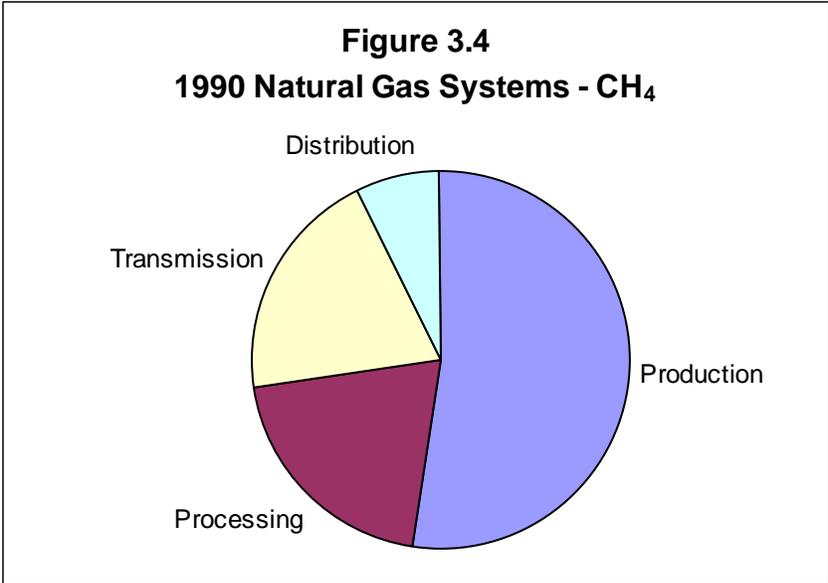


Table 3.3					
Alternative Method Natural Gas Systems - CH ₄					
		1990		1999	
		Emissions	MTCE	Emissions	MTCE
		(metric tons)		(metric tons)	
Production					
Gas Production					
	Low	109,756	628,604	76,586	438,629
	High	200,415	1,147,834	139,847	800,940
	Median	155,034	887,925	108,181	619,579
Venting and Flaring					
	Low	4,628	26,505	3,162	18,108
	High	21,552	123,435	14,725	84,331
	Median	13,090	74,970	8,943	51,220
Processing, Transport and Distribution					
	Low	37,277	213,496	32,611	186,771
	High	77,201	442,150	67,537	386,802
	Median	57,239	327,823	50,074	286,786
TOTAL - Low		151,661	868,605	112,359	643,508
TOTAL - High		299,169	1,713,420	222,108	1,272,073
TOTAL - Median		225,364	1,290,718	167,197	957,585





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4. Methane Emissions from Coal Mining

Overview

Methane (CH₄) is naturally present as an imbedded gas in coalfields throughout the world. It is stored in both the coal itself and in the surrounding rock strata. The volume of CH₄ stored in a coal seam is dependant upon the specific rank of the coal and the pressure (or depth) of the coalbed. The deeper the coal, the more stored CH₄. Oklahoma coal beds lie in the Arkoma Coal Basin and are mined primarily from the surface.

Methane is released when the pressure within a coalbed is reduced. Thus, underground mining operations will release more CH₄ than surface mining operations. In addition to CH₄ being released during the mining of the coal, post-mining processing and storage will also release CH₄. For safety and health reasons, CH₄ in underground mines is controlled by ventilation systems and degasification systems. No degasification systems were in use in Oklahoma during the study years.

Methods

Total CH₄ released from coal mining was the sum of: 1) the emissions from underground mining, 2) the emissions from surface mining, and 3) the emissions from post-mining activities. Total CH₄ emissions were tallied for 1990 and 1999 coal mining operations in Oklahoma.

Underground

Methane from underground mining in Oklahoma was released through ventilation systems only. Ventilation data was acquired from Mine Safety and Health Administration. Ventilation data were reported as quarterly readings in cubic feet per 24 hours. The readings for each quarter of the year were summed and averaged to obtain an annual daily average reading in cubic feet per 24 hours. The daily average value was multiplied by 365 days/year to obtain an annual emissions value.

Surface

Methane released from surface mining was the product of the yearly amount of surface-mined coal from each basin and a basin-specific emission factor. The emission factor for the Arkoma Basin was 6.4 ft³/ton and was developed by the Environmental Protection Agency. State coal production data for 1990 and 1999 were obtained from the Oklahoma Geological Survey.

Post-Mining

Some CH₄ was released from coal during the processing, transporting and storage activities. Total CH₄ from post-mining activities was the sum of emissions from underground post-mining activities and surface post-mining activities. Underground mining production was obtained by subtracting the surface mining production from the total state production. A post-mining emissions value for underground mines was then calculated by multiplying the statewide underground coal production by the EPA's basin-specific, post-mining emission factor. The post-mining emissions value for surface mines was calculated by multiplying the statewide surface coal production by the EPA's basin-specific, post-mining emission factor.

Results

Total coal production in Oklahoma increased only 1.5% from 1990 to 1999, while underground coal production in the State increased by 94% during the same period. Although there were underground mines in operation, MSHA reports ventilation emissions for 1990 as 0.0 ft³/yr of methane. In some cases, it was possible that ventilation readings were below the MSHA detectable concentrations and were reported as “no sampling required.” Only one underground mine was operating in 1999 and the ventilation data for it resulted in a daily average of 190,357,282.0 ft³/yr of CH₄ released.

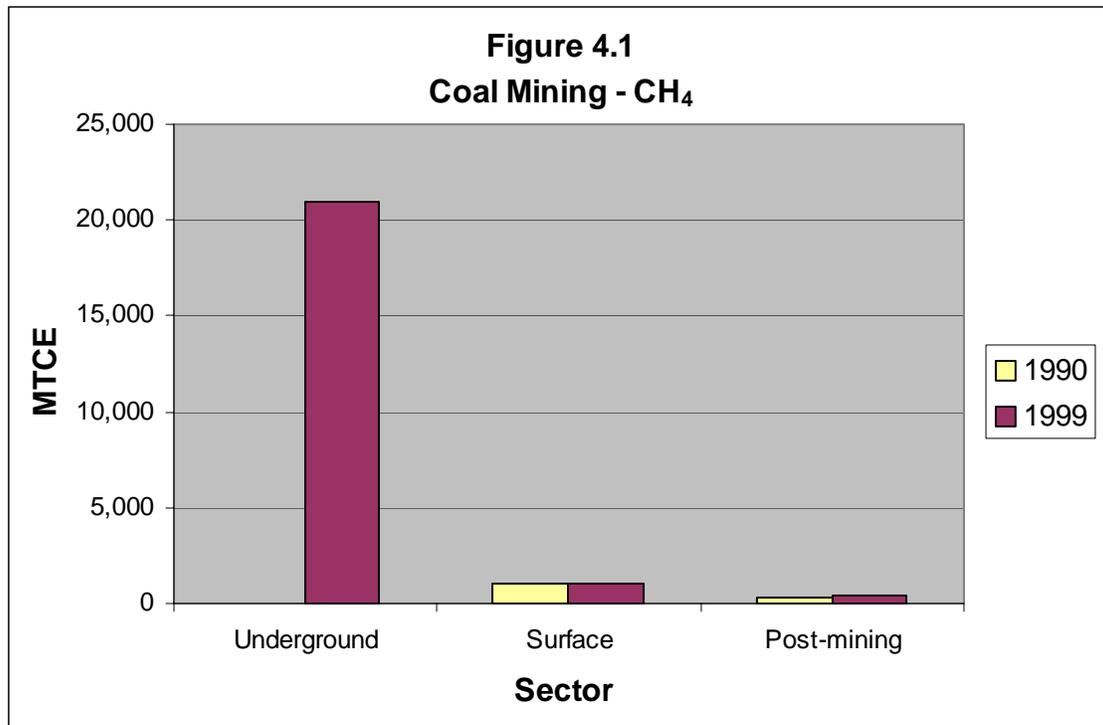
Surface mining production showed nearly a 5% decrease from 1990 to 1999. Methane emissions released from surface mining were relatively the same in 1990 and 1999 at 9,816,300.8 and 9,351,897.6 respectively.

Post-mining emissions were subdivided into surface and underground. As with surface production emissions, surface post-mining emissions were relatively the same in 1990 and 1999. Underground post-mining emissions increased by 94% from 1990 to 1999. Since underground post-mining releases more CH₄ than surface post-mining, it was given more credence with a higher emission factor. Total post-mining CH₄ emissions increased nearly 43% from 2,923,797.5 ft³ in 1990 to 4,157,994.0 ft³ in 1999.

Considering the 94% increase in underground coal production and the MSHA ventilation data, total CH₄ emissions from the coal mining industry increased from 12,740,098.3 ft³ in 1990 to 203,867,173.6 ft³ in 1999. This was a 1500% increase from 1990 to 1999. Conversion of these totals to metric tons of carbon equivalent resulted in 1,400.9 MTCE and 22,418.0 MTCE respectively.

Summary

Table 4.1						
Coal Mining - CH ₄						
	1990			1999		
	Production (tons)	Emissions (ft ³ /yr)	MTCE	Production (tons)	Emissions (ft ³ /yr)	MTCE
Underground	102,963	0	0	199,760	190,357,282	20,932
Surface	1,533,797	9,816,301	1,079	1,461,234	9,351,898	1,028
Post-mining		2,923,798	322		4,157,994	457
TOTAL		12,740,098	1,401		203,867,174	22,418



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5. Methane, Carbon Dioxide, and Nitrous Oxide Emissions From Municipal Waste Disposal

Overview

As humans consume natural resources from day to day activities, waste is generated from the unutilized portion of materials used. Few practical or economical uses for the waste generated have been found. The solution to this problem is landfills, large collection sites where waste is disposed and ultimately left stationary subject to only natural decomposition and various waste management practices. These processes ultimately produce greenhouse gases such as methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O).

The decomposition process occurs in two ways, each producing a different greenhouse gas. The first and most important process for decomposition is anaerobic, or in the absence of oxygen. Waste located toward the center and bottom of a landfill has little access to oxygen and is thus decomposed anaerobically; CH_4 tends to be the result. The second process occurs aerobically, or in the presence of oxygen. When waste is decomposed on or near the surface of a landfill, it is exposed directly to oxygen and gives off CO_2 as a by-product.

A large percentage of waste in place at landfills consists of biogenic materials such as grass, paper, cardboard, tree trimmings, etc. This material was originally produced from plants that received CO_2 from the atmosphere. The aerobic decomposition process simply returns the same CO_2 back to the atmosphere, thus no net emissions have occurred. So, CO_2 emitted from biogenic materials are not considered for this report. Aerobic CO_2 emissions will, however, be measured for the percentage of waste in place that is considered non-biogenic, such as plastics, textiles, rubber, etc.

In addition to the decomposition processes, certain management practices involved with landfill operations also contribute to either emission or sequestration of greenhouse gases. Direct flaring of CH_4 and incinerating solid waste are two such examples. Flaring of CH_4 chemically changes the gas into CO_2 . While this reduces the total amount of CH_4 emitted, it does not increase the amount of CO_2 measured. The CO_2 emitted by flaring is categorized similarly to that of aerobic decomposition. It is the same CO_2 that was absorbed from the atmosphere as the plant matter was growing, thus no net increase in emissions result.

Some landfill facilities utilize a percentage of the waste in place and incinerate it for the energy it creates. This practice reduces the total volume of waste to be managed but consequently releases another greenhouse gas into the atmosphere. Solids burned at high temperatures combine with nitrogen in the air and in the organic materials to produce N_2O .

Methods

The methods for determining greenhouse gas emissions from municipal waste disposals were those suggested by the EIIP guidance document. Emissions of CH₄, CO₂, and N₂O were calculated for years 1990 and 1999.

Methane

The EIIP guidance offered two methods for determining CH₄ emissions; one relied on theoretical considerations and kinetic models to simulate laboratory conditions, the other relied heavily on state-level data from field measurements and statistical models developed by the U.S. EPA Office of Air and Radiation. The latter provided a better representation of actual CH₄ emissions.

To calculate CH₄ emissions, the following raw data were required:

- 1) State population estimates for 1990 and 1999,
- 2) Annual amount of landfilled waste for each year,
- 3) Number of landfills, large and small, operating in each year,
- 4) Average yearly rainfall in the State, and
- 5) Amount of CH₄ flared or recovered from landfills.

Population data were obtained from the State Intercensal Population Estimates, 1990-1999. The EIIP guidance provided an average annual amount of waste landfilled per person in the United States for 1990. The value for 1999 was calculated by finding the average percent of generated waste that was actually landfilled during the years 1960 to 1995. This average percent landfilled was multiplied by 365 days/year and by the U.S. daily amount of waste generated for 1999, which was provided by the EPA's Basic Facts – Municipal Solid Waste sheet. This resulted in the average annual amount of waste landfilled per person for 1999. To achieve a total amount of landfilled waste, the annual waste landfilled per person was then multiplied by the state population for each study year. Since CH₄ from waste generates over a period of thirty years, a 30-year multiplier was factored into the calculation. The resulting value was referred to as total waste in place (WIP.)

Since small and large landfills produced CH₄ at different rates, the amounts of waste in large and small landfills were estimated separately. The provided method gave a default value of 81% waste in large landfills and 19% in small landfills for both years in Oklahoma. This percentage breakdown may closely reflect 1999, however, it was not an accurate representation in the State for 1990. As a result of regulation changes in the mid-1990's, many small landfills operating in 1990 were closed, resulting in the higher percentage waste in large landfills in 1999. According to EIIP, large landfills were defined as those containing 1.1 million tons or more WIP. There were 120 operational landfills in the State of Oklahoma in 1990 and a total WIP of roughly 47 million tons. An alternate method was used to calculate a percentage of waste in large landfills to more accurately reflect the conditions prior to the closings. Since individual data could not be obtained from the eighty landfills that closed between 1990 and 1999, an *average* WIP per landfill was used for 1990. Dividing the total WIP by the number of landfills gave an average WIP per landfill of only 391,000 tons, well below the 1.1 million ton threshold. So, for 1990 the fraction of large landfills to small landfills was 0%. Note that an extremely small number was used to prevent subsequent calculations from being divided by zero.

Multiplying the percentage of each size landfill by the total number of landfills for a given year yielded the estimated number of large and small landfills for that year.

Small Municipal Solid Waste Landfills

Tons of waste in small landfills was calculated by multiplying total WIP by the percentage of waste in small landfills. A methane conversion factor (MCF) provided by the EIIP guidance represented the CH₄ producing capacity of small landfills in a given area. The state was categorized as arid or non-arid according to average yearly rainfall. The threshold for an arid classification was 25 inches or less of rainfall per year. Oklahoma's yearly rainfall exceeded this amount and was thus considered a non-arid state.

The MCF was multiplied by the previously calculated waste in place for small landfills to give total CH₄ production in cubic feet per day. Once converted to tons per year, the calculation for total CH₄ produced from small landfills was complete.

Large Municipal Solid Waste Landfills

The method for estimating CH₄ production from large landfills was very similar but involved a few extra steps. Tons of waste in large landfills was calculated by multiplying total WIP by the percentage of waste in large landfills. The total waste in large landfills was divided by the total number of large landfills resulting in an average waste in place per large landfill. The average waste-in-place was then entered in a formula including the total number of large landfills and the MCF for large landfills. The result gave the amount of CH₄ generated from large landfills in cubic feet per day and was converted to tons per year.

After emissions for both large and small landfills were estimated, the totals were summed to get total CH₄ emissions from all municipal solid waste landfills.

Industrial Waste Landfills

The EPA estimated that CH₄ generated by industrial landfills was approximately 7% of that generated by municipal solid waste landfills. Multiplying 7% by the total CH₄ production of municipal solid waste landfills gave the total CH₄ from industrial waste landfills.

The sum of industrial landfill CH₄ generation and municipal solid waste landfill CH₄ generation gave the total CH₄ generation in Oklahoma for each given year.

Flared or Recovered Methane

Some landfills flared excess CH₄ to reduce emissions and possible safety hazards while others recovered CH₄ for energy use and sale. The CH₄ involved in these practices was not emitted into the atmosphere, and therefore was treated as a decrease in CH₄ for this report.

The amount of CH₄ flared or recovered in Oklahoma was obtained by directly contacting individual landfills in the State. The amounts in tons per year were summed and then subtracted from the total amount of CH₄ generated from municipal waste disposal in the State.

Oxidation of Methane

Another factor that decreased the amount of total CH₄ generated was the process of oxidation. This occurred when CH₄ generated from deep below the surface gradually rose to the surface and came into contact with soil and air. Although little data was available to support the degree to

which CH₄ was oxidized, EIIP guidance suggested that approximately 10% of total CH₄ not flared or recovered underwent this process. Multiplying the total CH₄ generated after flare adjustment by 90% resulted in the final total of all CH₄ generated by all landfills in the State. Converting to metric tons of carbon equivalent (MTCE) was performed by converting to metric tons and multiplying by the ratio of carbon to CO₂ and then by the global warming potential of CH₄.

Carbon Dioxide

CO₂ had two roles related to greenhouse gas emissions from waste disposal; it was both sequestered from incomplete decomposition and generated through waste combustion. EIIP guidance states that 0.18 tons of carbon remains intact per ton of waste after decomposition. Since this waste was former plant material and originally received this carbon in the form of CO₂, it was considered sequestered and ultimately reduced the amount of CO₂ in the air. Carbon sequestered was simply the amount of waste in tons generated in a given year (not total waste-in-place) multiplied by 0.18 and was represented as a negative number. MTCE was calculated by converting to metric tons.

As discussed in the overview, CO₂ was generated in abundance during waste combustion. However, only a small fraction of this CO₂ came from non-biogenic sources. Only the portions from non-biogenic sources were considered emitted as a greenhouse gas.

The amount of waste combusted in 1990 and 1999 was obtained from internal data sources. Other data incorporated the fraction of combusted waste that included non-biogenic carbon and the percentage of that carbon that ultimately converted to CO₂. EIIP provided estimates for both. All three figures were multiplied together resulting in the amount of short tons of CO₂ emitted by waste combustion. To represent this total as MTCE, it was converted to metric tons and then multiplied by the ratio of carbon to CO₂ and by the global warming potential of CO₂.

Total MTCE produced from municipal waste disposal CO₂ emissions was acquired by subtracting MTCE of sequestered CO₂ from MTCE of waste combustion CO₂.

Nitrous Oxide

The estimation for N₂O was very similar to that of CO₂. First, the same data for combusted waste was needed. EIIP guidance states that 0.0001 tons of N₂O was released per ton of waste combusted. This factor was multiplied by the tons of waste combusted to arrive at the amount of N₂O emitted per ton of combusted waste. Tons of N₂O was converted to MTCE by converting to metric tons and by multiplying by the ratio of carbon to CO₂ and by the global warming potential for N₂O.

Results

Methane

The number of landfills decreased from 120 in 1990 to only 40 in 1999. This along with the different categorization of landfill size from 1990 to 1999 resulted in a 200% increase in MTCE from CH₄. MTCE from CH₄ in 1990 was 244,279 and 742,777 in 1999.

Carbon Dioxide

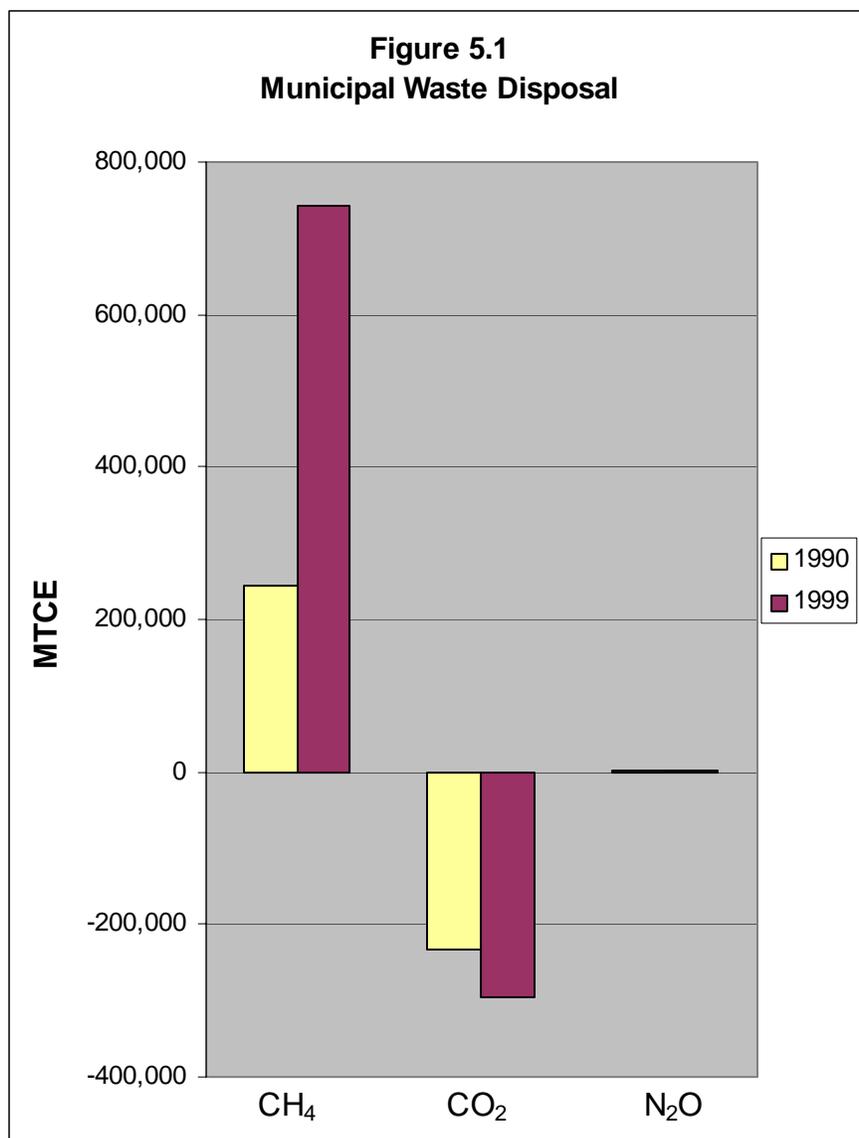
Sequestration of CO₂ increased by 22% from 1990 to 1999 and CO₂ released from combustion decreased by 9% during this time. These combined resulted in a net deficit MTCE of CO₂ of -232,318 in 1990 and -294,471 in 1999.

Nitrous Oxide

Waste combustion in the state decreased from 1990 to 1999 by 9%. MTCE of N₂O from combustion was 3,026 and 2,761 for 1990 and 1999 respectively.

