Colorado Greenhouse Gas Emissions Inventory & Forecast

1990 through 2015
(revised October 2002)

Colorado Department of Public Health and Environment

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INTRODUCTION

This document represents an updated version of the 1990 inventory of anthropogenic greenhouse gas emissions and sinks for Colorado. The 1990 inventory was revised in 1998 using the most current data at the time. The second revision in 2000 was to provide a perspective on the projections presented for 2015 and to determine the most current amount of greenhouse gas emissions. The main purpose of the 2000 inventory was to determine the change in greenhouse gas emissions, and what approaches can be taken to reduce future greenhouse gas emissions. Data from 1997, 1998, and 1999 were used to represent emissions for each sector, depending on when the most recent data were available. These figures were used in totals to represent approximate emissions in the year 2000, but are not actual emissions for the year 2000.

THE INVENTORY PROCESS

The inventory identifies and catalogs the anthropogenic emissions and natural sinks of our greenhouse gases – **carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O),** and **ozone depleting compounds (CFCs/HCFCs)**. Although carbon dioxide, methane, and nitrous oxide are naturally occurring, their increase in concentration in the atmosphere is largely due to anthropogenic activities.

DATA AND METHODOLOGY

The inventory developed in 2000 used EPA's *States Workbook: Methodologies for Estimating Greenhouse Gas Emissions Vol. VIII*, which was released in December 1998. The methodology has remained relatively the same since the original inventory developed in 1995 and revised in 1998. Sections have been added and different emission factors for some emission calculations have been used. Updated emission factors and calculations have altered the emission totals. The reason for these changes was to achieve a better estimate on the amount of greenhouse gas emissions being released. The appendix provides calculations.

As with the previous inventory the data obtained for activities, consumption, source, and processes were compiled and published by state and federal agencies to the extent possible. The change in the amounts of emissions is the primary reason for the change between the 2000 and the 1990 emissions inventory, although methodology for certain calculations of emissions also had some effect. Data was converted to Metric Tons of Carbon Equivalent (MTCE) to incorporate Global Warming Potential (GWP) for each gas and to be consistent with comparisons. Carbon accounts for 12/44ths of carbon dioxide's molecular weight.

$$MTCE = (\text{Metric Tons of Gas}) * (GWP) * (12/44)$$

QUALITY ASSURANCE

In order to assure high quality emission estimates the EPA developed the Data Attribute Ranking Systems (DARS) scores. The DARS scores can be viewed in EPA's *States Workbook: Methodologies for Estimating Greenhouse Gas Emissions Vol. VIII* at the end of each chapter.

<u>Table A-1</u>: Changes in Emission Calculations Between 1998 and 2000

Section	Methodology changes	Emission Factor changes
Fossil Fuel Use	- Biomass is no longer a fuel considered to contribute to greenhouse gas emissions - Ethanol is subtracted from gasoline consumption since it is an additive to gasoline and is not included in greenhouse emissions since it is a biogas	none
Methane from Oil and Gas Systems	none	low, median, and high
Methane from Coal Mining	- Used only one emission factor (in previous inventory low, average, and high emission factor was used) - Used actual methane emission measurements from underground mining	- Emission factor was used in 1990 for underground mines, not actual emissions
Methane from Landfills	- Large MSW landfills used equation in *workbook* to find methane emissions - Methane recovered was factored into total for 1998	-Large MSW landfills incorporated an equation to better estimate emissions, rather than using emission factor
Methane from Wastewater Treatment	- Factored in % treated anaerobically, since only anaerobic decomposition gives off methane	- Used 15% default of wastewater treated anaerobically
Fertilizer	none	-An emissions factor of 0.0117 was changed to 0.0125
Domestic Animals	- Did not treat "feedlot" cattle separately - Added "weanling system steers"	- The emission factor that was used for "feedlot cattle" was not used. - Used emission factor for "weanling system steers" - The emission factor for "mature dairy cattle" was changed from 262.5 to 307.3
Manure Management	- "other" MCF was factored into data	- Used 90% MCF for cattle and 10% for swine and sheep

ORGANIZATION
The greenhouse gas emissions inventory presents data from ten different sectors. In presenting the results from in this inventory, the ten sectors were divided into three parts, allowing similar sectors to be grouped accordingly.

Part I covers emissions from energy production and consumption. In **Section I** of **Part I**, emissions from fossil fuel consumption are presented by sector. In **Section II**, methane emissions from oil and gas systems during production, storage, transportation, and distribution are estimated. **Section III** provides estimates of methane emissions from underground and surface coal mining activity.

Part II of the inventory focuses on process and municipal activity source emissions. In **Section I** of **Part II**, carbon dioxide emissions from cement, lime, and limestone production and processes are calculated. **Section II** looks at ODC emissions from air conditioning and refrigeration processes derived from data obtained from sales of ozone depleting compounds. **Section III** presents methane emissions from landfills and **Section IV** estimates emissions from wastewater treatment facilities.

Part III of the inventory presents emission data and carbon sink data (where applicable) from agriculture, forest and land use changes. **Section I** of **Part III** estimates methane emissions from domestic animals and **Section II** focuses on methane emissions from manure management systems domestic animals. In **Section III**, nitrous oxide from fertilizer use in agriculture is presented. Carbon dioxide sinks in forests and emissions from land use changes are given in **Section IV**.