Summary

Table 5.1							
Municipal Waste Disposal							
		1990			1999		
		Waste (tons)	Emissions (tons/yr)	MTCE	Waste (tons)	Emissions (tons/yr)	MTCE
CH₄							
	Small landfills	46,957,945	126,552		10,857,756	29,262	
	Large landfills	0	0		46,288,328	196,941	
	Industrial landfills		8,859			15,834	
	Flared/recovered		-83,160			-83,160	
	Oxidized		-5,225			-15,888	
TOTAL - CH ₄			47,025	244,279		142,989	742,777
CO₂							
	Sequestration	1,659,291	-298,672	-270,896	2,019,296	-363,473	-329,670
	Combustion	394,560	155,956	38,578	360,000	142,296	35,199
TOTAL - CO ₂			-142,716	-232,318		-221,177	-294,471
N₂O							
	Combustion	394,560	39	3,026	360,000	36	2,761
TOTAL - N ₂ O			39	3,026		36	2,761



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6. Methane Emissions from Domesticated Animals

Overview

Methane (CH₄) is a natural by-product of animal digestion, especially that of ruminants like cattle, buffalo, sheep and goats; and to a lesser extent from non-ruminants such as pigs and horses. CH₄ is produced as a result of bacterial fermentation in the rumen. It is also produced in the large intestine of ruminants. Non-ruminants have limited fermentation taking place in the large intestine and therefore produce less CH₄. Only domesticated animals are considered here because emissions from wild animals are not the result of human activity.

The amount of CH₄ produced by domesticated animals depends on the type of animals, the age and weight of the animals, and the quantity and quality of the feed consumed. CH₄ production is also related to the portion of feed energy intake that is converted to CH₄. Higher levels of conversion result in higher emissions, similarly, higher levels of intake translate into higher emissions. Most ruminants in a temperate climate will convert 5.5-6.5 percent of their feed energy intake to CH₄. Methane emissions can be estimated by considering the amount of feed energy consumed and production statistics.

Methods

Direct measurement of CH₄ production from domesticated animals was not practical. However, emission factors for specific animal types had been developed to assist with CH₄ estimation. These emission factors were obtained from the EIIP guidance document. When emission factors varied from one region to another, only region specific emissions factors were used. According to the guidance document, Oklahoma was in the South Central Region.

The data on animal population were collected from the Internet database of the National Agricultural Statistics Service, U.S. Department of Agriculture. Data were gathered for cattle, sheep, and swine for years 1990 and 1999 from the U.S. and State-level option of the database. Data for goats and horses categories were not available for 1990 and 1999. Instead, U.S. Department of Agriculture 1997 Census provided data for years 1992 and 1997. Animal populations varied over the course of the inventory year, thus, the average animal population for the year was used. The cattle population data was aggregated to a simplified set of sub-categories to match the emission factors.

CH₄ emissions were estimated for each type of animal by multiplying the emission factor by the applicable animal population. The dairy heifer category was calculated using the emission factor for 'Dairy Cattle – Replacements 12-24 months.' Emission from dairy cows was calculated using the 'Dairy Cattle – Mature Cows' emission factor. The calves category was not distinguished between dairy and non-dairy and thus the higher emission factor for 'Beef Cattle – Replacements 0-12 months' was used. In Oklahoma, most yearling cattle were wintered-over prior to going to the feedlot, therefore the higher factor of 'Beef Cattle – Yearling System' was used for all steers and all non-replacement heifers. Heifer replacement was calculated using the

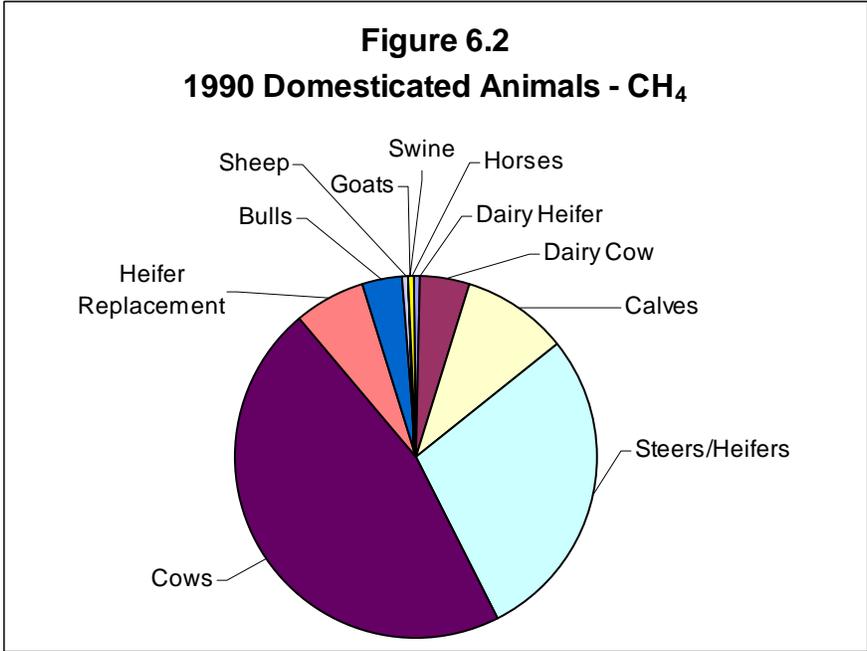
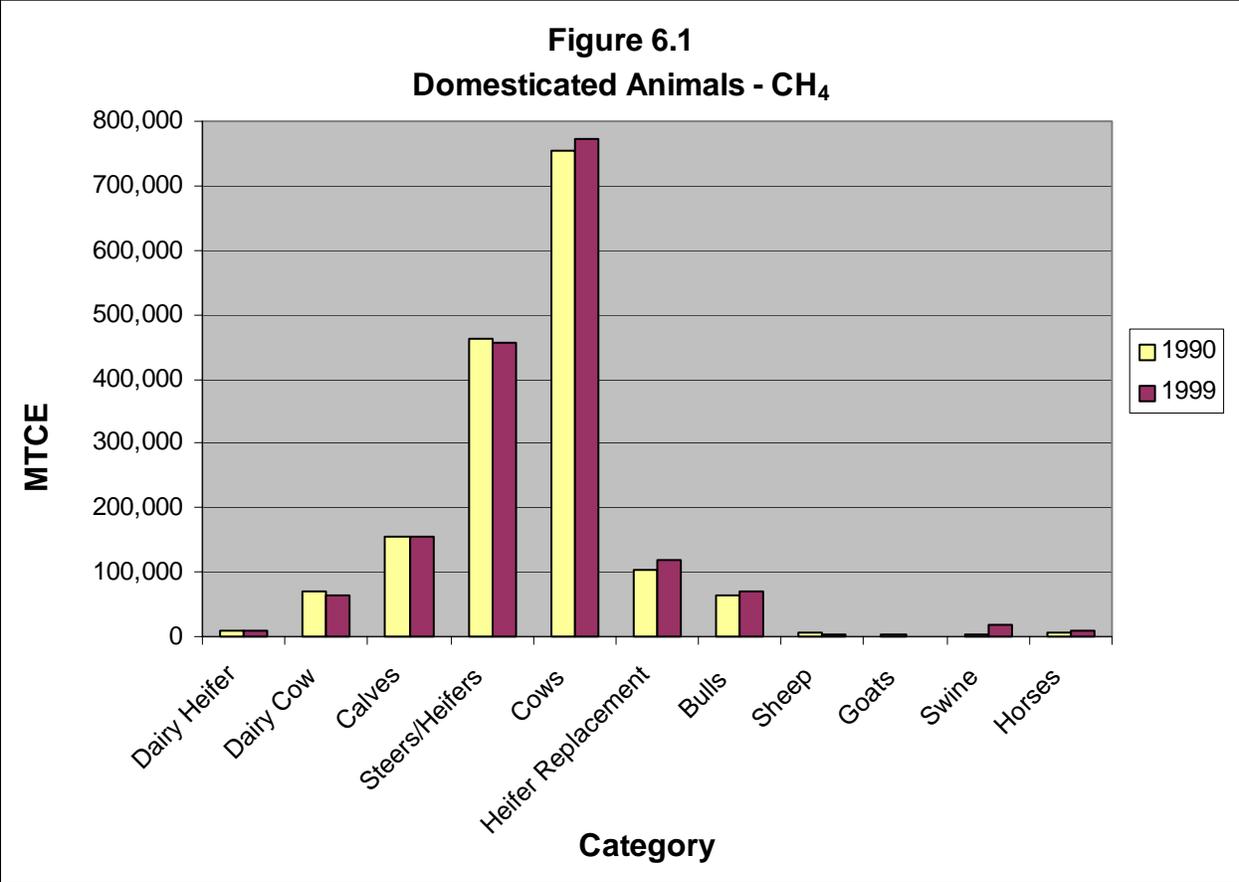
emission factor for ‘Beef Cattle – Replacements 12-24 months.’ Emissions from the remainder of the categories were calculated using emission factors directly associated with the category.

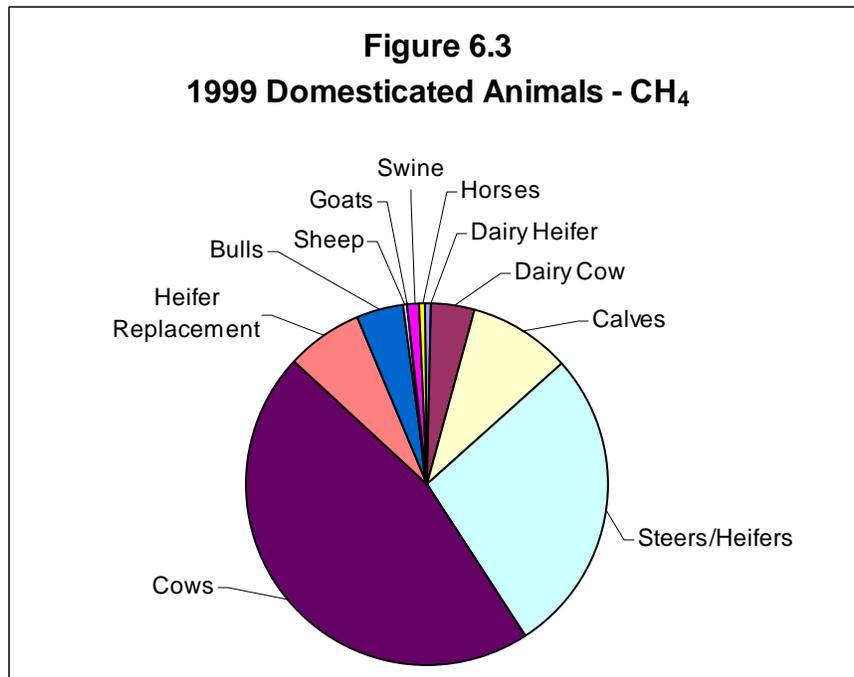
Results

The largest contributor of CH₄ emissions from the domesticated animal sector was non-dairy cows at over 140,000 tons per year for both 1990 and 1999. Steers/heifers follow at over 85,000 tons per year. CH₄ emissions from domesticated animals had a net increase from 1990 to 1999 of only 3 percent. Sheep and goats had large decreases from 1990 to 1999 of 54% and 47% respectively. The horse population increased, resulting in a 34% increase in CH₄ emissions. The largest emissions increase from 1990 to 1999 was seen in the swine category with an increase of 951%. However, after the increase, swine contributed only 1 percent of the total CH₄ emissions from the domesticated animals category for 1999. Total MTCE contributed by Domesticated Animals was 1,629,273 in 1990 and 1,681,154 in 1999.

Summary

Table 6.1						
Domesticated Animals - CH ₄						
	1990			1999		
	Population	Emissions (tons)	MTCE	Population	Emissions (tons)	MTCE
Dairy Heifer	30,000	2,036	10,576	30,000	2,036	10,576
Dairy Cow	100,000	13,285	69,026	92,000	12,222	63,504
Calves	1,140,000	29,583	153,707	1,160,000	30,102	156,404
Steers/Heifers	1,695,000	88,733	461,040	1,680,000	87,948	456,960
Cows	1,860,000	144,987	753,323	1,908,000	148,729	772,764
Heifer Replacement	265,000	19,729	102,509	310,000	23,080	119,916
Bulls	110,000	12,100	62,869	120,000	13,200	68,585
Sheep	119,000	1,047	5,441	55,000	484	2,515
Goats	60,784	334	1,737	31,967	176	914
Swine	215,000	355	1,843	2,260,000	3,729	19,375
Horses	70,006	1,386	7,202	93,712	1,855	9,641
TOTAL			1,629,273			1,681,154





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7. Methane and Nitrous Oxide Emissions from Manure Management

Overview

Manure management systems (MMS) are sources of methane (CH₄) and nitrous oxide (N₂O.) It is well documented that MMS are a large source of these greenhouse gas emissions; however, data have never been reported at the state level. Both CH₄ and N₂O are produced from the bacterial decomposition of nutrients in animal wastes in one of two ways, anaerobic or aerobic. When a system is void of oxygen (anaerobic) CH₄ is the primary waste product. Alternatively, in the presence of oxygen (aerobic) NO₂ is the major by-product.

Although there are many factors that contribute to the total CH₄ emission from MMS, only factors that have quantifiable supporting data will be addressed in this report. These factors include: the type and amount of each animal being managed, the CH₄ production rate of each animal's manure, the methane conversion factors (MCF) associated with each type of MMS, and the extent to which each MMS is used for each animal. It is notable that some of these factors are determined by several other variables such as temperature, pH, water content, animal diet, and contact with oxygen. Most of the data for the four major factors are presented as constants, which have not changed (or have not significantly changed) over time. The only exception is the number of head for each animal type category.

Methods

The methods used for calculating the CH₄ and N₂O emissions were taken from the EIIP guidance. This report considered only animals that were managed by humans and were listed in the EIIP methodology guidelines; wild animals, pets, and managed animals not listed in guidelines were excluded. Animal population data for 1990 and 1999 were obtained from the Internet database of the U.S. Department of Agriculture, National Agricultural Statistics Service. Data for horses, goats, and turkeys were not available for target years 1990 and 1999. These data were obtained from the Oklahoma Agricultural Census Reports of 1992 and 1997 from the above-mentioned database. Annual average population data were gathered for cattle, swine, poultry, sheep, goats, and horses. Cattle, swine, and poultry were subcategorized based on age or production system. Steers category equaled total steers minus feedlot steers. Heifers category equaled heifers-other plus heifers-beef replacement minus heifers on feed.

Methane

To begin the process of determining CH₄ emissions from manure management, the total amount of volatile solids (TVS) produced by each animal type was calculated by multiplying the animal population by the typical animal mass (TAM) and volatile solids (VS.) TAM was the average mass of each animal type (given in kg but converted to lbs.) and VS was the amount of volatile solids produced per unit animal mass per year, both were obtained from EPA's *U.S. Greenhouse Gas Emissions and Sinks 1990-1999*. VS for sheep, horses, and goats were not available from

the above document, thus values from the EIIP guidance were used. This document was published in 2001 and contained updated constants and factors pertaining to this chapter.

Once the TVS for each animal type were calculated, each animal type was then subcategorized into manure management systems to estimate CH₄ emissions. Since each animal type exhibited different combinations of MMS, each MMS required a different MCF. To obtain CH₄ emissions, TVS for each animal type-MMS was multiplied by three factors. First, it was multiplied by the CH₄ producing capacity of the manure, which was obtained from EPA's *U.S. Greenhouse Gas Emissions and Sinks 1990-1999*. Second, it was multiplied by the state-specific MCF of the manure system as supplied by the EIIP guidance. Third, it was multiplied by the state-specific MMS percentage of use for each animal type, which was also supplied by the EIIP guidance. For example, MMS percentage breakdown for swine in Oklahoma was 60% anaerobic lagoon, 30% drylot, and 10% pit storage. No MMS percentage breakdown was available for turkeys in Oklahoma; therefore the U.S. average breakdown percentages were used. The result of this calculation was the yearly CH₄ emissions in cubic feet for each animal type.

From this point, CH₄ emissions from manure management could be calculated in several ways. The first method was to sum the emissions in cubic feet for one final total and convert directly to metric tons of carbon equivalent (MTCE). While this calculation would provide the correct final emissions, it would give little insight to individual animal and individual MMS contribution. The second method was to categorize the emissions by animal type. The total cubic feet of CH₄ per animal type was individually converted to MTCE. This allowed identification of specific animals that significantly contributed to CH₄ emissions. The third and last method reported was the one specifically suggested by EIIP. It categorized emissions per MMS by summing emissions of all animal types using a management system and then converting to MTCE. This allowed identification of management practices that contributed the most to CH₄ production. The second and third methods were used for this inventory. Carbon equivalency was calculated using the ratio of the molecular weight of carbon to that of CO₂ and the CH₄ global warming potential of 21.

Nitrous Oxide

For N₂O emissions, the process was somewhat similar. To calculate the amount of nitrogen excreted by each animal type managed, the same animal population data and categories were used as in the above calculation for CH₄. Two significant differences for N₂O production were 1) the addition of a percentage of total nitrogen that volatilized into NH₃ and NO_x, and 2) MMS characterized as "daily spread" (i.e., pasture, paddock, range) were not included in the calculations as they were covered under agricultural sources in Chapter 9. This explained the absence of NO₂ emissions from horses, goats, and sheep since 100% of these animals in Oklahoma were managed as daily spread.

Population of each animal type was multiplied by the specific TAM and by the daily rate of nitrogen excreted by the respective animal type. The nitrogen rate constants were provided by the EIIP guidance. Next, it was multiplied by the state-specific MMS percentage of use for each animal type, which was also supplied by the EIIP guidance. No MMS percentage breakdown was available for turkeys in Oklahoma; therefore the U.S. average breakdown percentages were used. Pasture, range, and paddock deposits and daily spread systems were not included and were addressed in chapter 9. This daily emission of nitrogen was multiplied by 365 to arrive at a

yearly figure. All of these factors together gave the total nitrogen that could potentially form N₂O. Since 20% of this nitrogen volatilized to NH₃ and NO_x, the percentage of volatilized nitrogen was then deducted by multiplying by 0.80 to arrive at the total nitrogen available to produce N₂O. A nitrogen conversion factor (NCF) associated with each MMS had to be considered and was provided by the EIIP guidance. Litter, deep pit, and pit storage < 1mo NCF data were not available for calculation. For purposes of this report, these MMS's were assumed to have a NCF of at least 0.001. This NCF was multiplied into the amount of nitrogen available to produce N₂O to arrive at the actual amount of nitrogen producing N₂O in each MMS/yr and was in units kg N₂O-N.

As in the CH₄ calculations, different methods of presentation gave different views of the same data. First, the total N₂O emissions were summed by MMS and converted to MTCE to show N₂O contribution by MMS. Second, the data were summed by animal type and converted to MTCE to show individual animal type contribution of N₂O. To convert to MTCE, units of kg N₂O-N must be converted to units of kg N₂O by multiplying by 44/28 and then converting to metric tons. Then multiply metric tons by the global warming potential of N₂O (310) and by the ratio of the atomic weight of carbon to the molecular weight of CO₂ (12/44.)

It was clear that the processes used in determining CH₄ and N₂O emissions from manure management systems were still in their infancy. Several sources do note that given current knowledge, the methods presented in this report were the best available however indefinite the results. Many studies are currently underway to improve the validity of the methods and will eventually produce results more representative of actual greenhouse gas emissions. Totals given were a result of the *best available* data to date, future research could and most likely would change many of the factors referred to as “constant” in this report especially from year to year.

Results

After all calculations were complete, the results showed a considerable increase in CH₄ MTCE and a substantial increase in N₂O MTCE from 1990 to 1999. The State of Oklahoma calculated that in 1990 CH₄ emissions were 1,578,904 MTCE and 3,308,353 MTCE in 1999. The overall N₂O emissions for 1990 were 52,229 MTCE and 67,860 MTCE in 1999.

Methane

Total CH₄ MTCE from manure management increased by 109% from 1990 to 1999. The largest animal type contributor to CH₄ production from manure management was ‘poultry: broilers’ for both years at 37% in 1990 and 27% in 1999. All five swine categories exhibited substantial CH₄ increases from 1990 to 1999. CH₄ MTCE from ‘market swine over 180 pounds’ increased by over 2,600% from 1990 to 1999. When combined, the swine categories increased from 9 percent of total in 1990 to 48% of total in 1999. The predominant MMS in 1990 was ‘litter’ which released over 37% of total CH₄ MTCE. In 1999, ‘anaerobic lagoons’ became the largest contributor at 51%. The largest MMS emission change from 1990 to 1999 was the ‘pit storage’ category at over 1,000% increase. Both the ‘anaerobic lagoons’ and ‘pit storage’ categories were MMS of the swine industry.

Nitrous Oxide

MTCE from manure management N₂O increased by 30% from 1990 to 1999. As in CH₄, swine categories had the largest increases of MTCE from N₂O. However, 'cows' and 'dairy cows' were the largest contributors at 27% and 32% respectively in 1990 and 21% and 23% respectively in 1999. The largest percent of MTCE from MMS N₂O was from the 'drylot' category for both years 1990 and 1999. The largest increases from 1990 to 1999 were in the 'anaerobic lagoons' and 'pit storage' categories at 402% and 1,045% respectively.

Summary

Table 7.1						
Manure Management by Animal - CH ₄						
	1990			1999		
	# Head	Emissions (ft ³ /yr)	MTCE	# Head	Emissions (ft ³ /yr)	MTCE
Dairy Cows	100,000	4,323,122,248	465,272	92,000	3,977,272,468	428,050
Dairy Heifers	30,000	665,718,728	71,647	30,000	665,718,728	71,647
Feedlot Steers	211,000	175,772,052	18,917	255,000	212,425,940	22,862
Feedlot Heifers	113,000	94,133,848	10,131	155,000	129,121,650	13,897
Bulls	110,000	93,593,362	10,073	120,000	102,101,849	10,989
Calves	1,140,000	218,229,855	23,487	1,160,000	222,058,449	23,899
Heifers	687,000	327,338,528	35,229	685,000	326,385,578	35,127
Steers	949,000	342,361,114	36,846	895,000	322,880,081	34,750
Cows	1,860,000	1,277,941,034	137,537	1,908,000	1,310,920,126	141,087
Swine: Market <60	75,000	218,725,528	23,540	820,000	2,391,399,101	257,372
Swine: Market 60-119	55,000	251,328,012	27,049	310,000	1,416,576,067	152,458
Swine: Market 120-179	30,000	228,680,496	24,612	270,000	2,060,371,959	221,746
Swine: Market >180	20,000	204,393,941	21,998	550,000	5,620,833,369	604,937
Swine: Breeding	35,000	375,547,604	40,418	310,000	3,326,278,778	357,988
Sheep	119,000	4,220,843	454	55,000	1,950,810	210
Goats	60,784	2,495,116	269	31,967	1,312,210	141
Horses	70,006	41,216,367	4,436	93,712	55,173,388	5,938
Poultry: layers	4,750,000	383,646,803	41,290	4,000,000	323,070,992	34,770
Poultry: Broilers	142,200,000	5,358,290,307	576,681	216,400,000	8,154,247,696	877,593
Poultry: Turkeys	488,766	83,794,879	9,018	698,837	119,809,810	12,894
TOTAL		14,670,550,665	1,578,904		30,739,909,050	3,308,353

Figure 7.1
Manure Management by Animal - CH₄

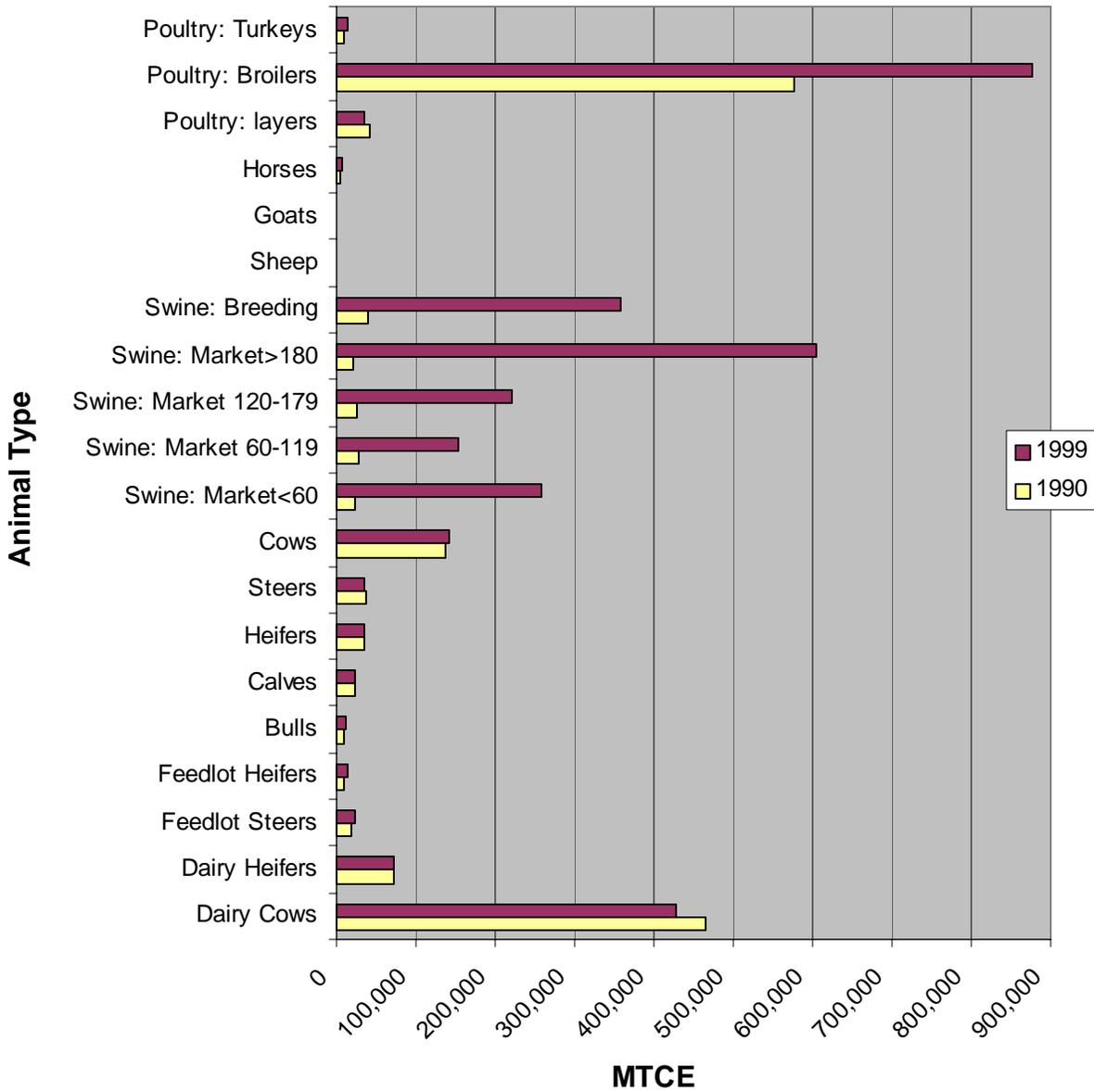


Figure 7.2
1990 Manure Management by Animal - CH₄

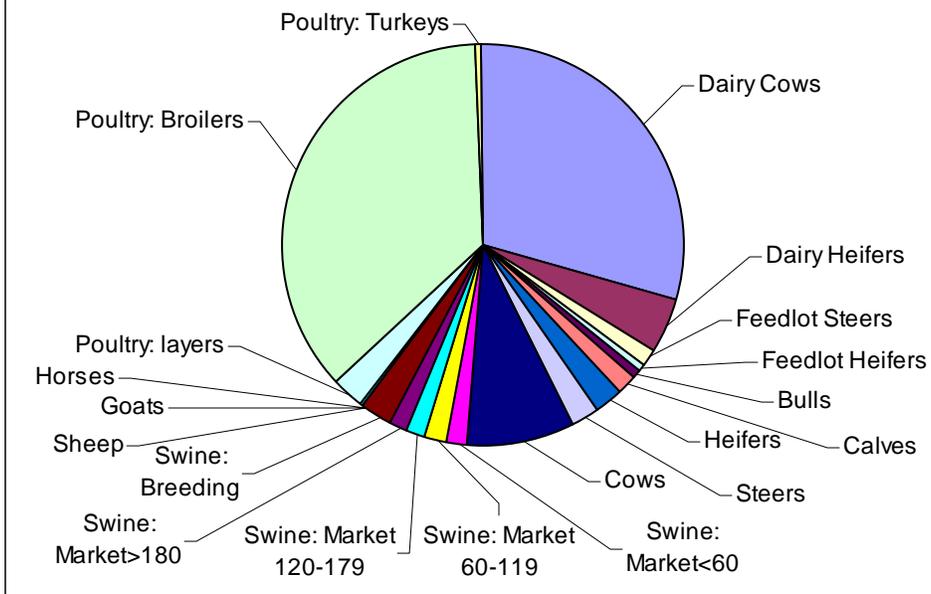


Figure 7.3
1999 Manure Management by Animal - CH₄

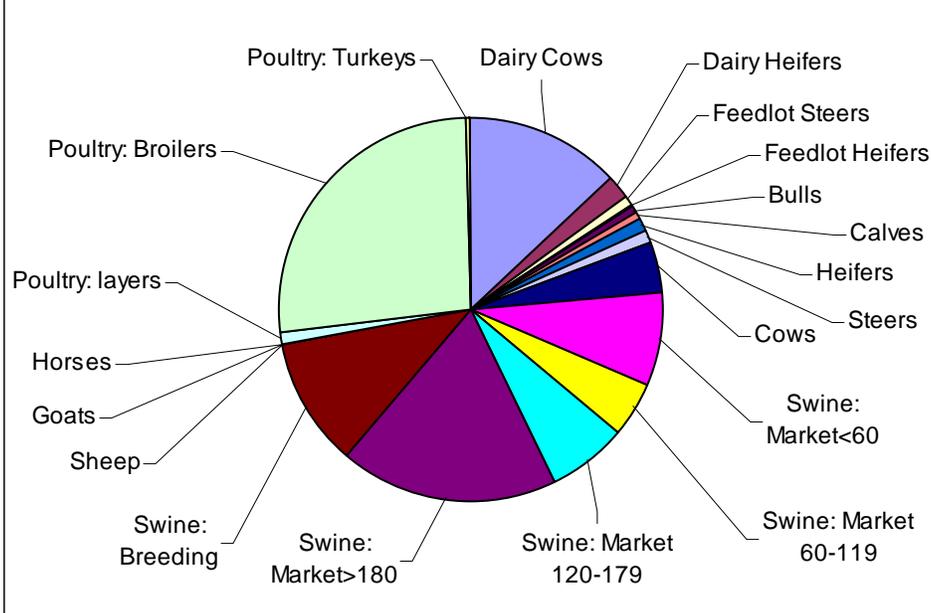
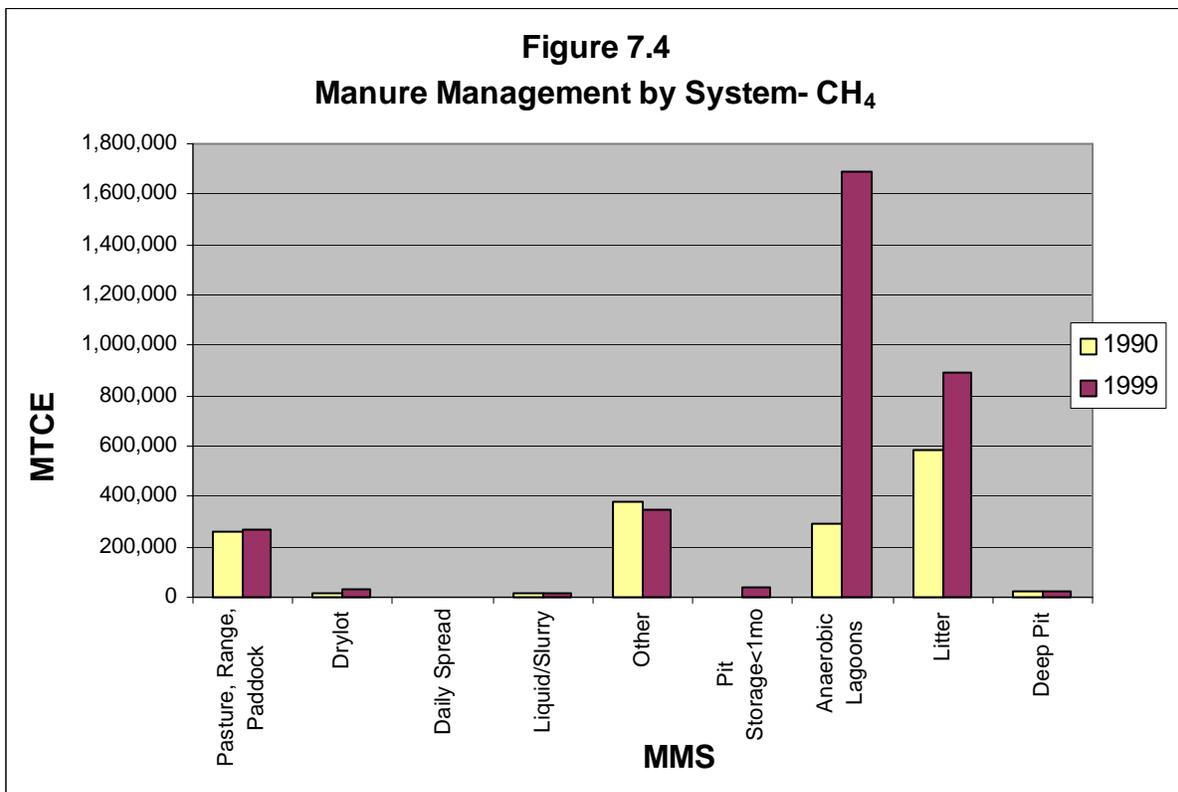


Table 7.2				
Manure Management by System - CH ₄				
	1990		1999	
	Emissions (lbs/yr)	MTCE	Emissions (lbs/yr)	MTCE
Pasture, Range, Paddock	99,520,002	259,340	103,692,386	270,213
Drylot	7,491,465	19,522	13,457,453	35,069
Daily Spread	90,527	236	84,251	220
Liquid/Slurry	6,619,220	17,249	5,574,080	14,526
Other	144,842,975	377,448	134,801,783	351,281
Pit Storage<1mo	1,353,382	3,527	15,677,986	40,855
Anaerobic Lagoons	112,034,283	291,951	646,842,492	1,685,613
Litter	224,716,494	585,591	341,659,061	890,332
Deep Pit	9,225,393	24,041	7,768,752	20,245
TOTAL	605,893,741	1,578,904	1,269,558,244	3,308,353



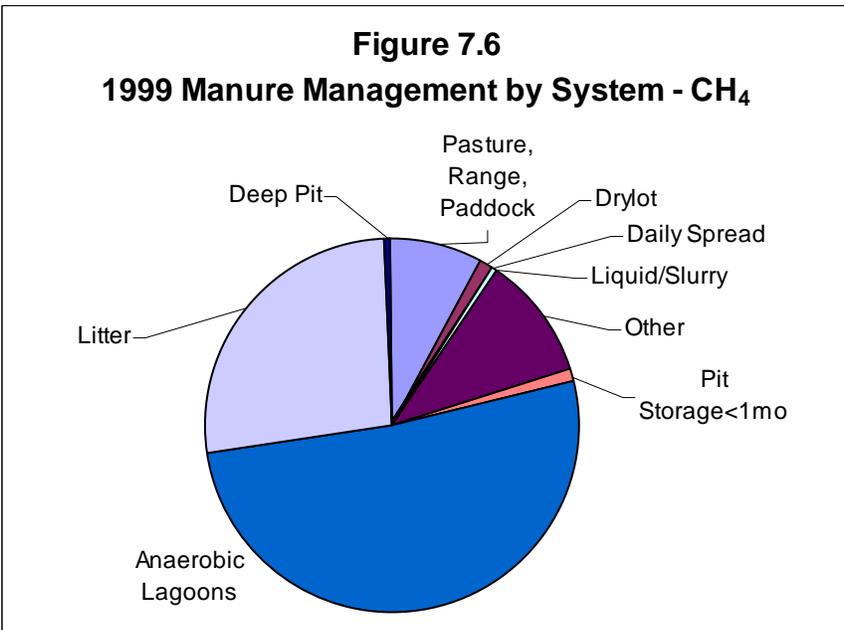
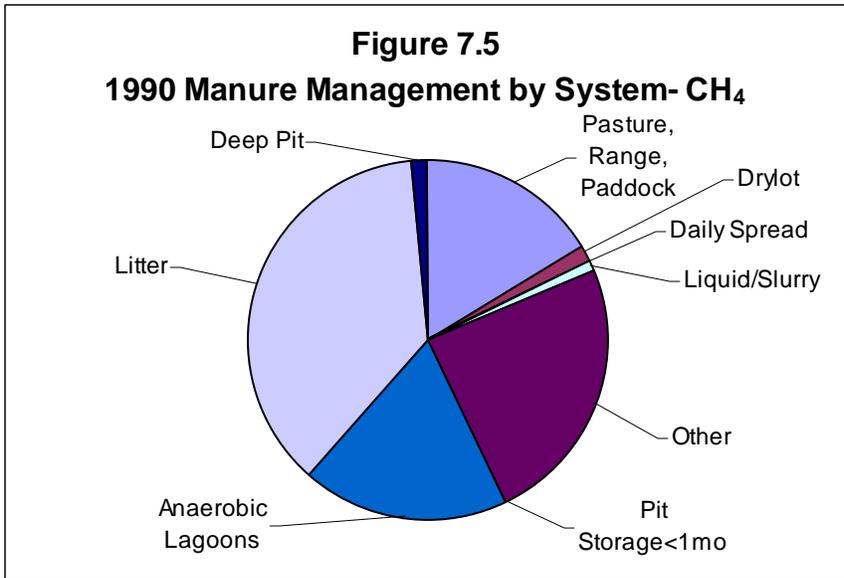


Table 7.3

Manure Management by Animal - N₂O

	1990			1999		
	# Head	Emissions (tons)	MTCE	# Head	Emissions (tons)	MTCE
Dairy Cows	100,000	217	16,651	92,000	200	15,319
Dairy Heifers	30,000	36	2,773	30,000	36	2,774
Feedlot Steers	211,000	13	1,032	255,000	16	1,246
Feedlot Heifers	113,000	7	552	155,000	10	758
Bulls	110,000	13	992	120,000	14	1,082
Calves	1,140,000	28	2,109	1,160,000	28	2,147
Heifers	687,000	45	3,470	685,000	45	3,460
Steers	949,000	47	3,629	895,000	45	3,423
Cows	1,860,000	183	14,049	1,908,000	188	14,412
Swine: Market<60	75,000	2	186	820,000	27	2,033
Swine: Market 60-119	55,000	3	244	310,000	18	1,374
Swine: Market 120-179	30,000	3	222	270,000	26	1,998
Swine: Market>180	20,000	3	198	550,000	71	5,452
Swine: Breeding	35,000	6	433	310,000	50	3,829
Poultry: layers	4,750,000	2	140	4,000,000	2	117
Poultry: Broilers	142,200,000	71	5,461	216,400,000	108	8,311
Poultry: Turkeys	488,766	1	87	698,837	2	126
TOTAL		681	52,229		885	67,860