SUMMARY OF INVENTORY RESULTS

Table 1.0: Colorado Greenhouse Gas Emissions from 1997-1999 Compared to 1990

Source	CO2 (tons)	MTCE	CH4 (tons)	MTCE	N2O (tons)	MTCE	CFC (tons)	MTCE
Fossil Fuel Combustion								
1997	89,165,880.86	22,061,260.12	2,258.30	12,933.89	2,532.19	737,345.35		
1990	78,720,580.81	19,476,902.98	NA	NA	NA	NA		
Oil & Natural Gas Systems **								
1998			89,461.85	464,824.25				
1990			47,294.80	245,733.46				
Coal Mining								
1999			182,929.38	1,047,686.48				
1990			102,947.70	589,609.56				
Production Processes								
1998	1,628,424.38	444,115.74					800.00 *	989,672.72
1990	912,182.04	225,690.42					2,400.00*	2,969,018.18
Landfills								
1998			97,864.51	508,482.64				
1990			81,064.51	421,193.51				
Wastewater Treatment Systems								
1998			3,737.49	21,405.62				
1990			3,035.60	17,385.71				
Domestic Animals								
1998			196,567.13	1,021,319.92				
1990			216,552.32	1,125,158.61				
Manure Management Systems								
1999			43,048.87	223,672.54				
1990			13,332.53	69,272.91				
Fertilizer								
1999					3,318.77	254,548.48		
1990					2,984.44	228,905.46		
Land Use Changes								
1999	19,968.96	4,940.68						
1990	723,836.64	179,090.34						
Totals								
Recent	**90,814,274.20**	**22,469,102.60**	**613,609.23**	**3,287,391.45**	**3,318.77**	**254,548.48**	**800.00 ***	**989,672.72**
1990	**80,356,599.49**	**19,881,683.74**	**464,227.46**	**2,468,353.76**	**2,984.44**	**228,905.46**	**2,400.00***	**2,969,018.18**
Total MTCE								
Recent	**26,052,256.47**							
1990	**22,578,942.96**							

*CFC values are included for informative purposes only and not included in MTCE totals. More information available under separate cover.

** Used median emissions from oil and natural gas systems.

Note: The most recent year to 2000 was used to achieve a better representative of emission trends throughout the decade of 1990. The average year used was 1998. For the total 1997 and 1999 data are used as representative of data in 1998.
Nitrous oxide and methane emissions were not calculated in the total, since these calculations were not used in 1990.

Future Estimates (1990)
In the original 1990 forecast, future estimates of carbon dioxide emissions from fossil fuel use were expected to top the list as the dominant greenhouse gas for Colorado. By 2015, the estimated increase in carbon dioxide emissions was 43% due to fossil fuel combustion activities. Methane from coal mining was expected to increase 34%. Methane from landfills was expected to increase 28%, and methane from wastewater treatment was expected to increase 42.2%. These two increases in methane emissions from municipal activities can be primarily attributed to a projected increase in population growth. Methane emissions from domesticated animal agriculture were expected to rise 9% from domesticated animals and 13% from manure management systems. All other methane sources were expected to show little or no growth. *Table 1.1* presents a summary of 1990, 1997, 1998, or 1999, and 2015 projections of greenhouse gas emissions.

Table 1.1: Greenhouse Gas Emissions Change (1990 ~ 2000 and 1990 - 2015)

Sector	Pollutant	1990 Values (MTCE)	1997,1998, or 1999 Values (MTCE)	Percent Change (1990~2000)	2015 Projected Values (MTCE)	Percent Change (1990-2015)
Fossil Fuel	$C0_2$	19,476,902.98	22,061,260.12	13.3%	27,890,925.07	43.2%
Oil and Natural Gas Systems	CH_4	245,733.46	464,824.25	89.1%	303,480.82	23.5%
Coal Mining	CH_4	589,609.56	1,047,686.48	77.7%	792,435.25	34.4%
Production Processes	$C0_2$	225,690.42	444,115.80	78.5%	225,690.42	0.0%
Landfills	CH_4	421,193.51	508,482.64	20.7%	539,970.08	28.2%
Wastewater Treatment	CH_4	17,385.71	21,405.62	23.0%	24,722.47	42.2%
Domesticated Animals	CH_4	1,125,158.61	1,021,319.92	-9.2%	1,223,047.41	8.7%
Manure Management Systems	CH_4	69,272.91	223,672.54	222.9%	78,001.30	12.6%
Fertilizer	N_20	228,905.46	254,548.48	11.2%	228,905.46	0.0%
Land Use	$C0_2$	179,090.34	4,940.68	-97.0%	179,090.34	0.0%
Total		**22,578,942.96**	**26,052,256.47**	**13.3%**	**31,486269.62**	**28%**

The Global Warming Potential (GWP) Concept

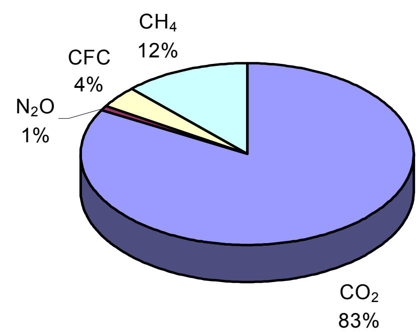
The concept of Global Warming Potential (GWP) was developed in order to compare the ability of each greenhouse gas to trap heat relative to the other greenhouse gases. Each greenhouse gas may influence global warming in various ways, depending on the gas. The gases may contribute to the greenhouse effect either directly or indirectly. A gas contributes to global warming directly when the gas itself is a greenhouse gas. Indirect warming occurs when the gas undergoes a chemical transformation and produces gases that are greenhouse gases. Furthermore, indirect effects can occur when a gas chemically influences the atmospheric lifetimes of other gases.

GWP concept was developed in order to rank the potency of greenhouse gases relative to one another over some period of time, usually 100 years. Carbon dioxide is the most common of the greenhouse gases, has a direct global warming effect, and was chosen as the reference gas to measure other gases against. Carbon dioxide is given a value of 1.0. Methane is ranked as 21, compared to carbon dioxide. This means that methane has 21 times the global warming potential of carbon dioxide over 100 years. Nitrous oxide has a global warming potential of 310. Chlorofluorocarbons have, by far, the highest global warming potential of all. The warming potential for chlorofluorocarbons can range from as much as 93 to over 11,000 times that of carbon dioxide depending on which chlorofluorocarbon compound is being discussed. For this inventory, the Global Warming Potential applied to chlorofluorocarbons is 5,000 based on a 100-year time horizon.*

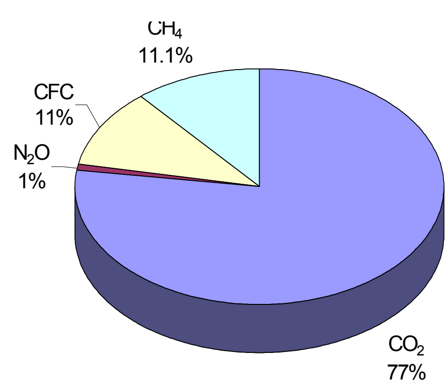
The 2000 inventory indicated that CO_2 emissions amounted to 83% of GWP emissions. Based on the results of the 1990 inventory, carbon dioxide accounted for 78% of Colorado's total emissions global warming potential. The relative contribution of methane, with a global warming potential of 21 was 11.1% in 1990 and 12.3% in 2000. Chlorofluorocarbons accounted for 11.0% in 1990 and 3.7% in 2000, based on a global warming potential of 5,000. Nitrous oxide (at 310) was 1% in 2000 and 0.9% in 1990. It should be noted that data from 1997, 1998, and 1999 were used to represent the year 2000 and actual emissions of the year 2000 have not been calculated. A concentration on each sector should be evaluated and not the total emissions by gas.

* Chlorofluorocarbon GWP recommended by the Alternative Fluorocarbons Environmental Acceptability Study, February 24, 1998. GWP values for chlorofluorocarbons have a typical uncertainty of ±35%.

<u>Figure 1.0(a)</u>: Greenhouse Gas Emissions by Gas (~2000)



<u>Figure 1.0(b)</u>: Greenhouse Gas Emissions by Gas (1990)



PART I

EMISSIONS FROM ENERGY PRODUCTION AND CONSUMPTION

Overview
Carbon dioxide and other greenhouse gases are released from fossil and biomass fuels during the production, storage and consumption of energy. Part I of the inventory presents estimates from these energy-related processes in Colorado during 1990, and the most recent data since 1997. The energy production and consumption processes included in Part I are as follows:

> **Section I**: Greenhouse Gas Emissions from Fossil Fuel Consumption
> **Section II**: Methane Emissions from Natural Gas and Oil Systems
> **Section III**: Methane Emissions from Coal Mining

Section I provides data on fossil fuel consumption in the transportation, industrial, commercial, utilities, and residential sectors. Combined, this sector contributes the most significant portion of greenhouse gas emissions, accounting for 78,720,580.81 short tons in 1990 and 89,165,880.86 short tons in 1997 of carbon dioxide, or 76% of total carbon dioxide emissions in Colorado in 1990 and 82% of carbon dioxide emissions in 1997. Section II estimates methane emissions from fossil fuel production, distribution and storage. This sector contributed 47,294.80 short tons of methane in 1990 and 89,461.85 short tons of methane in1998 to Colorado's inventory, and it should be noted that these figures are median emissions from these sources and can vary more or less. In Section III, underground and surface mining were estimated to contribute 113,478.50 short tons of methane (589,609.56 MTCE) in 1990 and were estimated to contribute 201,641.73 short tons of methane (1,047,686.48 MTCE) in 1999. Methane and nitrous oxide emissions from fossil fuel combustion were not included in the 1998 version of the state inventory but were included in the 2000 inventory revision for the reason that EIIP's *States Workbook Vol. VIII* does include methane and nitrous oxide emissions from mobile and stationary sources presented in *Table 1.1.8* and *Table 1.1.9*, whereas the first and second editions of the workbook did not include these emissions. In 1997 methane emissions from mobile sources amounted to 2,258.30 Mg of methane (12,933.89 MTCE), and the estimated methane emissions of methane from stationary sources was not available due to insufficient data. Nitrous oxide emissions from mobile sources were estimated to be 1,983.78 Mg (687,175.24 MTCE) and 593.41 metric tons (50,170.11 MTCE) from stationary sources.