Figure 7.7
Manure Management by Animal - N₂O

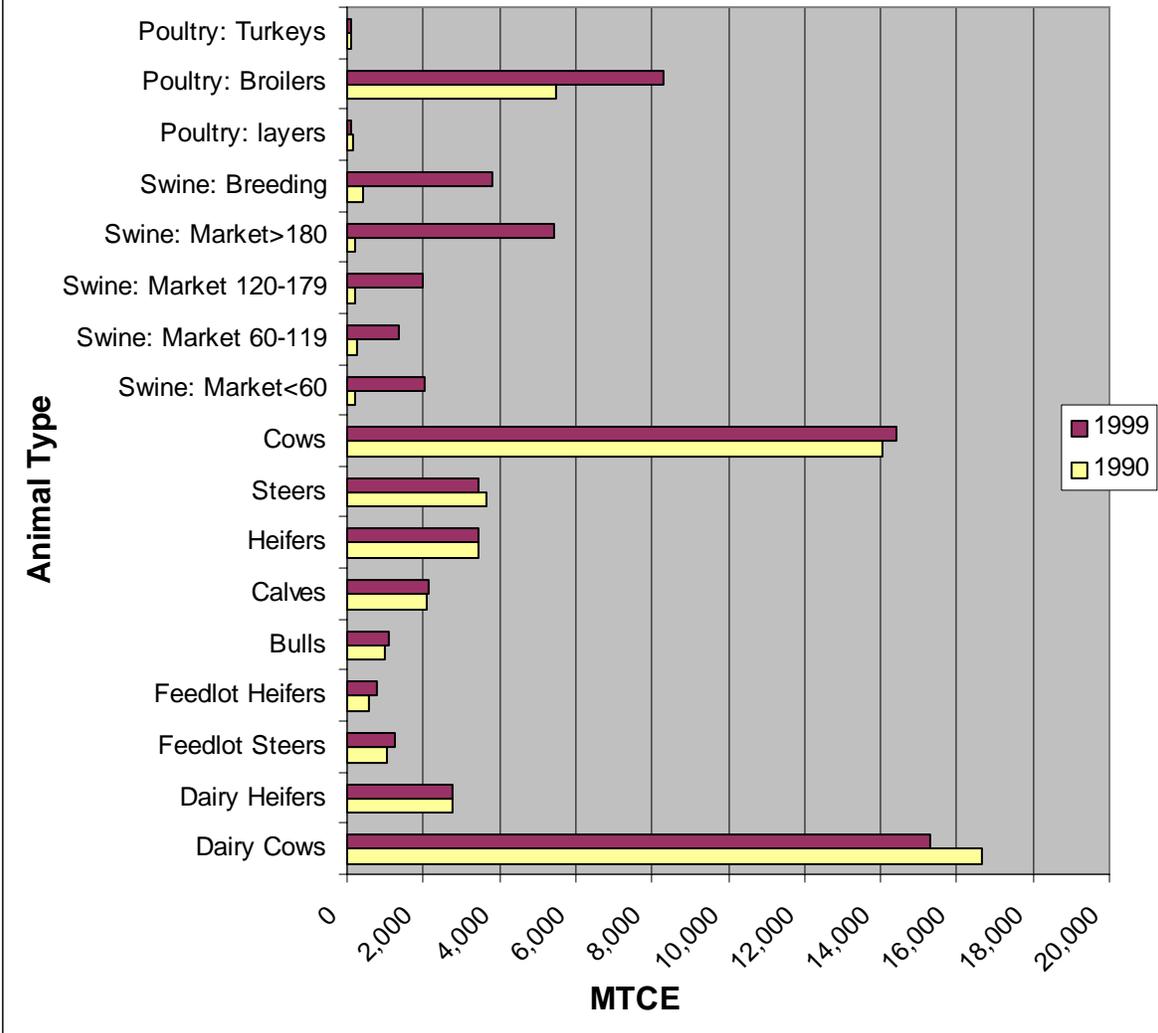


Figure 7.8
1990 Manure Management by Animal - N₂O

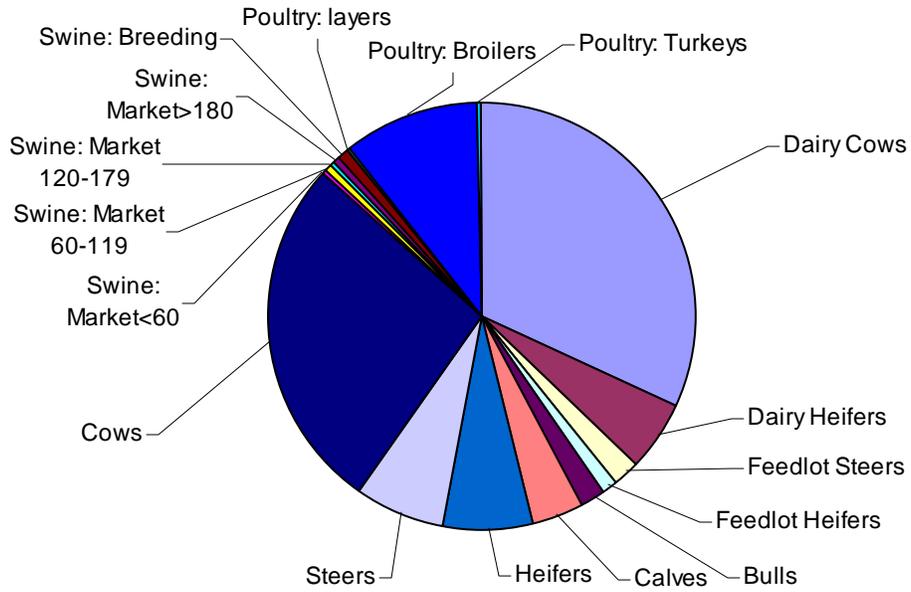


Figure 7.9
1999 Manure Management by Animal - N₂O

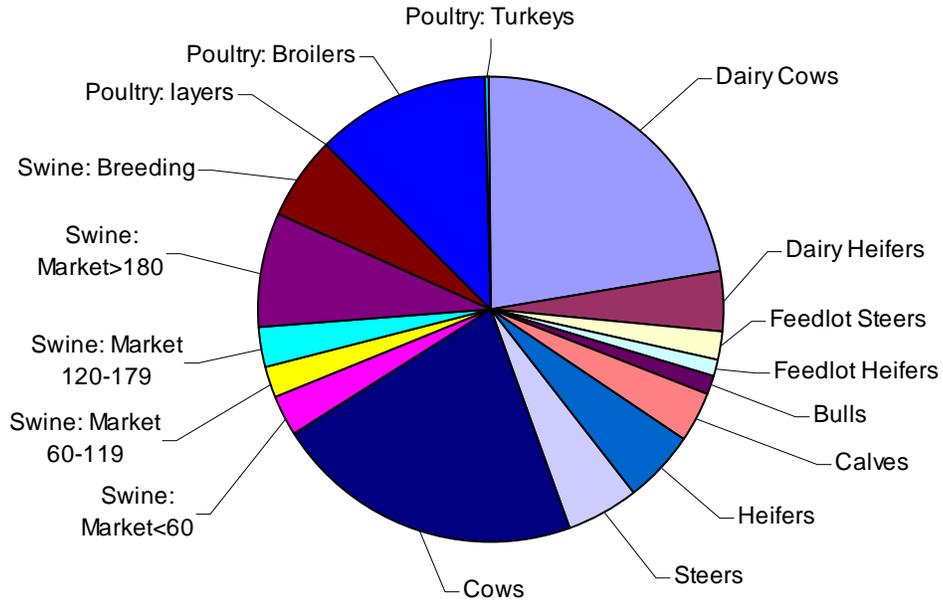
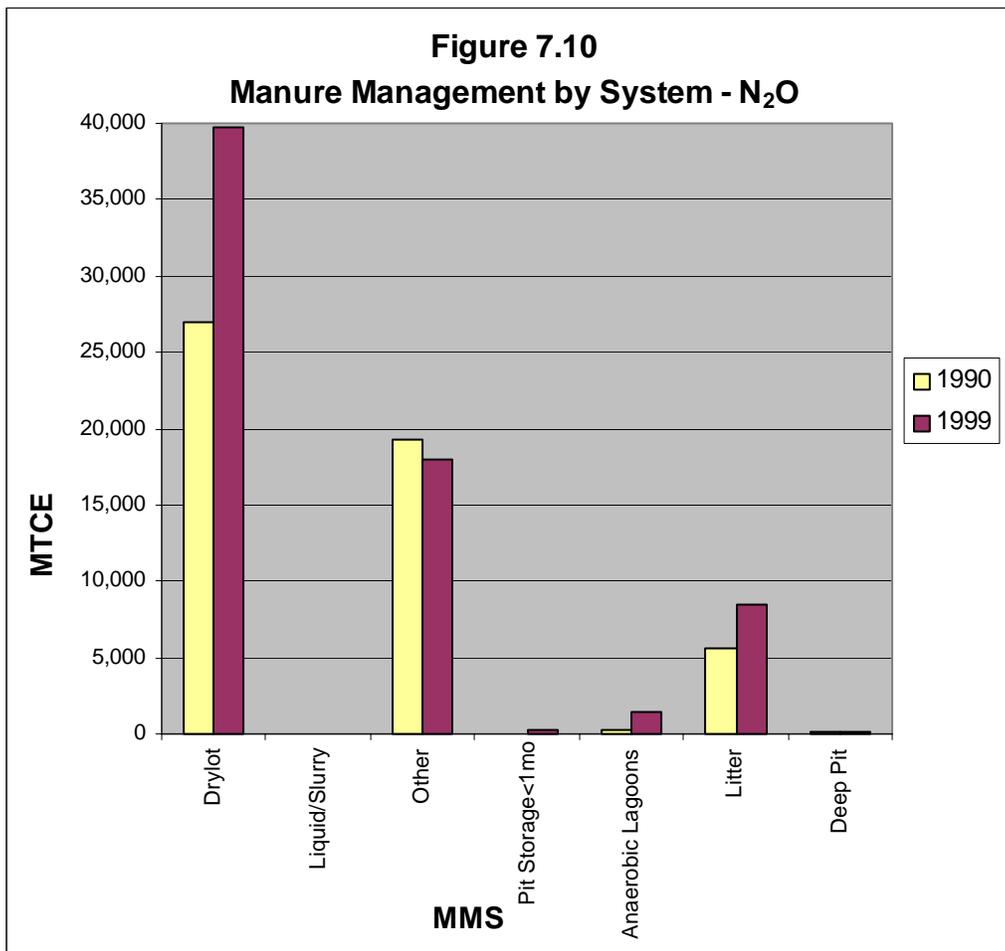
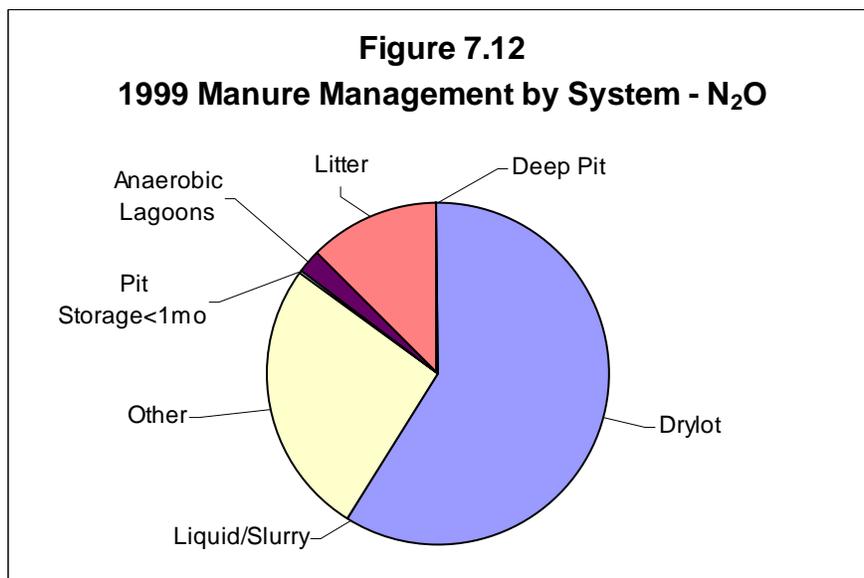
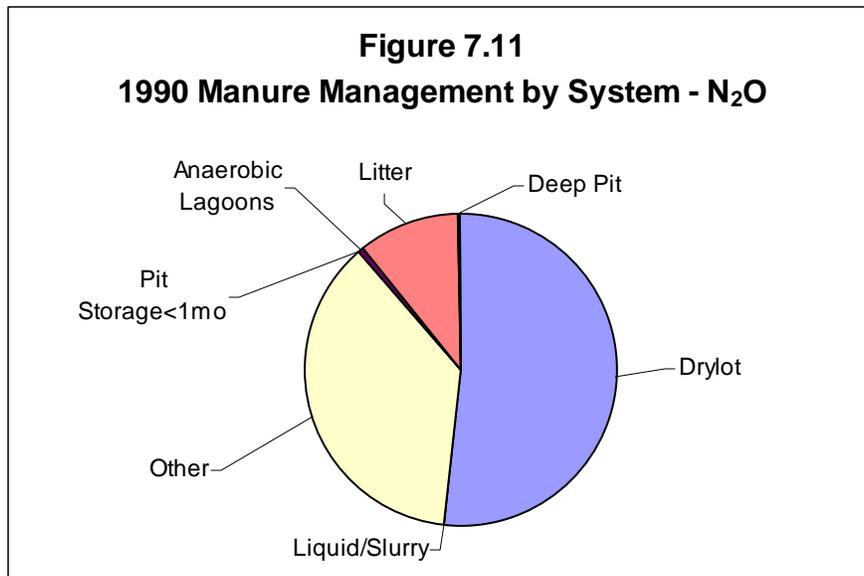


Table 7.4				
Manure Management by System- N ₂ O				
	1990		1999	
	Emissions (kgs/yr)	MTCE	Emissions (kgs/yr)	MTCE
Drylot	319,144	26,982	469,327	39,679
Liquid/Slurry	330	28	278	23
Other	227,614	19,244	212,005	17,924
Pit Storage<1mo	226	19	2,593	219
Anaerobic Lagoons	3,492	295	17,544	1,483
Litter	65,635	5,549	99,788	8,437
Deep Pit	1,318	111	1,110	94
TOTAL	617,760	52,229	802,643	67,860





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8. Methane Emissions from Flooded Rice Fields

Overview

All rice grown in Oklahoma is produced in flooded fields. When rice fields flood, organic materials decompose aerobically and gradually deplete soils and flood water of oxygen. The resulting anaerobic conditions produce methane (CH₄) during the decomposition of organic matter by methanogenic bacteria. However, only 20%-40% of produced CH₄ escapes to the atmosphere due to the soil's aerobic methanotrophic bacteria that oxidize methane. Some CH₄ also dissolves and leaches into the soil.

Other factors associated with CH₄ release from rice fields include floodwater depth, flooding duration, soil temperature, soil type, and fertilizer type. Rice fields with more than 3.3 feet of water (deepwater) are thought to release less CH₄ into the atmosphere than fields with shallower flooding. Fields that are drained during the growing season are thought to release only negligible amounts of CH₄. Several of these practices, however, have not been fully quantified. But, the method used in this report for estimating emissions uses a combination of a broad U.S. cross-section of rice farming practices, circumstances and locations but has been deemed reliable by the U.S. EPA for estimating methane release.

Methods

Methane emissions were estimated for years 1990 and 1999. Acres of rice grown in Oklahoma and the growing seasons were obtained from the Oklahoma Department of Agriculture. The planting period ranged from May 18 to July 15 and the cultivation period ranged from October 15 to December 21. Given the large ranges for planting and cultivation, two growing seasons were established for estimating emissions. The short (low) growing season represented the season having the latest planting and the earliest cultivation (July 15 to October 15.) The long (high) growing season represented the season having the earliest planting and the latest cultivation (May 18 to December 21.) Both the low and high seasons were converted to number of days.

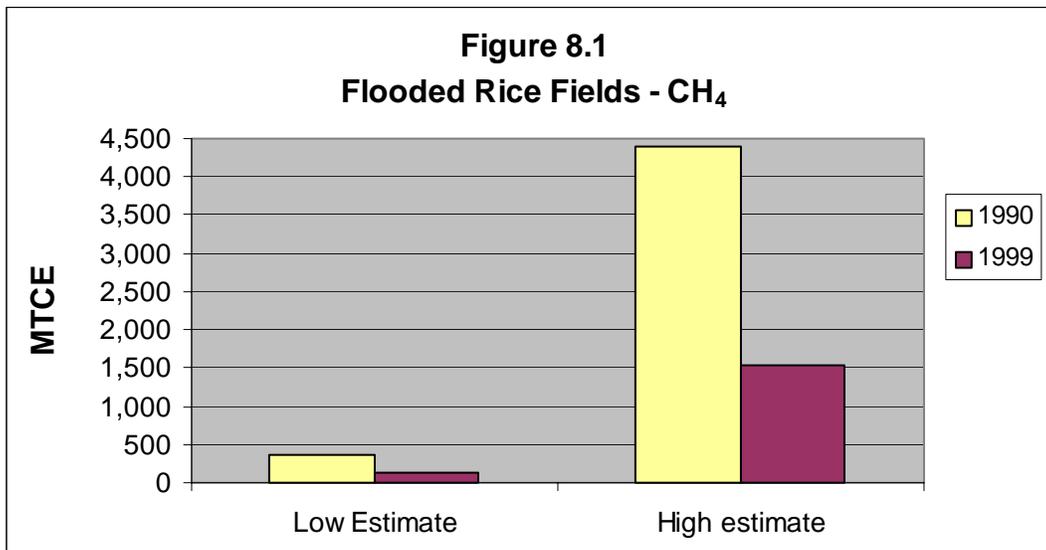
Acre-days of rice flooding were calculated by multiplying the number of acres by the number of days. This was done for each season. The result was a low estimate for acre-days and a high estimate for acre-days. CH₄ emissions were then calculated by multiplying the low estimate acre-days by the low estimate emission factor and by multiplying the high estimate acre-days by the high estimate emission factor. The CH₄ emission factors for flooded rice fields were provided by the EIIP guidance document. The resulting kg CH₄/acre-day values were converted to metric tons of carbon equivalent (MTCE) using the ratio of the molecular weight of carbon to carbon dioxide and the global warming potential of methane provided by the guidance document.

Results

Rice producing land in Oklahoma decreased by 65% from 1,550 acres in 1990 to 543 acres in 1999. The CH₄ MTCE estimates ranged from 355 tons to 4,392 tons in 1990 and from 124 tons to 1,538 tons in 1999.

Summary

Table 8.1						
Flooded Rice Fields - CH ₄						
	1990			1999		
	Acres	Emissions(tons)	MTCE	Acres	Emissions(tons)	MTCE
Low Acres	1,550	68	355	543	24	124
High Acres	1,550	845	4,392	543	296	1,538



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9. Greenhouse Gas Emissions From Agricultural Soils

Overview

Numerous practices in agriculture deposit nitrogen to the land, thereby increasing the amount of nitrogen available for production of nitrous oxide (N₂O.) The amount of N₂O emitted into the atmosphere is directly related to the amount of nitrogen available in the soil. N₂O emissions from soils are classified in one of two categories – direct or indirect. Emissions are considered direct when the nitrogen introduced to the soil through management practices enters the atmosphere directly in the form of N₂O. Some nitrogen introduced to the soil will first produce ammonia or nitrogen oxides instead of N₂O. A percentage of these gases will, in turn, volatilize into N₂O. This process for N₂O production is considered indirect. These processes are treated differently because each has a different associated emission factor.

Direct additions of nitrogen to soils occur in several ways and are collectively referred to as “cropping practices.” They include addition of synthetic and organic fertilizers, daily spread of animal wastes, production of nitrogen-fixing crops, the incorporation of crop residues, cultivation of high organic soils or histosols, and direct deposition of animal waste on pastures, ranges, and paddocks. Indirect emissions will occur from volatilization of synthetic and organic nitrogen from fertilizer, volatilization of animal wastes, and surface runoff and leaching from applied nitrogen. Each of these processes will be discussed in detail in the methods section.

Carbon dioxide (CO₂) emissions also occur as a result of several management practices. These include the application of limestone and dolomite (referred to as liming), conversion of land to pasture and forest, land-use change activities, tillage, and erosion control. The CO₂ emissions from liming occur when lime is applied to soils in an attempt to control the acidity level of the land. The carbon stored in the lime will, over a period of years, dissolve and be released as CO₂. Only liming of soils was considered in this report since methodologies have not yet been produced for the other sources.

Methods

Nitrous Oxide

The sources of N₂O were distributed among four categories: cropping practices, animal production, indirect volatilization, and leaching and runoff. Each category resulted in a subtotal amount of nitrogen available for N₂O emission in units of kg-N₂O/year. These totals were converted to metric tons of carbon equivalent (MTCE) by multiplying by the global warming potential of N₂O and the ratio of carbon to CO₂ and then dividing by 1,000. The subtotals were then summed for a final total of kg-N₂O/year for all of agricultural soils.

Cropping Practices (Direct)

Synthetic Fertilizers – The amount of synthetic fertilizer consumed in 1990 and 1999 in the State was obtained from the Fertilizer Institute. The data were reported in tons and were first

converted to kilograms by multiplying by 907.2. This gave the amount of nitrogen available for N₂O production. According to the EIIP methods, 10% of the available nitrogen volatilized into NH₃ and NO_x. The remaining 90% was unvolatilized and emitted as N₂O directly to the atmosphere. To calculate unvolatilized nitrogen, total available nitrogen was multiplied by 0.90. The result represented the amount of nitrogen released as N₂O from synthetic fertilizers.

Organic Fertilizers – Organic fertilizer consisted of many types of substances including manure, dried blood, compost, sewage and tankage. However, only total organic consumption was available for the target years and thus was not separated individually for this report. This was significant since, according to the EIIP methods, manure had a nitrogen emission factor of 1% and the remaining substances had an emission factor of 4.1%. According to state fertilizer officials, the greater portion of organic fertilizer used in Oklahoma was compost, so the 4.1% emission factor was used for all organic fertilizers. Due to this, emissions from cropping practices as a whole may be slightly overstated.

The total organic fertilizer consumed in 1990 and 1999 in the State was obtained from the Fertilizer Institute. The data were reported in tons and were first converted to kilograms by multiplying by 907.2. This resulted in the amount of nitrogen available for N₂O production. Of the available nitrogen, 20% volatilized into NH₃ and NO_x. The remaining 80% was unvolatilized and emitted as N₂O directly to the atmosphere. Available nitrogen was multiplied by 0.80 and by the nitrogen emission factor of 0.041, which was supplied by the EIIP guidance. This gave the amount of nitrogen in kg/yr released directly as N₂O from organic fertilizers.

Daily Spread of Animal Manure – Only two animal types in Oklahoma produced manure that was used for daily spread activities – dairy cows and dairy heifers. To calculate the total amount of available nitrogen from this manure, called Kjeldahl nitrogen, several data figures from Chapter 7 of this document were needed:

- 1) The population of each animal type for each year,
- 2) Percentage of each animal's manure used as daily spread,
- 3) Each animal types average typical animal mass (TAM), and
- 4) Amount of Kjeldahl nitrogen produced per day per 1,000 kg mass for each animal.

The TAM was divided by 1000 and then multiplied by the population, the percentage of manure, and the amount of Kjeldahl nitrogen produced per animal and subsequently multiplied by 365 days per year. The result was total Kjeldahl nitrogen excreted by each animal type to be used as daily spread in a given year. The totals for dairy cow and dairy heifer were then summed for final total nitrogen available. As in organic fertilizers, 20% of this nitrogen volatilized as NH₃ and NO_x. Consequently, the total available nitrogen was multiplied by 0.80 resulting in the final amount of nitrogen (kg-N/yr) applied by daily spread.

Incorporation of Crop Residues – The biomass of cultivated crops (both N-fixing and non-N-fixing) not harvested for food nor burned contains the nitrogen that may eventually be emitted as N₂O. In Oklahoma, only four crops produced residues that resulted in significant nitrogen deposition to the soil. They were wheat, corn, peanuts, and soybeans. The amounts of actual residual biomass were difficult to estimate, so residue was assumed to be all crop biomass not harvested nor burned. In order to calculate the residue from crops, the production amounts of each crop were needed. Production data were obtained from the internet database of the U.S.

Department of Agriculture, National Agricultural Statistics Service. Data were reported in either pounds per year or bushels per year; both were converted to kg per year. Production values were multiplied by 1) the residue to crop mass ratio, 2) the residue dry matter fraction for above-ground biomass, 3) the fraction unburned, and 4) the nitrogen content of the residue. All four of these constants were provided by the EIIP guidance. Nitrogen contents from all crops were then summed to get a total of all nitrogen available for N₂O emission from crop residues in kg-N/yr.

Production of Nitrogen-Fixing Crops – There were three N-fixing crops produced in the State that were considered for this analysis. They were soybeans, peanuts and alfalfa. Production data were obtained from the internet database of the U.S. Department of Agriculture, National Agricultural Statistics Service. Data were reported in either pounds or bushels and were converted to kilograms per year. According to EIIP methodology, data for N-fixing crops were to be reported on a dry weight basis, so water content needed to be addressed. The default value of 15% water in all crops was used and thus the amount of each crop was multiplied by 0.85 to obtain data on a dry weight basis. These amounts were multiplied by 1) one plus the residue to product mass ratio, 2) the fraction of dry matter in above ground biomass, and 3) the fraction of nitrogen in the crops. All three constants were provided by the EIIP guidance. These constants for alfalfa were not available, so reasonable defaults were used. Nitrogen values were then summed for all N-fixing crops to yield the total nitrogen available for N₂O emission from this source in kg-N/yr.

Cultivation of High Organic Soils or Histosols – The State had no data concerning histosols therefore this section was omitted from the analysis.

The five subtotals were each multiplied by an EIIP provided emission factor of 0.0125 to yield kg N₂O-N/yr. They were then converted to kg N₂O/yr by multiplying by the ratio of the molecular weights of N₂O to N₂O-N (44/28). Lastly, the values were converted to MTCE by multiplying by the global warming potential of N₂O and the ratio of molecular weights of carbon to CO₂ and then dividing by 1,000. Summing the five MTCE values resulted in the total direct N₂O emissions from cropping practices.

Animal Production

This section of N₂O production was a continuation of a section from Chapter 7 of this document. In Chapter 7, all N₂O emissions from animal excretions were accounted for with the exception of those raised on pastures, ranges, and paddocks. These animals were intentionally selected for this chapter since their wastes were essentially unmanaged and deposited directly to the soil.

The calculations for nitrogen excreted from these animals were the same as those used in Chapter 7. The factors included were as follow:

- 1) Population of each animal type,
- 2) Percentage of manure deposited on pasture, range, and paddock,
- 3) Average typical animal mass for each animal type (TAM)/1,000,
- 4) Kjeldahl nitrogen excreted per day per 1000 kg mass, and
- 5) 365 days per year.

These factors were multiplied for each animal type to result in total Kjeldahl nitrogen deposited on soils and thus available for N₂O production. As in daily spread operations mentioned above, 20% of this nitrogen volatilized into NH₃ and NO_x. Total nitrogen was multiplied by 0.80 to

account for this loss of nitrogen. The remaining unvolatilized portion of nitrogen was multiplied by the EIIP emission factor of 0.02 kg N₂O-N/kg N and 44/28. The last factor (44/28) converted all values to units of kg N₂O/year. These units were then converted to MTCE by multiplying by the global warming potential of N₂O and the ratio of carbon to CO₂ and then dividing by 1,000.