Data
The updated 2000 inventory used the most recent version of the "State Energy Data Report" published in 1999. Data on biomass consumption came from the Forest Service's "Annual Cut and Sold" publication. Since biomass is no longer included in the state's inventory, data on biomass was not estimated.

For the 1998 inventory, estimating carbon emissions from the production and consumption of energy requires disaggregated data by fuel type and end-use sectors. Most of the data used in the 1998 inventory for the energy sector came from the Department of Energy, Energy Information Administration's "State Energy Data Report, 1992".

Section II data on natural gas and oil systems are based on production data by sector supplied by the Colorado Oil and Gas Commission. In **Section III**, coal mining data are from the Colorado Department of Natural Resources, Division of Minerals and Geology, while production figures were supplied by mine. Figures are broken down by type of mine (for example, underground mine production versus surface mine production). Data used for the 2000 revision were extrapolated from the previously mentioned sources.

Methodology

In **Section I**, emission estimates for Colorado's fossil fuel consumption were calculated based on the 1992 version of the *State's Workbook*. The revised edition of the inventory used the eighth edition of the *State's Workbook.* Using this methodology eleven fuel types were analyzed in 1990 and ten in 1997, the *State's Workbook Vol. VIII* does not include biomass fuels. Since ethanol is included as a biofuel, ethanol is omitted from gasoline consumption totals and is not counted as a fuel that contributes to greenhouse gas emissions for the reason that ethanol is a biofuel. Adjustments were made to the 1990 emissions to better compare emissions to those of 1997. Based on this calculation, carbon dioxide emissions are a function of a) the amount of fuel consumed (by fuel type), b) the carbon content of that fuel, and c) the fraction of carbon which is oxidized. The calculation proceeds as follows:

*CO_2 Emissions (tons) = [(Fuel Consumption Figure (MMBTU * Carbon Content Coefficient)] * [0.99 (oxidation factor)] * [(44/12) CO_2 Factor] * [1(ton)/2000 (lbs.)]*

Methane and nitrous oxide emissions were calculated in the 2000 version of the inventory, whereas the 1998 version inventory did not calculate these emissions.

In **Section II**, standard emission factors from ICC (1994) were used for 1990 data and emission factors from EIIP (1998) were used for 1998 data to determine methane emissions during the production, processing, and distribution of natural gas and oil systems. Basically, the methodology relies on production/consumption data because it provides some description of the oil and gas system's size and capacity. Emissions factors are provided for high, low, and median estimates of methane emissions from this source. Oil and gas venting and flaring have had the only emission factor changes and the necessary adjustments to the 1990 data have been made for comparison purposes. These emissions estimates can be no better than 'order of magnitude' estimates. Actual emissions depend on site-specific characteristics. The calculations proceed as follows:

Activity level (MMBTU) **x** *Emissions Factor (high; lbs CH_4/MMBTU) = lbs CH_4 (high)*

Activity level (MMBTU) **x** *Emissions Factor (low; lbs CH_4/MMBTU) = lbs CH_4 (low)*

Activity level (MMBTU) **x** *Emissions Factor (median; lbs CH_4/MMBTU) = lbs CH_4 (median)*

(Divide each figure by 2,000 to arrive at short tons)

In **Section III** the methodology recommended in the 1992 *State's Workbook* was used to estimate methane emissions from coal mining in 1990 and the 1998 *State's Workbook* was used for calculating 1999 data. Because coal recovered from deep, underground mines produces more methane than surface coal mining processes, a distinction is made between underground and surfaces coal mines when calculating methane emissions in this inventory. Underground mines have venting equipment that measures the amount of methane released in cubic feet per day. Thus, actual averages were used for 1999 data contrary to what was used for 1990 (production multiplied by an emission factor). The emission factors from the 1992 *State's Workbook* differed from the 1998 version and a single emission factor was used for each category. Calculations for low, high and average emissions were not necessary due to improved emission factors in the 1998 *State's Workbook*. The changes were made to the previous inventory using the updated emission factors and emissions from underground mining remained the same. No methane recovery/capture processes were factored into the methane emission calculation.

The estimates provided used the following steps:

Obtain the required data--1990, 1999 data from surface and underground mining
Calculate methane emissions from underground and surface mining
Calculate post-mining emissions
Calculate total mining emissions

SECTION I
Carbon Dioxide Emissions from Fossil Fuel Consumption
In 1990, Colorado emitted over 85 million tons of carbon dioxide from fossil fuel combustion, or roughly 5 percent of national carbon dioxide emissions. Fossil fuel consumption accounts for 98% of all carbon dioxide emissions. Coal contributes the largest share of emissions from energy consumption at 47.7% or 40.6 million tons carbon dioxide. The use of petroleum products is the second largest source, contributing 29.1% or 24.8 million tons carbon dioxide. Natural gas consumption emits 16.8% or 14.3 million tons of carbon dioxide. Biogas makes up the remaining 5.6% or 4.8 million tons carbon dioxide. *Figure 1.1.1a* and *1.1.1b* depict carbon dioxide emissions by major energy sectors in Colorado in 1997 and 1990 respectively.