Indirect Volatilization

Indirect emissions of N₂O occurred from volatilization of applied nitrogen. Applied nitrogen included organic and synthetic fertilizers and animal waste deposited from all manure management systems. Chapter 7 accounted for direct N₂O emissions from all manure management systems except pasture, range, paddock, and daily spread. However, it did not cover indirect emissions as a result of volatilization from any management system; therefore, all management systems' indirect emissions were accounted for in this chapter. This section accounted for the percentage of nitrogen from these sources that volatilized into NH₃ and NO_x. A percentage of this volatilized nitrogen was subsequently reintroduced to the soil through atmospheric deposition and released as N₂O.

Volatilization of Synthetic Fertilizers –Volatilized nitrogen was calculated as the amount of synthetic fertilizer applied to the soil, which was obtained from the cropping practices section above, multiplied by the fraction of nitrogen that volatilized or 0.10.

Volatilization of Organic Fertilizers –Volatilized nitrogen was calculated as the amount of organic fertilizer applied to the soil, which was obtained from the cropping practices section above, multiplied by 0.041, the fraction that is nitrogen and by 0.20, the fraction of nitrogen that volatilized.

The amounts of volatilized nitrogen from synthetic and organic fertilizers were summed. Total volatilized nitrogen from all fertilizers was then multiplied by the EIIP supplied emission factor of 0.01 and then by the ratio of the molecular weights of N₂O to N₂O-N (44/28). This value was converted to MTCE by multiplying by the global warming potential and the ratio of carbon to CO₂, and dividing by 1,000. It was important to note that a percentage of organic fertilizer was manure. This was the same manure accounted for in volatilization of animal wastes below. EIIP methodology required the percentage of manure be excluded from calculations to avoid duplicate emissions from the same source. Because no data on the exact percentage of manure in its organic fertilizer was available, it was still included in the calculation.

Volatilization of Animal Wastes –The calculation used was a variation of the previous equation used for direct emissions in both Chapter 7 and Chapter 9. There were two minor differences. First, the term “percentage of manure managed” in the equation was omitted. This was because 100% of all manure was accounted for in this calculation. Second, the equation was taken one step further by multiplying the total amount of nitrogen excreted from waste by the percentage of nitrogen that volatilizes, 0.20. In short, the amount of volatilized nitrogen from each animal was the product of:

- 1) Population of each animal type,
- 2) Average typical animal mass for each animal type (TAM) divided by 1,000,
- 3) Kjeldahl nitrogen excreted per day per 1,000 kg mass,
- 4) 365 days/yr, and
- 5) 20% nitrogen volatilized.

These factors were multiplied for each animal type to result in total Kjeldahl nitrogen deposited on soils and thus available for N₂O production. Finally, values for all animals were summed for one final total of indirect N₂O emissions from volatilization of animal wastes. Total volatilized nitrogen from animal waste was then multiplied by the EIIP supplied emission factor of 0.01 and then by the ratio of the molecular weights of N₂O to N₂O-N (44/28). This value was converted to MTCE by multiplying by the global warming potential and the ratio of C to CO₂, and dividing by 1,000.

Leaching and Runoff

Surface Runoff and Leaching – This section calculated the amount of applied nitrogen that migrated to streams and rivers through natural weathering. The amounts of unvolatilized nitrogen from synthetic and organic fertilizers and from animal waste were calculated in the above methods. EIIP guidance states that 30% of all unvolatilized applied nitrogen from fertilizers and animal wastes leached into streams. The amount of unvolatilized nitrogen from each source was multiplied by 0.30 to obtain the amount of leached nitrogen. The EIIP provided emission factor for N₂O from leaching nitrogen was 0.025 kg N₂O-N/kg N leaching. The amount of leached nitrogen was multiplied by this factor and then by the ratio of the molecular weights of N₂O to N₂O-N (44/28) to yield the total amount of N₂O emissions from leaching and runoff. The amount of N₂O leaching emissions from each source was converted to MTCE by multiplying by the global warming potential and the ratio of C to CO₂, and dividing by 1,000.

Carbon Dioxide

The rate of CO₂ emission from soil could not be accurately measured. All carbon stored in applied lime was considered to be released as CO₂ in the year in which it was applied. First, the amounts of limestone and dolomite used for agriculture in the State of Oklahoma for the target years were obtained. Data on lime consumption was not available for 1990, so figures from the earliest available year (1994) were used in its place. Original data was taken from the U.S. Geological Survey's 1995 and 2000 Minerals Yearbooks. Limestone used for agriculture was given in the documentation; however, dolomite used for agriculture was not directly available so it was estimated for both years. The estimation was based on the assumption that the ratio of total limestone to agricultural limestone was the same as the ratio of total dolomite to agricultural dolomite.

According to EIIP guidance, 12% of carbon contained in limestone and 13% of carbon in dolomite produced CO₂. The metric tons of each stone used for agriculture was then multiplied by the appropriate percentage to yield the respective amounts of CO₂ produced. Emissions from both stones were summed and multiplied by the ratio of CO₂ to carbon (44/12) to produce the total amount of CO₂ emissions from liming in metric tons. Lastly, metric tons were converted to MTCE by multiplying by the ratio of carbon to CO₂ (12/44).

Results

Nitrous Oxide

Cropping Practices (Direct)

The MTCE from N₂O releases during Cropping Practices was 993,036 in 1990 and 1,102,275 in 1999. This was an increase of 11%. Synthetic fertilizers comprised over 80% of the MTCE in this category during both years. While the use of synthetic fertilizer increased 14% from 1990 to

1999, organic fertilizer use decreased by 93%. Cropping Practices represented 43% of total MTCE from the agricultural soils sector for both years.

Animal Production (Direct)

This category contributed 500,734 MTCE and 515,252 MTCE in 1990 and 1999 respectively. MTCE from this category increased less than 3% from 1990 to 1999. Of the animals directly contributing to agricultural soil N₂O release, cows comprised the largest amount of MTCE at over 53% of this category during both years. Heifers and steers were the next largest components at 13% each. Animal Production represented 22% in 1990 and 20% in 1999 of total MTCE from the agricultural soils sector.

Indirect Volatilization

MTCE from this category was 155,535 in 1990 and 179,720 in 1999. This was an increase of over 15% from 1990 to 1999. Indirect Volatilization comprised 7% of total MTCE from the agricultural soils sector during both years.

Leaching and Runoff

This was the second largest category releasing N₂O from agricultural soils. Total MTCE from this category was 672,233 and 747,989 for 1990 and 1999 respectively. Leaching and Runoff represented 29% of total MTCE from agricultural soils in both years. Synthetic fertilizer contributed 72% in 1990 and 74% in 1999 of the release from this category.

Carbon Dioxide

CO₂ released from lime application was 29,095 MTCE in 1990 and 26,602 MTCE in 1999. This represented a decrease of just under 9% from 1990 to 1999.

Summary

Table 9.1					
Agricultural Soils					
		1990		1999	
N ₂ O		Emissions (kg/yr)	MTCE	Emissions (kg/yr)	MTCE
Cropping Practices					
	Synthetic Fertilizer	9,542,786	806,799	10,935,815	924,573
	Organic Fertilizer	7,465	631	490	41
	Animal Waste	8,891	752	8,281	700
	Crop Residues	846,832	71,596	798,715	67,528
	N-fixing Crops	1,339,608	113,258	1,294,356	109,432
	Total	11,745,582	993,036	13,037,658	1,102,275
Animal Production					
	Feedlot Steers	231,784	19,596	280,119	23,683
	Feedlot Heifer	124,131	10,495	170,268	14,395
	Bulls	222,970	18,851	243,240	20,565
	Calves	474,083	40,082	482,400	40,785
	Heifers	779,828	65,931	777,558	65,739
	Steers	815,617	68,957	769,207	65,033
	Cows	3,157,257	266,932	3,238,735	273,820
	Sheep	12,384	1,047	5,724	484
	Goats	16,065	1,358	8,449	714
	Horses	86,731	7,333	116,101	9,816
	Turkeys	1,806	153	2,582	218
	Total	5,922,657	500,734	6,094,382	515,252
Indirect Volatilization					
	Fertilizer	849,741	71,842	972,171	82,193
	Animal Waste	989,921	83,693	1,153,553	97,528
	Total	1,839,661	155,535	2,125,723	179,720
Leaching and Runoff					
	Synthetic Fertilizer	5,725,672	484,080	6,561,489	554,744
	Organic Fertilizer	4,479	379	294	25
	Animal Waste	2,220,996	187,775	2,285,393	193,220
	Total	7,951,147	672,233	8,847,176	747,989
TOTAL			2,321,538		2,545,236
CO₂					
		metric tons	MTCE	metric tons	MTCE
	Lime Application	106,680	29,095	97,540	26,602
TOTAL			29,095		26,602

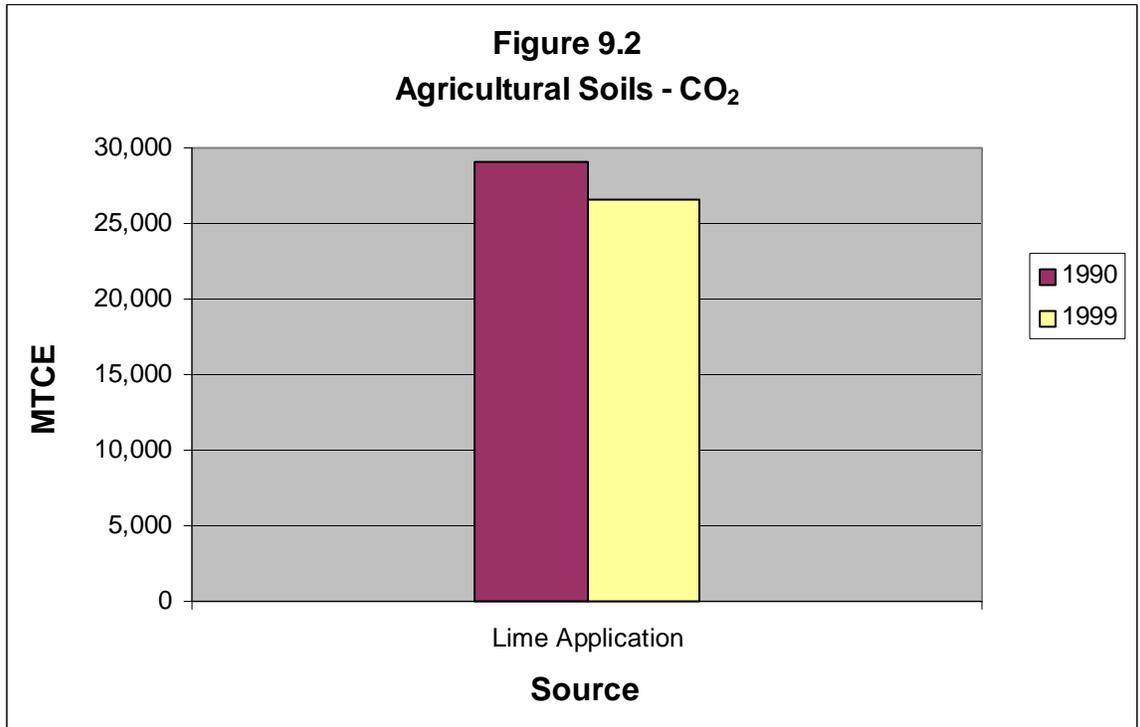
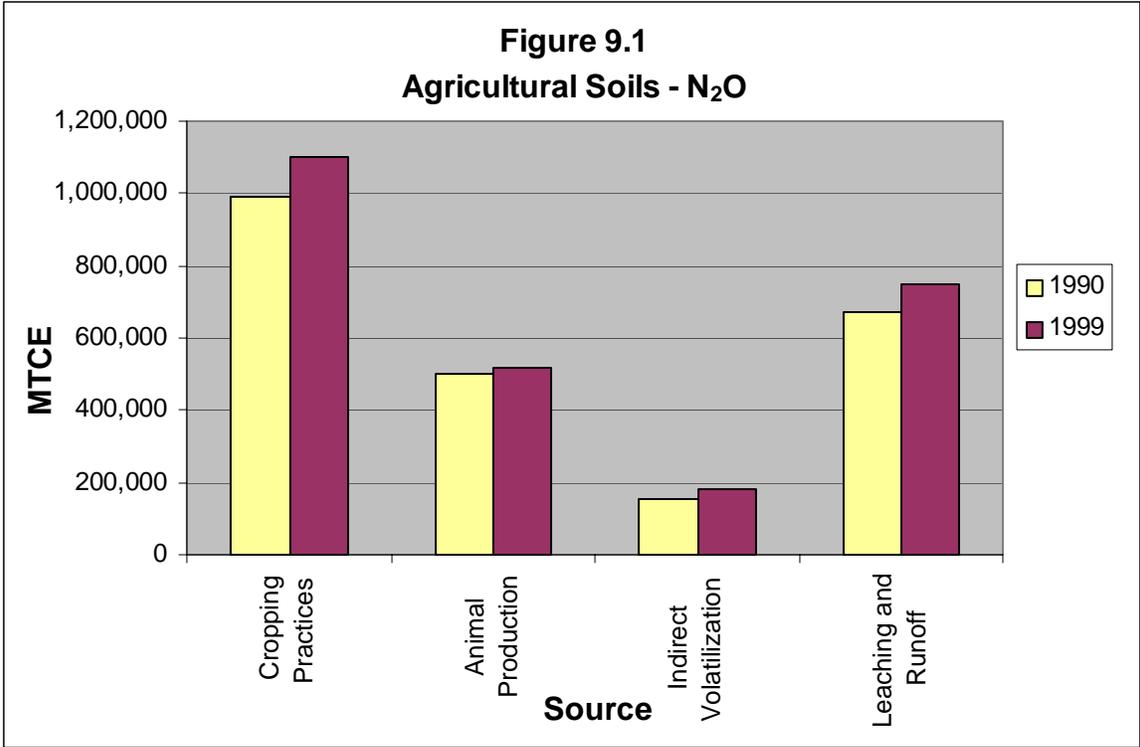


Figure 9.3
1990 Agricultural Soils - N₂O

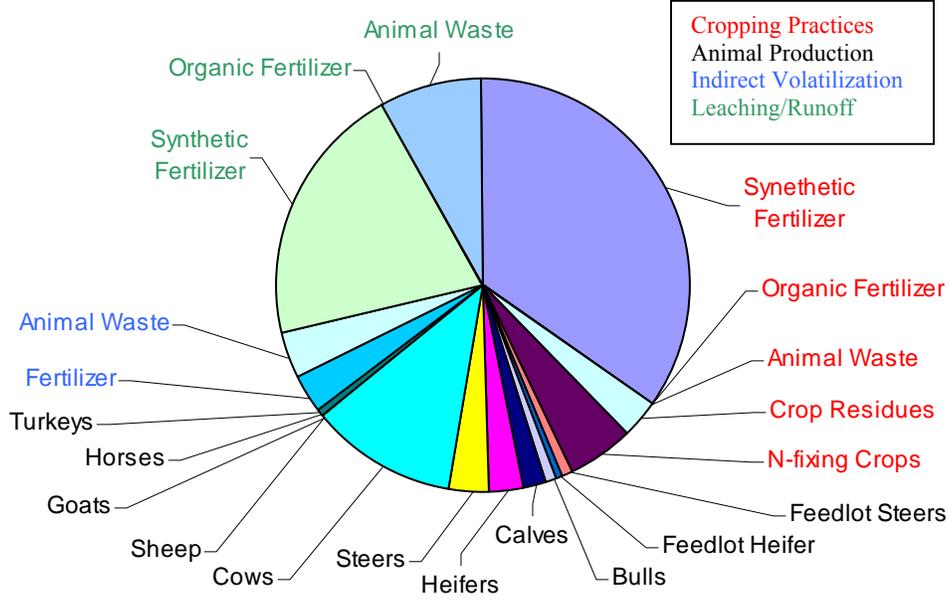
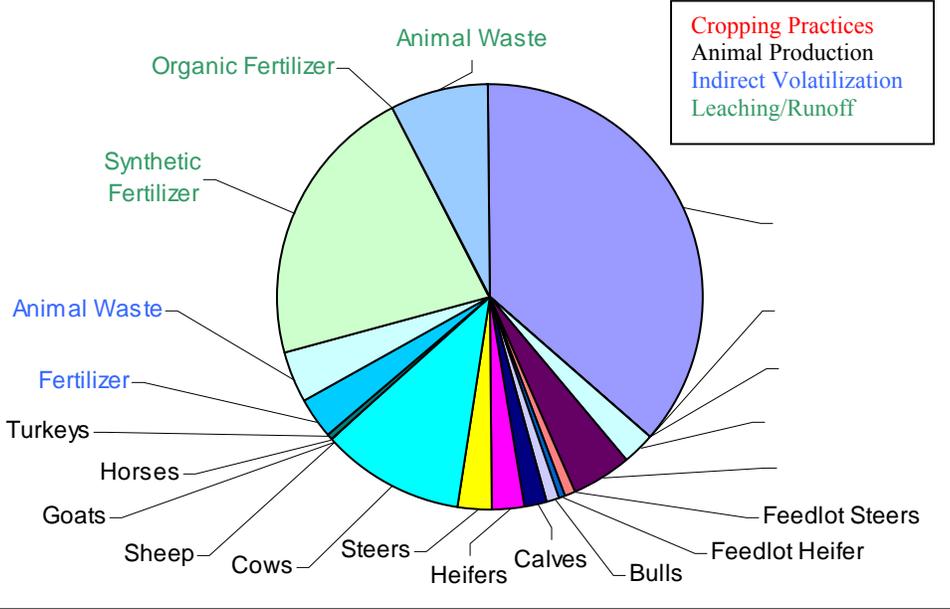


Figure 9.4
1999 Agricultural Soils - N₂O



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10. Carbon Dioxide Emissions From Forest Management And Land-Use Change

Overview

Carbon dioxide (CO₂) in the form of biomass carbon is stored abundantly in the forests of the United States. When forests are depleted, it is generally accepted that all biomass carbon is released as CO₂ directly into the atmosphere from the time it was cut down. This is of concern since CO₂ is a major greenhouse gas contributing to the threat of global warming. Unlike other sources of greenhouse gas emissions, forests consume CO₂ through growth as well as give it off when cut. Consequently, when forests are depleted faster than they grow the net flux of CO₂ is an increase. A decrease in CO₂ flux occurs when forest growth is greater than its depletion. Forest types are broken down into components, each of which serves as a separate storage pool for carbon. These components are tree biomass, understory biomass, forest floor biomass, and soil biomass. As trees are consumed, the associated understory, forest floor, and soil are also consumed and their carbon pool released as CO₂.

When trees are cut, CO₂ emissions do not occur immediately, but over varying periods of time. However, no state-level data is currently available for rate of CO₂ release due to decay and degradation. To combat this problem, it is assumed all trees cut immediately release all stores of carbon. Over a period of many years, an average yearly CO₂ emission rate can still be calculated within a certain degree of accuracy. When two years of forest acreage are compared, a net decrease in forest area will result in a positive amount of CO₂ emissions. Conversely, if there is a net increase in acreage, CO₂ sequestration will occur.

Methods

To measure average yearly CO₂ emission rates from forests in Oklahoma, data were obtained for each type of forest found within the state. Forest types were identified by and data were obtained from the Internet database site of the U.S. Department of Agriculture Forest Service. Forest inventories of Oklahoma had been performed by the Forest Service for years 1986 and 1993. EIIP guidance outlined a procedure using volume of biomass per forest type to obtain carbon flux. Volume data for these two years were only available by species rather than forest type. Apportioning the species into forest types was not realistic. An alternate method was identified from the *U.S. Greenhouse Gas Emissions and Sinks: 1990-2000* document published by the Environmental Protection Agency. This method incorporated area and carbon densities by forest type to calculate carbon flux. It also provided carbon density values and ratios for the calculations. Carbon densities of the Eastern region forests were used for Oklahoma and were converted to metric tons per acre. Ratio values for Oklahoma were from the South Central forest region.

Five forest types were identified and area data in acres were obtained for each forest type. After acreage was found, each forest was separated into its components of trees, forest floor, understory, and soil. Carbon from tree biomass was calculated using carbon density values for the appropriate forest type and multiplying by the acreage of each respective forest type for years

1986 and 1993. Metric tons of carbon for each forest type were summed by year to result in total carbon from tree biomass. Biomass from forest floor and soil were calculated using this same procedure.

Carbon from understory biomass was calculated using an additional step. The amount of understory carbon was calculated for each forest type using the ratio of understory carbon to live tree carbon. This percentage was multiplied by the carbon density values for the tree component to arrive at understory carbon density values. The density values were then multiplied by the forest type acreage resulting in carbon from understory biomass by forest type. Metric tons of carbon for each forest type were summed by year to result in total carbon from understory biomass.

The total CO₂ emissions for any given year were the sum of the emissions from each forest component. When the emissions from two different years were calculated, the total from the oldest year was subtracted from the most recent year. The difference was then divided by the number of years between inventories. The result was the average emission rate over that period of time for each year. As more data for different years become available and similar calculations made of varying time spans, trends can easily be recognized and yield valuable data on CO₂ emissions.