Figure 1.1.1(a): CO_2 Emissions by Fossil Fuel Type (1997)

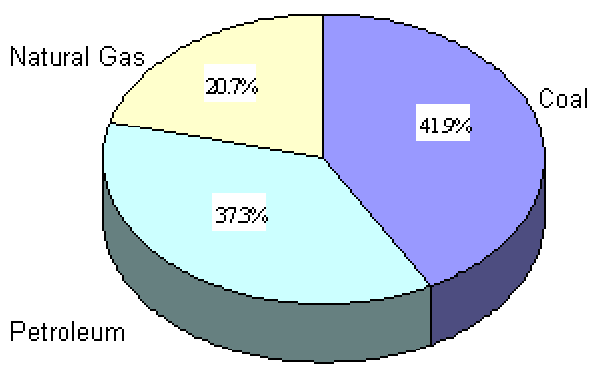
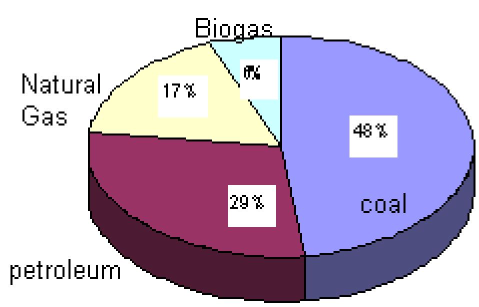


Figure 1.1.1(b): CO_2 Emissions by Fossil Fuel Type (1990)



In 1997, fossil fuel combustion amounted to over 89 million tons of released carbon. The utility sector accounted for the largest amount of carbon dioxide being released when compared to other sectors, the increase in emissions from utilities, predicted by the 2015 forecast, has been the case. It should be noted that EIA's *State Energy Report* has indicated an increase in Colorado for the use of hydroelectric utility generation, which in theory would result in less carbon dioxide emissions from the burning of fossil fuels. The transportation sector has also increased emissions since 1990 and has contributed the second largest portion of carbon dioxide among the various sectors. The industrial sector has had the largest increase in carbon dioxide emissions contributing the third largest amount of carbon dioxide emissions. The next largest amount and second largest increase in emissions is the residential sector, being directly attributable to the increase in Colorado's population. The least amount of carbon dioxide emissions and the smallest increase was in the commercial sector.

Combustion of coal in various sectors has amounted to the largest emission of carbon dioxide, emitting 41.9% of carbon dioxide attributable to energy combustion. Petroleum products contributed the second largest amount of carbon dioxide emissions, emitting 37.3% of carbon dioxide of the total amount of energy combustion. The remaining portion of carbon dioxide emissions is from the combustion of natural gas which had 20.7% of emissions from energy combustion. Biomass accounted for 0.1% of carbon dioxide emissions, as biomass has a small carbon coefficient (0.48) and the consumption of biomass is small. The small amount of carbon dioxide attributable to biomass is probably the reason for its exclusion in EPA's *State Workbook for Estimating Greenhouse Gas Emissions Vol. VIII.* It should be noted that carbon in *asphalt and road oil* is assumed to be sequestered 100%, and *lubricants* are sequestered 50%. The inclusion of these products for the 2000 revision was to get a better comparison with 1990 data.

In 1990, the utilities sector emitted the largest share of carbon dioxide at 49.6% or 38.9 million tons, predominately from the combustion of coal. The transportation sector emitted the second largest share of carbon dioxide, 24.7% or 19.4 million tons of carbon dioxide. The largest greenhouse gas emitter was the industrial sector at 12.5% or 9.8 million tons of carbon dioxide. The residential sector emitted 7.6% or 6.1 million tons, with the remainder emitted by the commercial sector at .5% or 4.4 million tons of carbon dioxide. *Figure 1.1.2* and *Table 1.1.1* provide a summary of total carbon dioxide emissions from each sector. *Tables 1.1.2 - 1.1.6* break down each sector and show total carbon dioxide from the type of fuels used by each of sector.

<u>Figure 1.1.2(a)</u>: 1997 CO_2 Emissions from Fossil Fuel Consumption by Sector

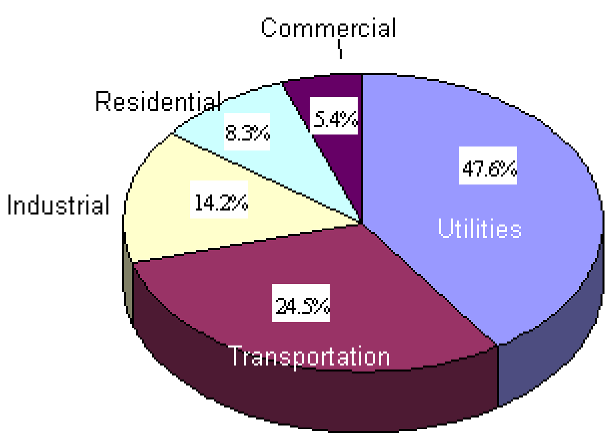


Figure 1.1.2(b): 1990 CO_2 Emissions Fossil Fuel Consumption by Sector

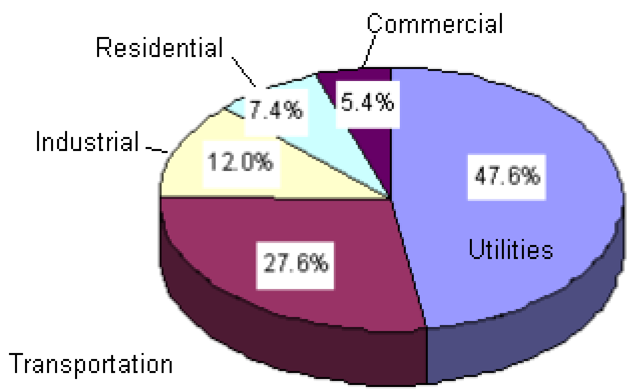


Table 1.1.1(a): 1997 Carbon Dioxide Emissions by Sector

Sector	Carbon Dioxide (tons)	Percent
Utilities	41,972,663.97	47.6%
Transportation	21,926,129.44	24.5%
Industrial	12,731,351.45	14.2%
Residential	7,626,985.76	8.3%
Commercial	4,908,750.24	5.4%
Total	**89,165,880.86**	**100%**

Table 1.1.1(b): 1990 Carbon Dioxide Emissions by Sector

Sector	Carbon Dioxide (tons)	Percent
Utilities	38,966,038.07	49.6%
Transportation	19,430,412.68	24.7%
Industrial	9,826,549.78	12.5%
Residential	6,052,128.37	7.6%
Commercial	4,445,451.91	5.6%
Total	**78,720,580.81**	**100%**

Figure 1.1.3: Comparison of CO_2 Emissions from Fossil Fuel Use, 1990 and 1997

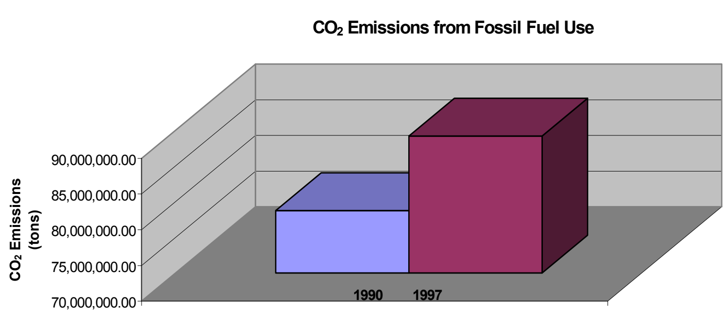


Table 1.1.2(a): Carbon Dioxide Emissions from Residential Fossil Fuel Use (1997)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Distillate Fuel	401,925.00	44.00	32,097.73
LPG	8,423,100.00	37.80	577,883.62
Kerosene	107,730.00	43.50	8,505.55
Anthracite Coal	0.00	62.10	0.00
Bituminous Coal	549,470.00	56.00	55,848.13
Natural Gas	119,480,000.00	31.90	6,952,650.72
Total	**128,962,225.00**		**7,626,985.76**

`Table 1.1.2(b): Carbon Dioxide Emissions from Residential Fossil Fuel Use (1990)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Distillate Fuel	157,275.00	44.00	12,559.98
LPG	6,806,667.00	37.80	466,985.00
Kerosene	124,740.00	43.50	9,848.53
Bituminous Coal	400,000.00	56.00	48,563.59
Anthracite	0.00	62.10	0.00
Natural Gas	92,760,000.00	31.90	5,514,171.26
Biomass	1,610,000.00	0.48	1,261.84
Total	**103,936,482.00**		**6,052,128.37**

Source: State Energy Data Report 1992 **Note:** Biomass is no longer included in the greenhouse gas inventory. (EPA's *State Workbook Vol VIII*)

Table 1.1.3(a): Carbon Dioxide Emissions from Commercial Fossil Fuel Use (1997)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Gasoline	194,361.00	42.80	15,098.35
Distillate Fuel	6,908,450.00	44.00	551,708.82
Residual Oil	0.00	47.40	0.00
LPG	1,488,081.00	37.80	102,092.77
Kerosene	28,350.00	43.50	2,238.30
Anthracite Coal	0.00	62.10	0.00
Bituminous Coal	1,003,380.00	56.00	101,983.54
Natural Gas	71,070,000.00	31.90	4,135,628.4
Total	**80,692,622.00**		**4,908,750.24**

Table 1.1.3(b): Carbon Dioxide Emissions From Commercial Fossil Fuel Use (1990)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Gasoline	1,381,539.00	42.80	107,320.71
Distillate Fuel	2,545,525.00	44.00	203,285.63
Residual Oil	0.00	47.40	0.00
LPG	1,199,289.00	37.80	82,279.62
Kerosene	56,700.00	43.50	4,476.61
Bituminous Coal	907,082.00	56.00	92,270.82
Anthracite	0.00	62.10	0.00
Natural Gas	67,980,000.00	31.90	3,955,818.52
Total	**74,070873.00**		**4,445,451.91**

Source: State Energy Data Report 1992

Table 1.1.4(a): Carbon Dioxide Emissions from Industrial Fossil Fuel Use (1997)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Distillate Fuel	23,684,450.00	44.00	1,891,440.18
LPG	6,024,522.00	37.80	413,324.38
Other Oil	10,380,150.00	44.00	828,958.78
Lubricants	1,449,535.00	44.60	117,338.41
Kerosene	28,350.00	43.50	2,238.30
Bituminous Coal	18,634,200.00	56.00	1,893,980.09
Asphalt/Road Oil	17,081,064.00	45.50	1,410,596.97
Natural Gas	106,090,000.00	31.90	6,173,474.35
Total	**183,372,271.00**		**12,731,351.45**