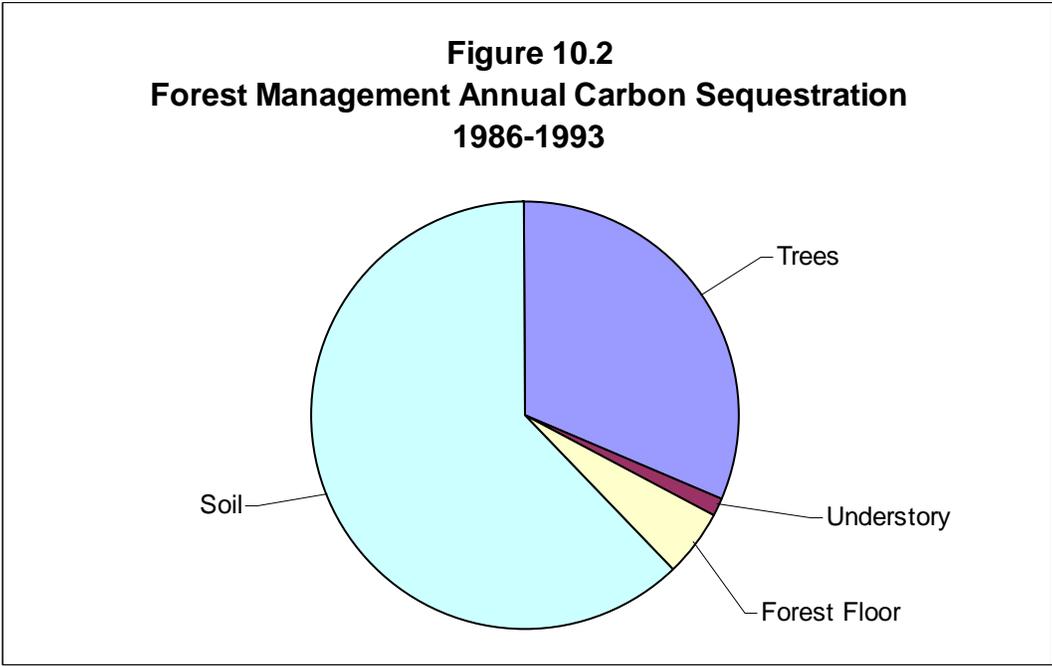
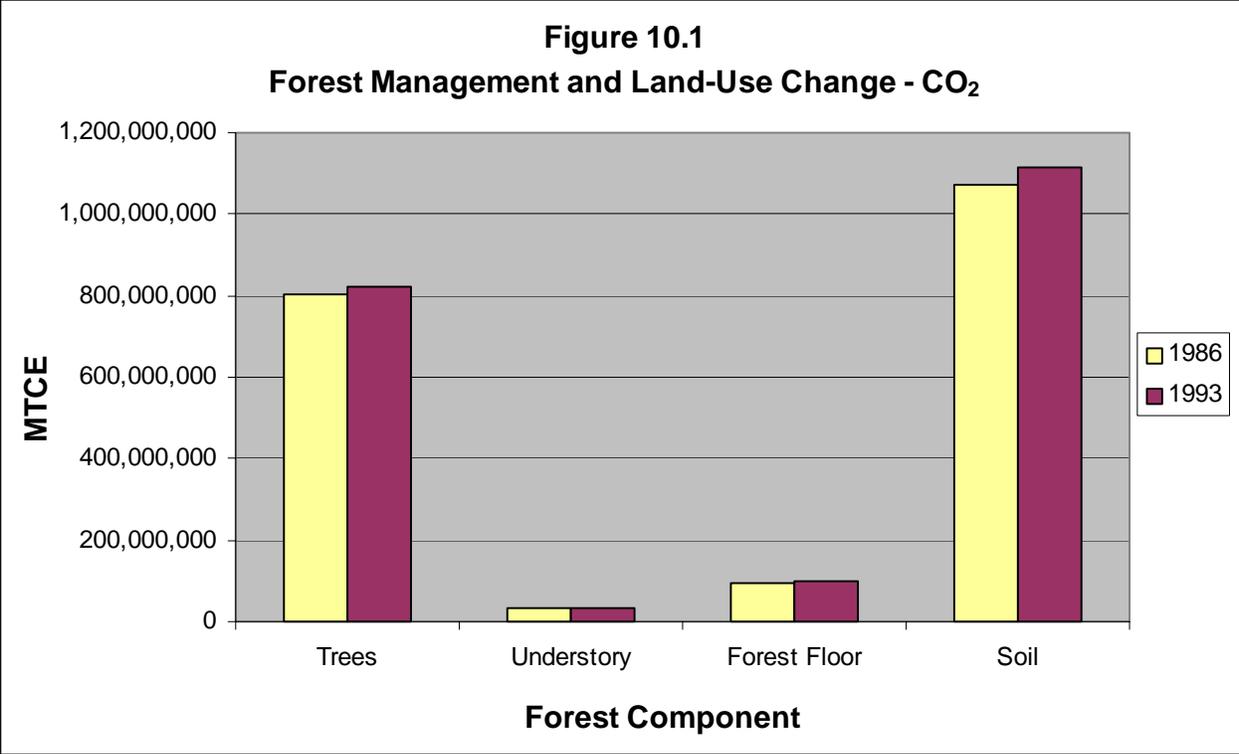
Results

There was a total increase in forest area in Oklahoma from 1986 to 1993 of approximately 3.25% or 154,300 acres. The increase suggests immediately that there was a net sequestration of carbon from the atmosphere between 1986 and 1993.

The soil component sequestered the largest portion of carbon at 62%. Trees sequestered an additional 32%. The Loblolly-Shortleaf Pine forest type exhibited the largest amount of sequestration in all forest components. While the Oak-Pine forest type actually had an increase in carbon emissions. Considering all forest components together, a net sequestration occurred during this time period. The total carbon sequestration between the years of 1986 and 1993 was -71,458,321 metric tons of carbon. The average yearly carbon sequestration during the period was -10,208,332 metric tons of carbon.

Summary

Table 10.1						
Forest Management and Land-Use Change - CO ₂						
	1986		1993			
Forest Type	Acres	MTCE	Acres	MTCE	Total Flux	Yearly Flux
Trees						
Elm-Ash-Cottonwood	78,400	13,090,605	94,000	15,695,368	-2,604,763	-372,109
Loblolly-Shortleaf Pine	956,100	116,425,253	1,098,600	133,777,621	-17,352,368	-2,478,910
Oak-Gum-Cypress	360,300	76,534,926	409,900	87,070,958	-10,536,032	-1,505,147
Oak-Hickory	2,599,600	489,923,216	2,590,800	488,264,759	1,658,457	236,922
Oak-Pine	746,800	105,695,351	702,200	99,383,068	6,312,283	901,755
Total - Trees		801,669,350		824,191,774	-22,522,423	-3,217,489
Understory						
Elm-Ash-Cottonwood	78,400	287,993	94,000	345,298	-57,305	-8,186
Loblolly-Shortleaf Pine	956,100	6,869,090	1,098,600	7,892,880	-1,023,790	-146,256
Oak-Gum-Cypress	360,300	1,683,768	409,900	1,915,561	-231,793	-33,113
Oak-Hickory	2,599,600	18,127,159	2,590,800	18,065,796	61,363	8,766
Oak-Pine	746,800	4,650,595	702,200	4,372,855	277,740	39,677
Total - Understory		31,618,606		32,592,390	-973,784	-139,112
Forest Floor						
Elm-Ash-Cottonwood	78,400	4,453,904	94,000	5,340,140	-886,236	-126,605
Loblolly-Shortleaf Pine	956,100	21,490,260	1,098,600	24,693,232	-3,202,973	-457,568
Oak-Gum-Cypress	360,300	5,339,646	409,900	6,074,718	-735,072	-105,010
Oak-Hickory	2,599,600	42,378,679	2,590,800	42,235,222	143,458	20,494
Oak-Pine	746,800	21,397,314	702,200	20,119,434	1,277,879	182,554
Total - Forest Floor		95,059,803		98,462,746	-3,402,944	-486,135
Soil						
Elm-Ash-Cottonwood	78,400	22,869,829	94,000	27,420,458	-4,550,629	-650,090
Loblolly-Shortleaf Pine	956,100	216,555,694	1,098,600	248,831,801	-32,276,108	-4,610,873
Oak-Gum-Cypress	360,300	135,449,020	409,900	154,095,347	-18,646,326	-2,663,761
Oak-Hickory	2,599,600	545,786,020	2,590,800	543,938,460	1,847,560	263,937
Oak-Pine	746,800	151,810,251	702,200	142,743,918	9,066,333	1,295,190
Total - Soil		1,072,470,814		1,117,029,984	-44,559,171	-6,365,596
TOTAL - Forest		2,000,818,573		2,072,276,894	-71,458,321	-10,208,332



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11. Burning of Agricultural Crop Wastes

Overview

Burning of agricultural crop wastes like stubble and hay is an accepted practice for removing the crop residue and for preparing fields for the next planting cycle. Plants commonly burned in Oklahoma fields naturally release methane and nitrogen. This chapter addresses only methane (CH_4) and nitrous oxide (N_2O) although carbon monoxide, carbon dioxide and other nitrogen oxides are released. However, only methane and nitrous oxide are well understood and well quantified. Carbon monoxide and other nitrogen oxides, on the other hand, only have an indirect impact on the greenhouse effect or, are not well quantified. Carbon dioxide is not considered because the carbon dioxide released by burning was taken from the atmosphere by the plant during the growing season.

Methods

The EIIP guidance document was used as a template for estimating emissions from agriculture crop burning for the years 1990 and 1999. Only two crops of the three addressed in the guidance document were grown in Oklahoma, rice and to a much greater extent, wheat. Sugar cane was included in the national study but was not grown in Oklahoma. Calculating total CH_4 and N_2O released from agricultural burning factored in the amount of carbon and nitrogen in the combusted crop residue, the emission ratio of CH_4 to carbon release due to combustion, and the emission ratio of N_2O to combustion released nitrogen.

State wheat production data were obtained from the U.S. Department of Agriculture, National Agricultural Statistics Service Database. State rice production data were obtained from the Oklahoma Department of Agriculture. Production data was converted to pounds and then used to calculate the amount of dry matter combusted. This calculation incorporated a series of constants and factors provided by the guidance document and addressed issues of residue to crop ratio and combustion efficiency. Total carbon released from burning was calculated as the product of the amount of dry matter combusted and the carbon content constant for the specific crop as provided in the guidance document. The amount of CH_4 emissions was obtained by multiplying the amount of carbon released by the emission ratio of CH_4 to carbon, which was provided in the guidance document.

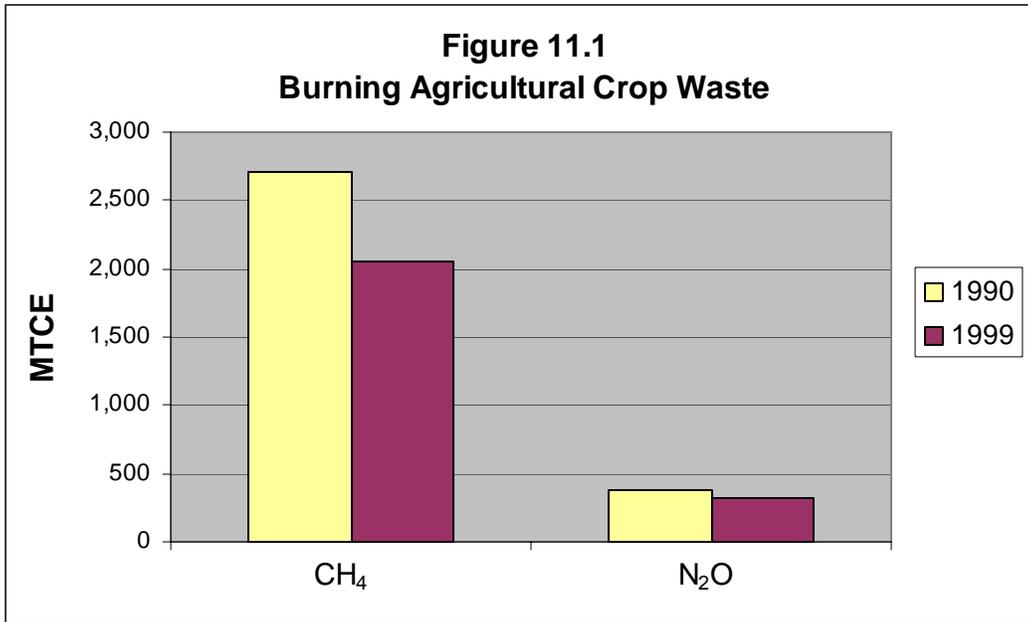
Total nitrogen released from burning was calculated as the product of the amount of dry matter combusted and the nitrogen content constant for the specific crop as provided in the guidance document. The amount of N_2O emissions was calculated by multiplying the amount of nitrogen released by the emission ratio of N_2O to nitrogen, which was provided in the guidance document. The emissions of CH_4 and N_2O were converted to full molecular weights and to metric tons. Metric tons of carbon equivalent (MTCE) for each gas were computed by considering its global warming potential and the carbon to carbon dioxide ratio.

Results

Total rice production in Oklahoma dropped from 382,000 pounds of rice in 1990 to 144,000 pounds of rice in 1999. The MTCE of CH₄ and N₂O were both less than one for rice in 1990 and 1999, thus rice represented only a fraction of one percent of total CH₄ and N₂O from agricultural crop burning. Wheat production decreased from 11,904 million pounds in 1990 to 9,030 million pounds in 1999, a decline of 24%. This reduction in wheat production resulted in a total CH₄ emission decrease of 24% and a total N₂O emission decrease of 17%. The total MTCE for CH₄ was 2,714 and 2,059 for 1990 and 1999 respectively. The total MTCE for N₂O was 381 and 316 for 1990 and 1999 respectively.

Summary

Table 11.1						
Burning Agricultural Crop Wastes						
	1990			1999		
	Production (lbs)	Emissions (lbs)	MTCE	Production (lbs)	Emissions (lbs)	MTCE
CH₄						
Rice	382,000	23	0	144,000	9	0
Wheat	11,904,000,000	783,650	2,714	9,030,000,000	594,453	2,059
TOTAL CH ₄	11,904,382,000	783,673	2,714	9,030,144,000	594,462	2,059
N₂O						
Rice	382,000	1	0	144,000	0	0
Wheat	11,904,000,000	6,330	381	9,030,000,000	4,802	316
TOTAL N ₂ O	11,904,382,000	6,330	381	9,030,144,000	4,802	316



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12. Methane and Nitrous Oxide Emissions from Municipal Wastewater

Overview

Industrial and municipal wastewaters generate methane (CH_4) during disposal and treatment using aerobic (with oxygen) as well as anaerobic (in the absence of oxygen) processes. CH_4 is produced when organic material in wastewater degrades anaerobically.

Oxygen is rapidly depleted in organic rich wastewater streams. The organic concentration in the wastewater known as “loading” is expressed in terms of biochemical oxygen demand (BOD), which reflects the amount of oxygen depleted by the decomposition of organic material. Generally, wastewater with higher BOD produces more CH_4 than one with lower BOD.

The nitrogen-rich organic matter in domestic and industrial wastewater also gives rise to nitrous oxide (N_2O) by the natural processes of nitrification and denitrification. The aerobic nitrification converts ammonia into nitrate; the anaerobic denitrification turns nitrate into N_2O . Human sewage is responsible for a significant portion of N_2O emissions from wastewater.

Methods

Methane

Population data for years 1990 and 1999 were obtained from the Oklahoma Department of Commerce. The daily BOD was calculated by multiplying the Oklahoma-specific factor of 0.17 lbs BOD per person per day with the population of the state for each year. The Oklahoma BOD generated per person per day was provided by the Water Quality Division of the Department of Environmental Quality.

The annual amount of wastewater BOD treated anaerobically was the product of the daily BOD, the fraction of BOD not removed as sludge, the fraction of wastewater BOD treated anaerobically, and 365 days per year. The fraction as sludge and the fraction treated anaerobically were provided by the EIIP guidance. CH_4 emissions were derived by multiplying the yearly anaerobic BOD by an emission factor of 0.25 lbs CH_4 /lb BOD, which was provided by the EIIP guidance. This gave CH_4 emissions in pounds per year. The amount of CH_4 recovered was then subtracted for a net emissions total. No recovery was recorded in the State of Oklahoma. This total was then converted to metric tons and multiplied by the mass ratio of carbon to CO_2 and the global warming potential for CH_4 (21) to arrive at metric tons of carbon equivalent (MTCE.)

The annual amount of sludge BOD treated anaerobically was the product of the daily BOD, the fraction of BOD that was removed as sludge, the fraction of wastewater BOD treated anaerobically, and 365 days per year. The fraction as sludge and the fraction treated anaerobically were provided by the EIIP guidance. CH_4 emissions were derived by multiplying the yearly anaerobic BOD by an emission factor of 0.25 lbs CH_4 /lb BOD, which was provided by

the EIIP guidance. This gave CH₄ emissions in pounds per year. The amount of CH₄ recovered was then subtracted for a net emissions total. No recovery was recorded in the State of Oklahoma. This total was then converted to metric tons and multiplied by the mass ratio of carbon to CO₂ and the global warming potential for CH₄ (21) to arrive at metric tons of carbon equivalent (MTCE.)

Nitrous Oxide

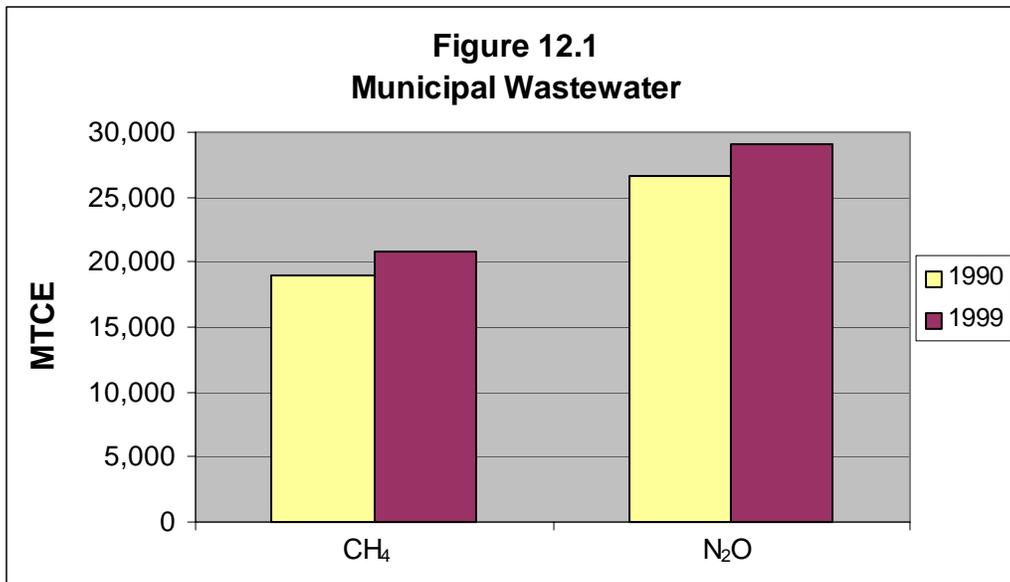
The estimate of annual per capita consumption of nitrogen in protein was made by multiplying the annual consumption of protein per person by the percentage of nitrogen in protein. Both values were provided by the EIIP guidance. The annual consumption of nitrogen in protein was obtained by multiplying the per capita consumption by the state population for each year. This number was then multiplied by the nitrogen emission factor, as provided by the EIIP guidance, to arrive at the total amount of N₂O-N from wastewater and sludge. This value was converted to metric tons. Multiply metric tons of N₂O-N by the mass ratio of N₂O to N (44/28) to obtain metric tons of N₂O. Multiply metric tons of N₂O by the mass ratio of C to CO₂ (12/44) and by the global warming potential for N₂O (310) to obtain MTCE of N₂O.

Results

MTCE of CH₄ was 19,011 and 20,773 for 1990 and 1999 respectively. MTCE of N₂O was 26,606 in 1990 and 29,072 in 1999. MTCE of CH₄ and N₂O increased from 1990 to 1999 by over 9 percent. The largest amount of CH₄ from wastewater treatment was from sludge at 90 percent.

Summary

Table 12.1						
Municipal Wastewater						
	1990			1999		
	BOD (lbs/yr)	Emissions (lbs)	MTCE	BOD (lbs/yr)	Emissions (lbs)	MTCE
CH ₄						
Wastewater	2,927,745	731,936	1,901	3,199,081	799,770	2,077
Sludge	26,349,704	6,587,426	17,110	28,791,727	7,197,932	18,696
TOTAL		7,319,362	19,011		7,997,702	20,773
	Consumption (kgs)	Emissions (kgs)	MTCE	Consumption (kgs)	Emissions (lkgs)	MTCE
N ₂ O						
	20,025,995	200,260	26,606	21,881,953	218,820	29,072
TOTAL		200,260	26,606		218,820	29,072



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13. Methane and Nitrous Oxide Emissions from Mobile Combustion

Overview

Methane (CH_4) is emitted as a by-product of combustion from mobile vehicle engines. The production of CH_4 is influenced by fuel composition, combustion conditions and available control technology. Methane emissions may result from hydrocarbons passing unburned or partially unburned through an engine. The emissions of unburned hydrocarbons, including CH_4 , from highway vehicles are lowest in uncontrolled engines when the air/fuel ratio is high. This means there is excess oxygen available in the combustion process. The lowest emissions currently occur in modern highway vehicles equipped with a three-way closed loop catalyst. This is accomplished when hydrogen, oxygen and carbon are present in precisely the proper ratio for complete combustion. Engine type and the type of fuel combusted strongly affect the type and volume of emissions.

Nitrous oxide (N_2O) emissions from mobile vehicles are formed when NO interacts with NH and NCO. The N_2O is then removed rapidly by the reaction between N_2O and hydrogen. A large amount of N_2O is formed in the combustion flame, but it will only survive if there is a very rapid quenching of the gases produced. This rarely occurs and only small amounts of N_2O are produced as engine emissions. N_2O can also be formed during catalytic treatment of exhaust gases. N_2O output from the catalyst is highly temperature dependent. At temperatures above 460°C , there is less N_2O exiting the catalyst than entering it. At temperatures below this level, the amount of N_2O exiting the catalyst may be up to 4.5 times the inlet values.

Methods

Emissions of CH_4 and N_2O from mobile sources were calculated for target years 1990 and 1999 from both road and non-road categories by using the EIIP guidance document. Road sources were vehicles that travel primarily on highways. Non-road sources included gasoline-fueled piston aircraft, jet aircraft, farm, industrial and construction equipment, boats, and ships. Except for gasoline-fueled aircraft, all of these sources were typically equipped with diesel engines. It should be noted that no diesel fuel consumption data were available for the non-road categories. Therefore, all non-road calculations included gasoline consumption only.

Road Sources

In order to calculate CH_4 and N_2O emissions from mobile sources in the road category, it was necessary to determine the total number of miles traveled in 1990 and 1999. All mileage data were obtained from the Oklahoma Department of Transportation (ODOT) and had been divided into three road categories: rural, small urban, and urban. ODOT advised that the urban and small urban categories should be combined to comply with EPA's urban category. The rural roads were further divided into interstates, principal arterials, minor arterials, major collectors, minor collectors, and local road types. Urban roads were subdivided into interstates, other freeways and expressways, principal arterials, minor arterials, collectors, and local road types.

Methane

Data were provided as daily vehicle miles traveled and were multiplied by 1.6 to convert to total daily vehicle kilometers (DVKT) traveled. DVKT were then distributed by vehicle class. Vehicle classes were determined by the type of vehicle and the type of fuel combusted. The Federal Highway Administration categories of vehicles were used as vehicle classes. The seven vehicle classes were:

1. LDGV (light duty gasoline vehicles) - gasoline-powered cars,
2. LDGT (light duty gasoline trucks) - gasoline-powered single-unit 2-axle trucks weighing less than 8500 pounds,
3. HDGV (heavy duty gasoline vehicles) - gasoline-powered single-unit 2-axle trucks with 6 or more tires and weighing more than 8500 pounds,
4. LDDV (light duty diesel vehicles) - diesel-powered passenger cars and light trucks,
5. LDDT (light duty diesel trucks) - diesel powered single-unit 2-axle trucks,
6. HDDV (heavy duty diesel vehicles) - buses and combination trucks (with single or multiple trailers), and
7. MC - motorcycles.