Table 1.1.4(b): Carbon Dioxide Emissions from Industrial Fossil Fuel Use (1990)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Distillate Fuel	15,628,475.00	44.00	1,248,090.01
LPG	3,906,714.00	37.80	268,027.93
Other Liquids	671,726.42	44.00	8,411,300.00
Lubricants	1,479,860.00	44.60	119,793.19
Kerosene	102,060.00	43.50	8,057.89
Bituminous Coal	17,415,810.00	56.00	1,770,142.93
Asphalt/Road Oil	21,613,452.00	45.50	1,784,892.90
Natural Gas	67,980,000.00	31.90	3,955,818.52
Total	**136,537,671.00**		**9,826,549.78**

Source: State Energy Data Report 1992

Table 1.1.5(a): Carbon Dioxide Emissions From Transportation Fossil Fuel Use (1997)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Gasoline*	226,015,578.00	42.80	13,799,814.40
Distillate Fuel	49,145,525.00	44.00	3,924,761.63
LPG	268,737.00	37.80	18,437.24
Lubricants	2,444,195.00	44.60	197,855.14
Aviation Gasoline	721,864.00	41.60	54,503.62
Jet Fuel	40,676,580.00	43.50	3,211,517.68
Natural Gas	12,360,000.00	31.90	719,239.73
Total	**331,632,479.00**		**21,926,129.44**

Note: Ethanol is subtracted from gasoline and is not included in total.

Table 1.1.5(b): Carbon Dioxide Emissions From Transportation Fossil Fuel Use (1990)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Gasoline	160,824,064.00	42.80	12,531,961.42
Distillate Fuel	41,794,375.00	44.00	3,337,698.79
LPG	300,825.00	37.80	20,638.70
Lubricants	2,498,780.00	44.60	202,273.74
Aviation Gasoline	843,016.00	41.60	63,651.08
Jet Fuel	34,638,030.00	43.50	2,734,759.06
Natural Gas	9,270,000.00	31.90	539,429.80
Ethanol	21,392,000.00	41.80	1,622,946.86
Total	**271,561,090.00**		**19,430,412.68**

Source: State Energy Data Report **Note:** Ethanol was subtracted from gasoline and the total.

Table 1.1.6(a): Carbon Dioxide Emissions From Utilities Fossil Fuel Use (1997)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Petroleum Coke	0.00	61.40	0.00
Kerosene	0.00	43.50	0.00
Other Oil	655,172.41	44.00	52,322.07
Bituminous Coal	408,901,240.00	56.00	41,560,722.03
Anthracite	0.00	62.10	0.00
Natural Gas	6,180,000.00	31.90	359,619.87
Total	**415,736,412.41**		**41,972,663.97**

Note: Biomass is no longer included in the greenhouse gas inventory. (EPA's *State Workbook Volume VIII*)

Table 1.1.6(b): Carbon Dioxide Emissions From Utilities Fossil Fuel Use (1990)

Type of Fuel	Fuel Consumption (MMBTU)	Carbon Coefficient	CO_2 Emissions (tons)
Petroleum Coke	0.00	61.40	0.00
Kerosene	0.00	43.50	0.00
Bituminous Coal	380,424,360.00	56.00	38,666,331.95
Anthracite	0.00	62.10	0.00
Natural Gas	5,150,000.00	31.90	299,683.22
Biomass	29,223.10	0.48	22.90
Total	**385,603,583.10**		**38,966,038.07**

Source: State Energy Data Report 1992

GRAND TOTAL(1997): 89,165,880.86 Short Tonsof CO_2**

GRAND TOTAL(1990): 78,720,580.81 Short Tons **of CO_2

**** Total number revised 5/30/96 after adding ethanol data to transportation tables - Phyllis Breeze (APCD - P&P)**
****The total number revised July 2000 by subtracting ethanol data - Matthew Jacobson (APCD - P&P)**

Forecast (1990)
Energy forecasts were obtained from the Department of Energy, Energy Information Administration's publication Annual Energy Outlook 1995. The percentage increases for each fossil fuel category were extrapolated from national averages, based on population, and are not Colorado-specific. The results of the forecast were calculated in the same manner as was the base year 1990, and are summarized in *Table 1.1.7.* Overall carbon dioxide emissions from fossil fuel and energy use were forecasted to grow by 86% by 2015.

Table 1.1.7: Forecast for Carbon Dioxide Emissions From Fossil Fuel Use Through 2015

Sector/Fuel	Energy Consumption (million BTU)	CO_2 Emissions (tons)
RESIDENTIAL		
Distillate Fuel	193,844.35	15,480.41
LPG	8,389,219.08	575,559.15
Kerosene	153,742.05	12,138.32
Bituminous Coal	588,888.50	59,854.63
Natural Gas	116,791,700.00	6,796,216.08
Biomass	1,984,168.84	1,555.09
Total		**7,460,803.68**
COMMERCIAL		
Gasoline	1,785,778.36	138,722.83
Distillate Fuel	3,290,344.45	262,766.91
LPG	1,550,199.36	106,354.53
Kerosene	73,290.42	5,786.46
Bituminous Coal	1,173,452.91	119,269.75
Anthracite	0.00	0.00
Natural Gas	87,870,948.00	5,113,291.01
Total		**5,746,191.50**
INDUSTRIAL		
Kerosene	135,099.09	10,666.41
Distillate Fuel	20,687,411.78	1,652,096.70
LPG	5,171,318.12	354,788.62
Other Liquids	11,134,038.98	889,164.35
Bituminous Coal	23,053,300.53	2,343,137.47
Lubricants	1,958,891.90	158,570.34
Asphalt and Road Oil	28,609,727.08	2,362,662.79
Natural Gas	89,985,126.00	5,236,316.97
Total		**13,007,403.65**
TRANSPORTATION		
Gasoline	252,915,896.83	19,647,012.70