The EIIP guidance provided default fractions for each vehicle class that when multiplied by the total DVKT by road type produced the DVKT for each respective vehicle class traveling on that road type. This distribution of total miles among the 7 vehicle classes was done for each road type for both years. The DVKTs for all road types were then summed by vehicle class. This resulted in total DVKT by each vehicle class on all combined road types.

Total DVKT by vehicle class was then apportioned by year of vehicle manufacture. The number of vehicles still in use for any previous manufacture year decreased each year as the fleet aged. The total number of vehicles in use for any given year of manufacture was determined by using default percentages provided by the Mobile 6 model. Calculations were performed going back 25 years from target years 1990 and 1999. The year 1990 included vehicles manufactured from 1966 through 1990. The year 1999 included vehicles manufactured from 1975 through 1999. Mobile 6 provided a percentage of vehicles in use during each previous year for each class of vehicle. By multiplying the total vehicle class DVKT by this percentage, the total vehicle class kilometers were apportioned by year of vehicle manufacture.

The vehicle class DVKT were then categorized by emission control systems. Emission control systems available changed throughout the 25 years of manufacturing represented and also differed by vehicle class. The type of controls varied from virtually no controls on early models to tier 1 three-way catalyst for gasoline engines and advanced controls for diesel engines on later models. The EIIP guidance provided lists of all emission controls available for each vehicle class. The lists also included the percentage use of each emission control for the respective years. The type of controls for gasoline engines were one of four types: non-catalyst control, oxidation catalyst, tier 0 three-way catalyst, and tier 1 three-way catalyst. Diesel powered vehicles had no controls prior to 1983. Moderate controls were in place from 1983 to 1990 and advanced controls were required on all engines manufactured in 1991 and in all subsequent years.

Vehicle class DVKT were summed for manufacture years having the same emission controls in use in the same proportions. These emission control type sums were then multiplied by the appropriate percentage use to result in DVKT by emission control type by year. The DVKT

were summed by emission control type and then multiplied by the CH₄ emission factor specific for the emission control type and the vehicle class. The resulting values were grams of CH₄ released per day from each emission control type. These totals were then summed to obtain total emissions of CH₄ released from all vehicle classes and all emission control types during the 25 year study period. Total grams of CH₄ was converted to MTCE by converting to metric tons and multiplying by the ratio of carbon to carbon dioxide (12/44) and by the global warming potential (21) of CH₄. This daily value was then multiplied by 365 to provide the yearly MTCE from CH₄ from the road category of mobile sources.

Nitrous Oxide

The same above process was used to determine N₂O emissions from the road category of mobile sources. The DVKT totals by emission control type were multiplied by the N₂O emission factor specific for the emission control type and the vehicle class. The resulting values were grams of N₂O released per day from each emission control type. These totals were then summed to obtain total emissions of N₂O released from all vehicle classes and all emission control types during the 25 year period. Total grams of N₂O was converted to MTCE by converting to metric tons and multiplying by the ratio of carbon to carbon dioxide (12/44) and by the global warming potential (310) of N₂O. This daily value was then multiplied by 365 to provide the yearly MTCE from N₂O from the road category of mobile sources.

Non-road Sources

Methane

All data for jet fuel and aviation gasoline were obtained from the Department of Energy's Energy Information Administration (EIA.) Data for boats, farm equipment, industrial and commercial, and construction categories of non-road sources were obtained from the U.S. Department of Transportation, Federal Highway Administration (FHA). Data from 1992 was used in place of 1990 for these categories. There was no data available concerning fuel consumption by railway locomotives; therefore this category was omitted from this study. Jet fuel consumption was not separated by type of aircraft. Since the guidance only provided an emission factor for jet turboprop aircraft, an assumption was made that turboprop aircraft consumed all jet fuel. The total consumption of the Industrial and Commercial category and the Construction category from the FHA data were combined to provide a more accurate total of all non-road emissions.

Some non-road category consumption data were provided in total yearly gallons and were first converted to barrels and then to trillion Btu (tBtu.) Other data were already provided in tBtu. To determine CH₄ emissions from each non-road category, yearly tBtu was multiplied by 1,054 joules/Btu to produce a total consumption in trillion joules or million megajoules. This value was then multiplied by the appropriate non-road mobile source emission factor for CH₄ and resulted in million grams or metric tons of CH₄. Category specific emission factors for CH₄ were provided by the EIIP guidance. Metric tons of CH₄ were converted to MTCE by multiplying by the ratio of carbon to carbon dioxide and by the global warming potential (21) of CH₄.

Nitrous Oxide

This same process was used to obtain N₂O emissions from each non-road category. Million megajoules was multiplied by the appropriate non-road mobile source emission factor for N₂O

and resulted in metric tons of N₂O. Category specific emission factors for N₂O were provided by the EIIP guidance. No emission factor for N₂O from jet aircraft was provided. Metric tons of N₂O were converted to MTCE by multiplying by the ratio of carbon to carbon dioxide and by the global warming potential (310) of N₂O.

Results

Methane

Total MTCE from CH₄ from mobile sources was 21,922 in 1990 and 19,211 in 1999. The largest contributor was LDGV in the road category at 50% in 1990 and 48% in 1999. LDGT was the second largest contributor at 32% and 31% respectively. The road category represented 95% of total MTCE while non-road represented less than 5% of MTCE. All gas powered road sources had decreases in MTCE production from 1990 to 1999. All diesel powered road sources had increases in MTCE production from 1990 to 1999, with the largest increase being HDDV at over 100%.

Nitrous Oxide

Total MTCE from N₂O from mobile sources was 194,017 in 1990 and 262,421 in 1999. The largest contributor was LDGV in the road category at 62% in 1990 and 58% in 1999. LDGT was the second largest contributor at 32% and 34% respectively. The road category represented over 99% of total MTCE while non-road comprised the remaining fraction. All road category sources had increases in MTCE production from 1990 to 1999. The largest increase was in HDDV at 138%.

Summary

Table 13.1					
Mobile Combustion - CH ₄					
		1990		1999	
Road		km	MTCE	km	MTCE
	Light Duty Gas Vehicles	92,702,342	11,033	115,807,968	9,230
	Light Duty Gas Trucks	37,897,184	7,100	47,342,880	6,045
	Heavy Duty Gas Vehicles	4,518,510	1,895	5,644,728	1,626
	Light Duty Diesel Vehicles	583,034	12	728,352	15
	Light Duty Diesel Trucks	291,517	6	364,176	8
	Heavy Duty Diesel Vehicles	8,601,466	516	10,745,341	1,055
	Motorcycles	1,020,309	304	1,274,616	346
Total		145,614,362	20,866	181,908,061	18,325
Non-Road		tBtu	MTCE	tBtu	MTCE
	Gasoline Aircraft	0.7	254	0.5	181
	Jet Aircraft	43.8	529	37.3	450
	Marine	2.4	71	2.1	63
	Farm Equipment	2.2	147	2.4	163
	Construction and Industrial Equipment	2.3	55	1.2	29
Total		51.4	1056	43.5	886
TOTAL - CH ₄			21,922		19,211

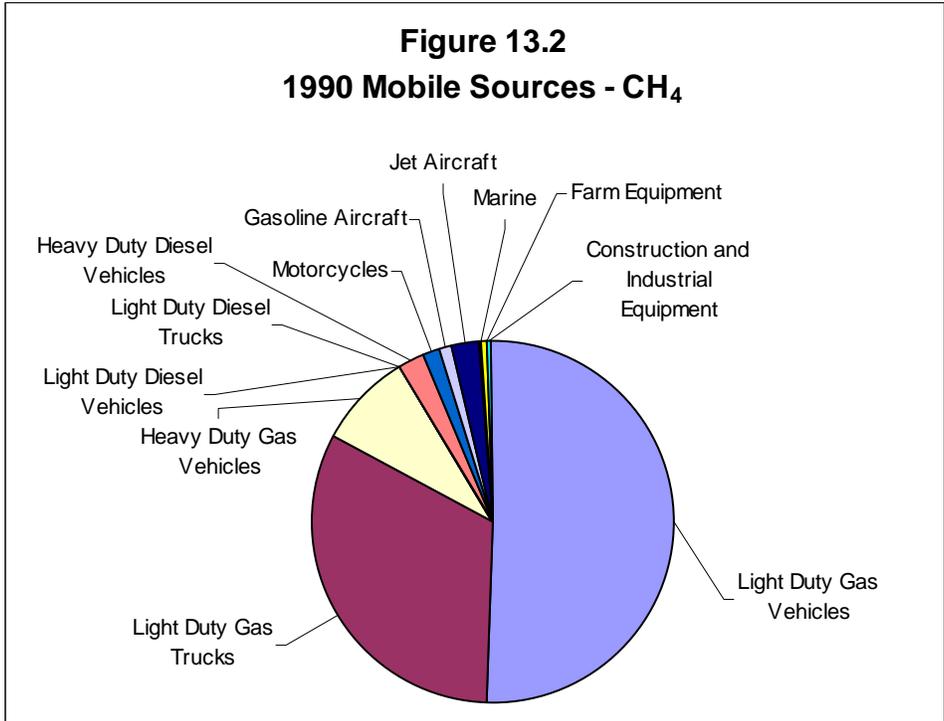
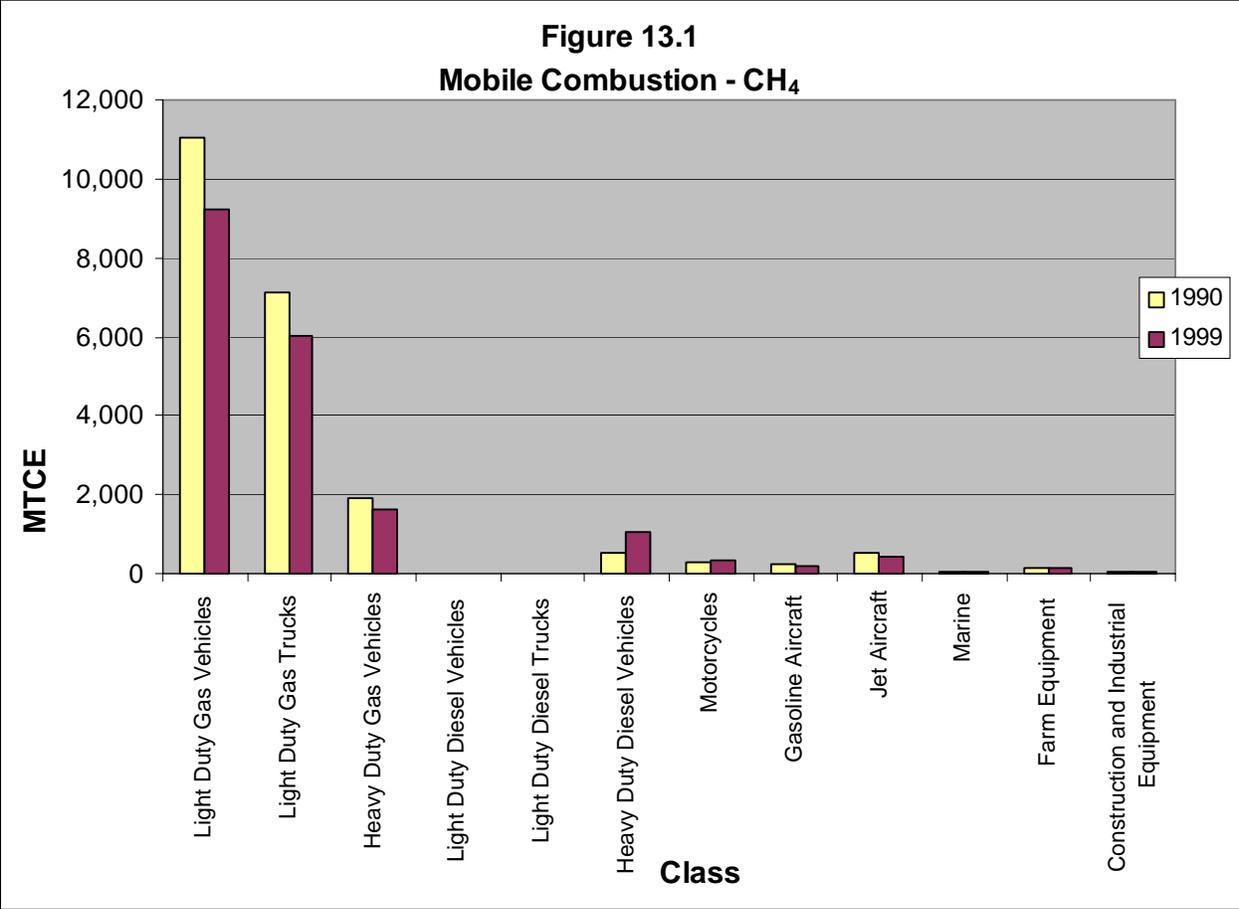


Figure 13.3
1999 Mobile Sources - CH₄

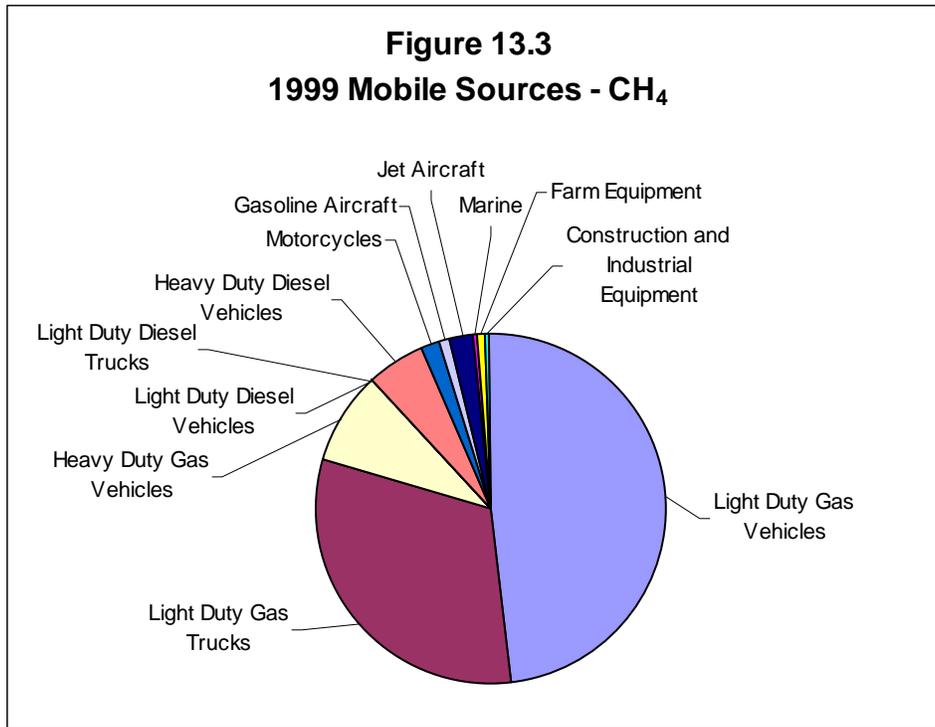
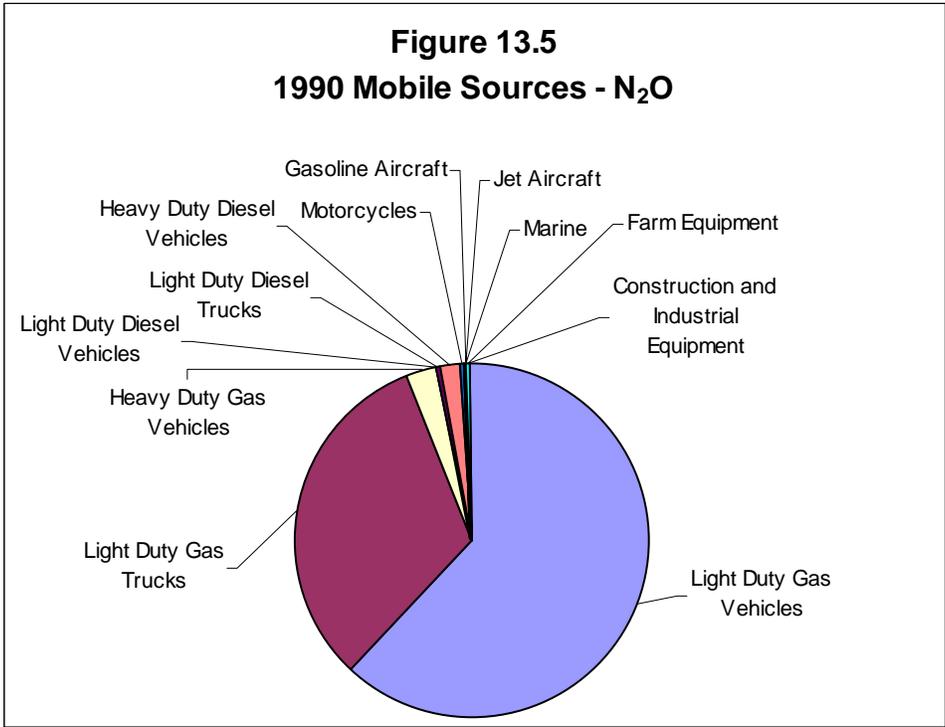
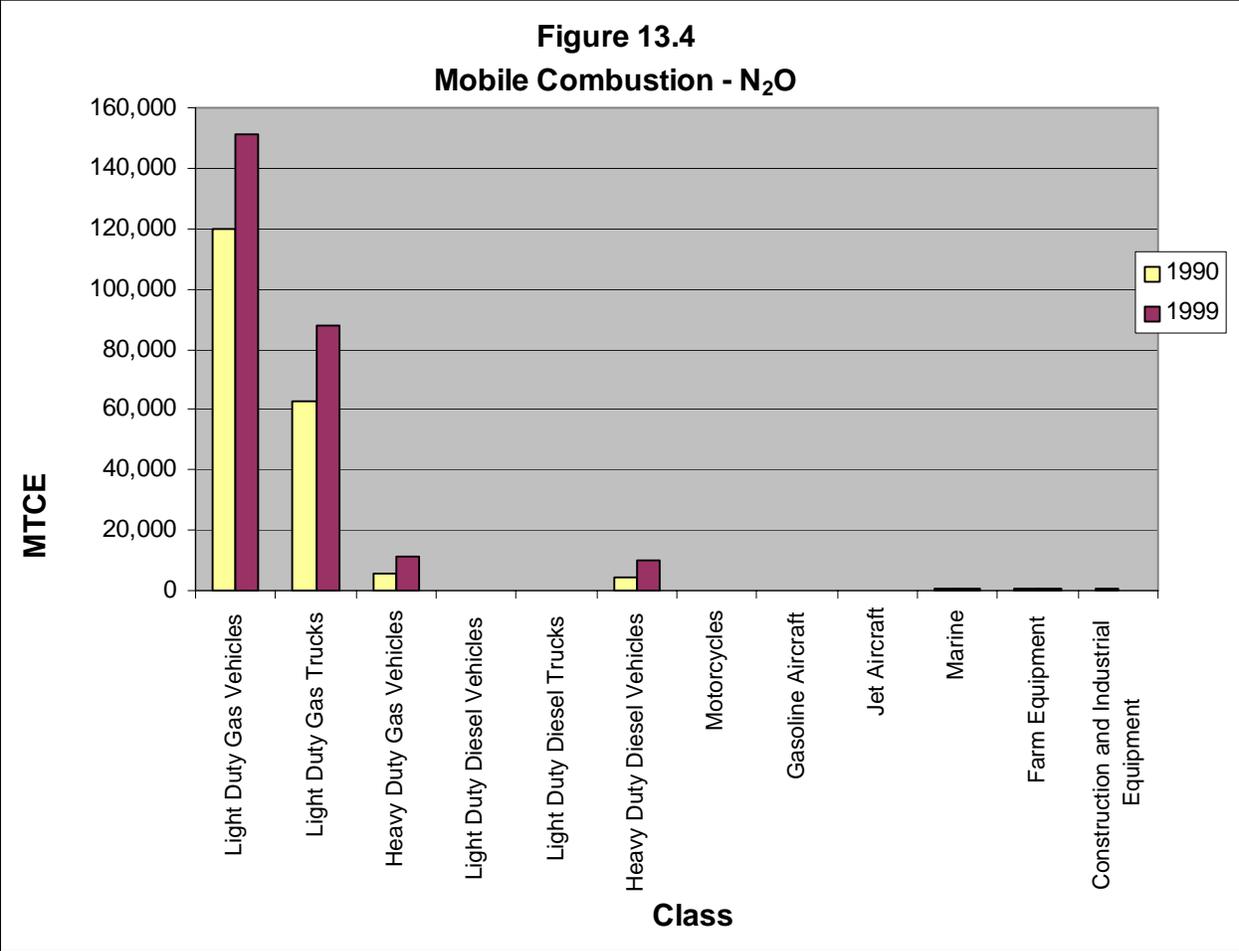
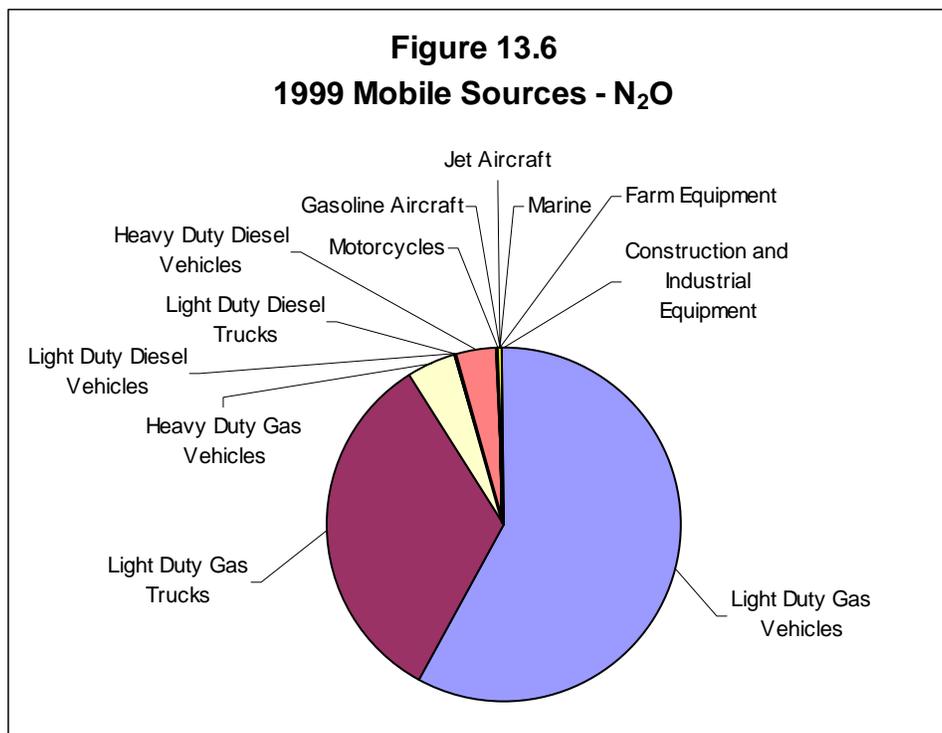


Table 13.2

Mobile Combustion - N₂O

		1990		1999	
Road		km	MTCE	km	MTCE
	Light Duty Gas Vehicles	92,702,342	119,699	115,807,968	151,352
	Light Duty Gas Trucks	37,897,184	62,978	47,342,880	88,139
	Heavy Duty Gas Vehicles	4,518,510	5,451	5,644,728	11,350
	Light Duty Diesel Vehicles	583,034	180	728,352	225
	Light Duty Diesel Trucks	291,517	180	364,176	225
	Heavy Duty Diesel Vehicles	8,601,466	4,183	10,745,341	9,948
	Motorcycles	1,020,309	129	1,274,616	157
Total		145,614,362	192,800	181,908,061	261,396
Non-Road		tBtu	MTCE	tBtu	MTCE
	Gasoline Aircraft	0.7	56	0.5	40
	Jet Aircraft	43.8	NA	37.3	NA
	Marine	2.4	420	2.1	372
	Farm Equipment	2.2	395	2.4	436
	Construction and Industrial Equipment	2.3	403	1.2	216
Total		51.3	1217	43.6	1025
TOTAL - N₂O			194,017		262,421





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14. Methane and Nitrous Oxide Emissions from Stationary Combustion

Overview

The combustion of fossil fuels by stationary sources results in emissions of five non-carbon dioxide greenhouse gases: methane (CH₄), nitrous oxide (N₂O), carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane volatile organic compounds (NMVOCs). Incomplete combustion results in the emission of unburned combustibles in the form of CO, CH₄, and NMVOCs. The emission of CH₄ and N₂O will vary with the size and vintage of the combustion technology involved. The way the source is operated, maintained, and the presence of any pollution control technology can affect emissions as well. N₂O is produced from the combustion of fossil fuels by a process that is well documented. The level of N₂O emissions is dependent upon the temperature of combustion. The highest N₂O emissions occur at a temperature of 1,000 degrees Kelvin. Combustion temperatures below 800 or above 1,200 degrees K produce negligible N₂O emissions. A global warming potential (GWP) has been developed for CH₄ and N₂O. This allows for normalization of all emissions to a common unit of metric tons of carbon equivalent (MTCE). There have not been any GWP's developed for CO, NO_x, and NMVOCs, consequently they cannot be included in this GHG inventory.

Methods

This report addressed the years 1990 and 1999. The MTCE produced by stationary sources were calculated using the EIIP guidance document. To calculate the CH₄ and N₂O emissions from stationary sources, the state-level consumption data was divided into four categories, residential, commercial, industrial, and electric utilities. Category-specific consumption data for Oklahoma was obtained from Department of Energy's Energy Information Administration (EIA) *State Energy Data Report 1999*. The data were provided in trillion British thermal units (tBtu). If the data were provided in units of barrels, tons, or billion cubic feet, conversions were made to Btu. Consumption data for electric utility category were obtained directly from the electric facilities

The EIA data were reported in higher heating values. These values (gross calorific values) were converted to lower heating values (net calorific values). The difference between these two values was the heat of condensation of moisture in the fuel during combustion; the lower heating value excluded this. Conversion percentages were provided by the EIIP guidance. The net calorific values for coal and petroleum products were about five percent lower than the gross calorific values. Lower heating values for petroleum products, coal, and wood (or other biomass) were obtained by multiplying the higher heating values by 0.95. For natural gas, lower heating values were obtained by multiplying the higher heating values by 0.90. These values were used in the calculations of CH₄ and N₂O.

To calculate CH₄, the four categories were subcategorized by source and technology as outlined by the EIIP guidance. Due to insufficient information, many assumptions were made when apportioning the consumption data to the subcategories. In the residential category, all natural gas consumption was defaulted to the heaters subcategory since no emission factor was available

for furnaces. It was assumed that all residual fuel and all LPG was combusted as fuel in the industrial category. Since it was not possible to differentiate natural gas use among the industrial subcategories, it was determined the majority of the sources were four cycle lean burning heavy duty compressor engines. Therefore, natural gas consumption was placed entirely in this subcategory. In the electric utility category, bituminous and sub-bituminous coal values were totaled and apportioned entirely to the pulverized bituminous combustion - dry bottom wall fired subcategory. Also in the electric utility category, all distillate fuel combusted was allocated to the large diesel fuel engines subcategory. Since it was not possible to differentiate natural gas use among the electric utility subcategories, it was determined the majority of the sources were large gas fired turbines. In addition, this subcategory had a higher emission factor, thus the total consumption value was treated as such.

The lower heating values for each sub category were converted from tBtu to terajoules. The result of this calculation was multiplied by the appropriate emission factor obtained from tables provided in the guidance manual. This calculation resulted in kg of CH₄, which was then converted to metric tons. The metric ton figure was multiplied by the ratio of carbon to carbon dioxide (12/44) and by the GWP for CH₄ (21.)

Calculations for N₂O emissions were performed in a similar fashion. The lower heating values were converted from tBtu to pounds of N₂O using emissions factors provided by the EIIP guidance. This figure was then converted to metric tons. MTCE was calculated by multiplying metric tons by the ratio of carbon to carbon dioxide (12/44) and by the GWP for N₂O (310.)

Results

Residential CH₄

Emissions from wood combustion were not included in these totals because no emission factor was provided. Combustion by sources in this category accounted for 2% of total CH₄ MTCE from stationary sources in 1999 and 1% in 1990. Oil consumption in this category increased by 80%, however, total residential CH₄ MTCE increased by less than 1% from 1990 to 1999.

Residential N₂O

Emissions from wood combustion were not included in these totals because no emission factor was provided. Residential N₂O emissions accounted for 2% of total stationary source MTCE for both 1990 and 1999. In 1990, 65% of residential N₂O was from natural gas combustion, but in 1999 it was split evenly between LPG and natural gas.

Commercial CH₄

There were no emission factors provided for LPG or wood, therefore those emissions were not included in the totals for this category. Commercial sources produced 1% of total MTCE from stationary source methane emissions in 1990 and in 1999 and increased by less than 3% during the period. Natural gas comprised 93% and 97% of the MTCE in this category for 1990 and 1999 respectively.

Commercial N₂O

Emissions from wood combustion were not included in these totals because no emission factor was provided. Commercial N₂O emissions were 1% of total MTCE in both 1990 and 1999. Natural gas was 44% and 60% of total commercial MTCE for years 1990 and 1999.

Industrial CH₄

Emissions from propane boilers were not included in these totals because no emission factor was provided. Wood and waste combustion totaled 21.7 tBtu in 1990 and 17.0 tBtu on 1999. The emissions from this source were not included in the inventory because no emission factor existed. The largest contributor to stationary source CH₄ MTCE was the industrial category. It accounted for 75% of total MTCE from CH₄ in 1990 and 69% in 1999. This category had a decrease of 23% from 1990 to 1999. Natural gas contributed 99% of the MTCE in this category.

Industrial N₂O

N₂O emissions from industrial category represented 20% of total MTCE for 1990 and 17% for 1999. LPG in the industrial category showed the largest increase of all sub-categories of stationary combustion at 282%. The largest contributor of N₂O MTCE in the industrial category was other oils at over 25% and natural gas and coal just slightly lower.

Electric Utility CH₄

The generation of electricity accounted for 23% of total MTCE from CH₄ in 1990 and 29% in 1999. From 1990 to 1999, MTCE from CH₄ increased by only 3%, with 84% of the MTCE coming from natural gas emissions in 1990 and 80% in 1999.

Electric Utility N₂O

The electric utility category was responsible for 77% and 80% of the N₂O MTCE from stationary combustion sources in 1990 and 1999 respectively. This category had the largest increase in MTCE production from stationary combustion at 28%. Sub-bituminous coal comprised 92% of N₂O MTCE from electric utility category. Sub-bituminous coal contributed over 70% of all MTCE from stationary sources for both years.

Summary

Table 14.1							
Stationary Combustion - CH ₄							
		1990			1999		
Fuel Type		Consumption (Tbtu)	Emissions (kgs)	MTCE	Consumption (Tbtu)	Emissions (kgs)	MTCE
Commercial							
Oil	Residual	0.5	702	4			
	Distillate	3.1	2,175	12	1.9	1,333	8
Natural gas	boilers	38	43,300	248	40.4	46,035	264
Total			46,177	264		47,368	271
Residential							
Oil	propane/butane furnace	4.6	5,072	29	8.3	9,151	52
Natural gas	heaters	66.9	63,526	364	62.9	59,728	342
Total			68,598	393		68,879	394
Industrial							
Coal	bit./sub-bit. pulverized	12.7	8,911	51	17.1	11,998	69
Oil	Residual fuel boilers	3.1	9,322	53	0.8	2,406	14
	Distillate fuel boilers	18	3,608	21	15.5	3,107	18
Natural gas	HD compressor engines	312.7	3,860,087	22,108	240.5	2,968,823	17,003
Total			3,881,928	22,233		2,986,334	17,104
Electric							
Coal	bit./sub-bit. pulverized	271	190,140	1,089	348	244,165	1,398
Oil	large diesel engines	0.025	100	1	0.01	40	0
Natural gas	large gas turbines	176.6	1,006,162	5,763	174.6	994,767	5,697
Total			1,196,403	6,852		1,238,972	7,096
TOTAL - All Sectors			5,193,105	29,742		4,341,553	24,865

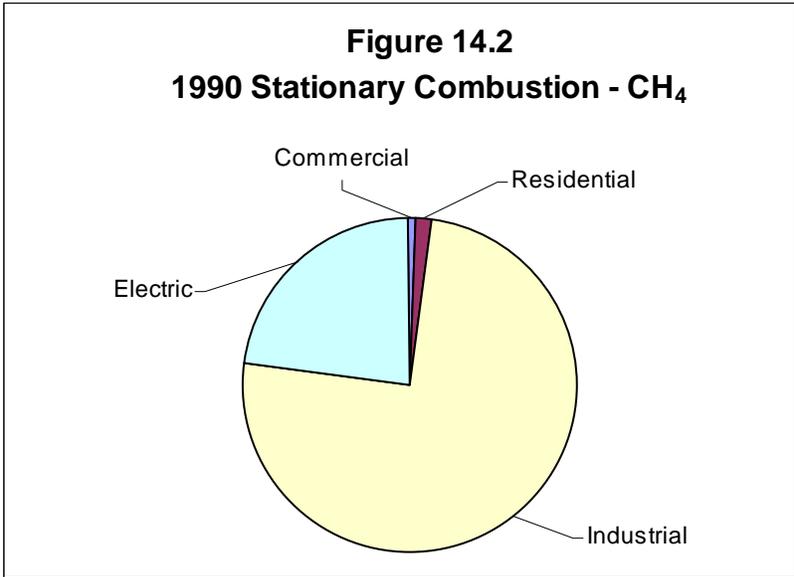
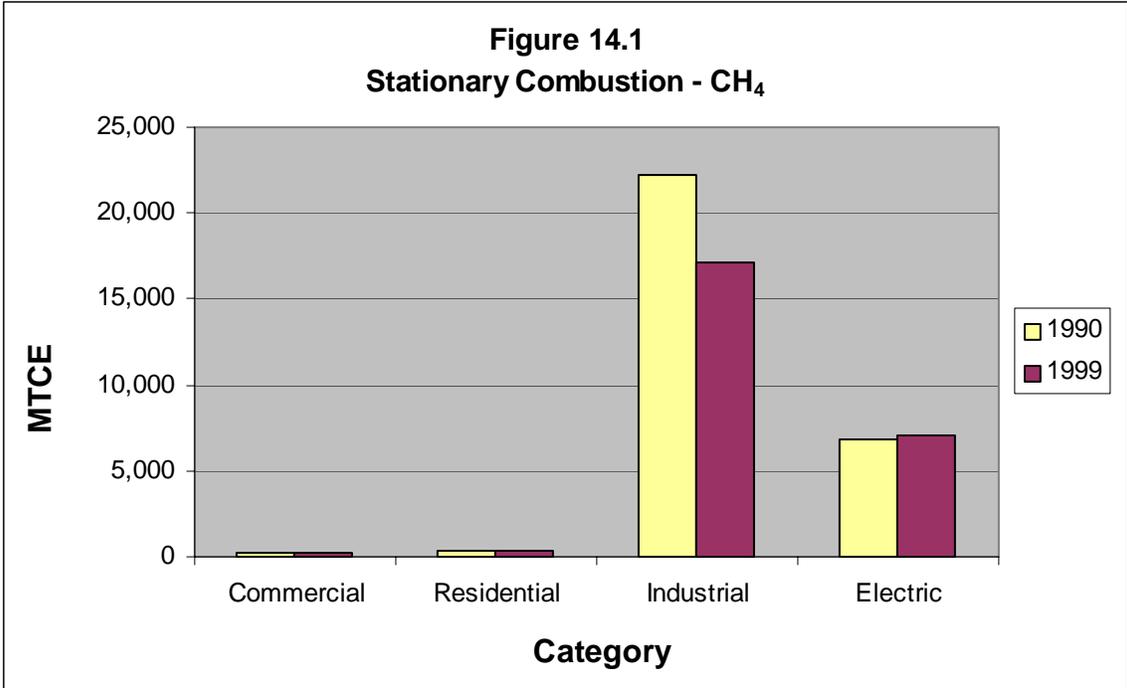


Figure 14.3
1999 Stationary Combustion - CH₄

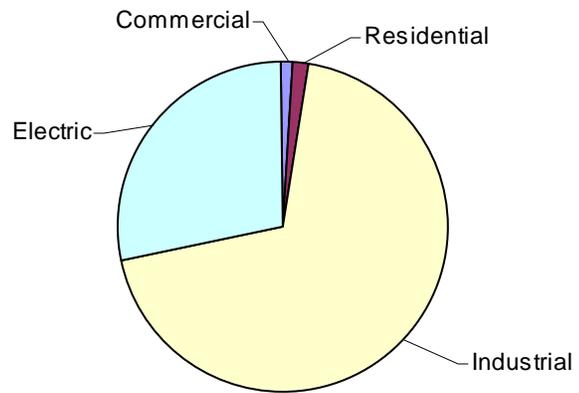
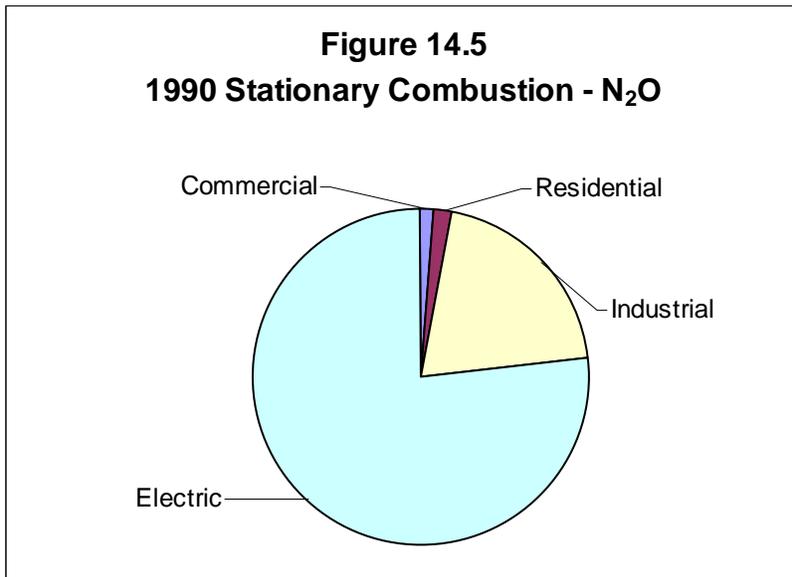
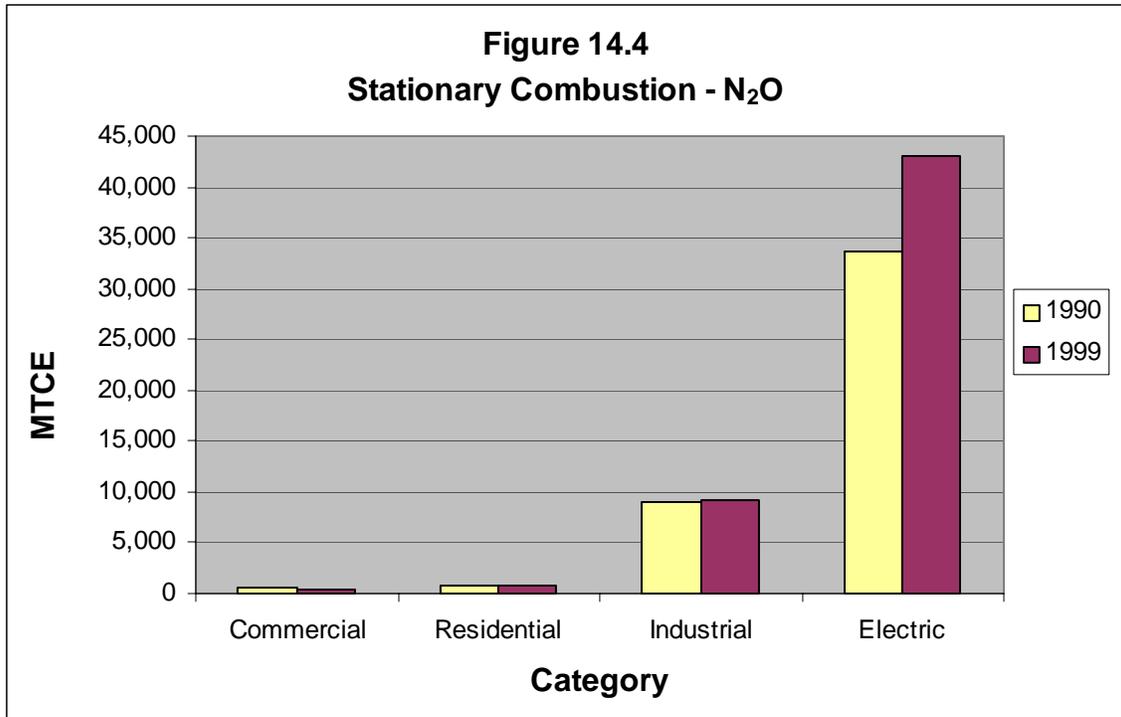
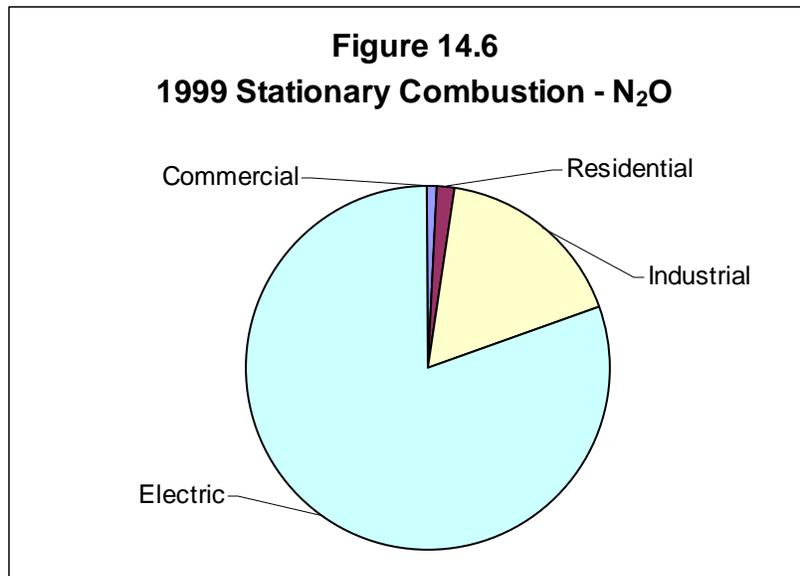


Table 14.2						
Stationary Combustion - N ₂ O						
Fuel Type	1990			1999		
	Consumption (Tbtu)	Emissions (pounds)	MTCE	Consumption (Tbtu)	Emissions (pounds)	MTCE
Commercial						
Distillate fuel oil	3.1	4123	158	1.9	2527	97
Kerosene	0.1	133	5	0.1	133	5
LPG	0.8	1064	41	1.5	1995	76
Motor gasoline	2	2660	102	0.2	266	10
Residual fuel oil	0.5	665	25			
Natural gas	38	6840	262	40.4	7272	279
Total		15485	594		12193	468
Residential						
Kerosene	0.1	133	5	0.1	133	5
LPG	4.6	6118	235	8.3	11039	423
Natural gas	66.9	12042	462	62.9	11322	434
Total		18293	701		22494	862
Industrial						
Asphalt & road oil	23.3	30989	1188	11.4	15162	581
Distillate fuel oil	18	23940	918	15.5	20615	790
Kerosene	0.1	133	5	0.1	133	5
LPG	6.1	8113	311	23.3	30989	1188
Lubricants	3.6	4788	184	3.7	4921	189
Motor gasoline	4.4	5852	224	3.6	4788	184
Other oils	44.8	59584	2285	51.1	67963	2606
Residual fuel oil	3.1	4123	158	0.8	1064	41
Coal-bituminous	12.7	38608	1480	17.1	51984	1993
Natural gas	312.7	56286	2158	240.5	43290	1660
Total		232416	8911		240909	9237
Electric						
Distillate fuel oil	0.025	33	1	0.01	13	1
Coal - bituminous	13.5	41040	1574	20.6	62624	2401
Coal - sub-bituminous	264.4	803776	30819	338.6	1029344	39468
Natural gas	176.6	31788	1219	174.6	31428	1205
Total		876637	33613		1123409	43074
TOTAL - All Sectors		1142831	43819		1399005	53642





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