Distillate Fuel	58,010,592.50	4,632,725.92
LPG	417,545.10	28,646.52
Aviation Gasoline	1,170,106.21	88,347.70
Jet Fuel	48,077,585.64	3,795,845.58
Lubricants	3,468,306.64	280,755.95
Natural Gas	12,866,760.00	748,728.56
Ethanol	86,955,424.00	6,597,047.15
Total		**35,819,110.08**
UTILITIES		
Bituminous Coal	540,659,105.21	54,952,591.45
Natural Gas	7,319,180.00	425,909.79
	41,531.16	32.55
Total		**55,378,533.80**
TOTAL PROJECTED TONS OF CO_2 EMISSIONS FROM 2015:		**117,412,042.71**

Source: State Energy Data Report 1992/EIA State Energy Outlook 1995 *figure is extrapolated from US EPA figures.

Other Greenhouse Gas Emissions From Fossil Fuel Combustion

Other greenhouse gas emissions from fossil fuel emissions calculated in 1997 were methane and nitrous oxide. The emissions of nitrous oxide (N_2O) and methane (CH_4) result from the incomplete combustion of transportation fuel, which is composed of hydrocarbons (HC). The amount of N_2O and CH_4 emitted from vehicles is dependent on the composition of the fuel, combustion conditions, and the control technology of the vehicle. In 1995 the amount of CH_4 emitted from mobile sources was 2,258.30 Mg (MTCE of 12,933.89) and the amount of N_2O emitted was 1,983.78 Mg (MTCE of 687,175.24). The reason for the larger MTCE of N_2O is due to the higher GWP of N_2O, which has a GWP of 310 compared to the 21 GWP of CH_4. Emissions of both CH_4 and N_2O from mobile sources were not estimated in 1990, although more Vehicle Miles Traveled (VMT) were reported 1995, thus more emissions would have occurred. To prevent higher emissions, there are more stringent emission tests and better emission control technologies. *Tables 1.1.8 and 1.1.9* present methane and nitrous oxide emissions in 1997 for stationary and mobile source combustion.

In addition to carbon dioxide, other greenhouse gases are released during fossil fuel combustion, including nitrogen oxides, ammonia, and non-methane volatile organic compounds. These gases are presented in this inventory for informational purposes and are not counted toward the overall inventory numbers. The data represent general estimates of non-carbon dioxide emissions from fossil fuel combustion. Most emissions from the residential and commercial sectors are from the consumption of natural gas. In the industrial sector, the majority are emitted during the combustion of coal. The nitrogen oxides from the transportation sector are from on-road mobile source emissions. *Table 1.1.10* presents emissions of volatile organic compounds, nitrogen oxides, and ammonia from fossil fuel combustion by sector.

Table 1.1.8: 1997 Methane and Nitrous Oxide Emissions from Mobile Combustion

Vehicle Type	Vehicle Kilometers Traveled (VMT) (10^6 miles)	CH_4 Emissions (Mg)	N_2O Emissions (Mg)	MTCE CH_4	MTCE N_2O
LDGV	15,371.42	1,243.00	974.90	7,119.00	601,879.09
LDGT	6,192.44	846.91	697.45	4,850.48	58,966.23
HDGV	738.33	96.29	121.16	551.48	10,243.53
LDDV	95.27	1.53	1.53	8.76	129.35
LDDT	47.63	1.53	0.77	8.76	65.10
HDDV	1,405.21	67.83	135.66	388.48	11,469.44
MC	166.72	1.21	52.31	6.93	4,422.5
Total	**24,017.02**	**2,258.30**	**1,983.78**	**12,933.89**	**687,175.24**

Source: Colorado Bureau of Transportation Statistics <www.colorado.edu/libraries/govpubs/colonumb/colotraffic.htm>

Table 1.1.9: 1997 Nitrous Oxide Emissions from Stationary Combustion

Type of Fuel	Fuel Consumption (10^{12} Btu)	Emission Factor (lbs/10^6 Btu)	Emissions (metric tons of N_2O)	MTCE
Coal	355.90	0.0032	516.50	43,667.72
Petroleum	78.70	0.0014	49.97	4,224.74
Natural Gas	297.00	0.0002	26.94	2,277.65
Total	**731.60**		**593.41**	**50,170.11**

Table 1.1.10: Other Greenhouse Gases From Fossil Fuel Consumption (1990)

Sector	Tons/year		
	Nitrogen Oxides	Volatile Organic Compounds	Ammonia
Utility Coal Combustion	4,092.00		3.65
Industrial and Commercial Fuel Combustion	63,054.00		113.15
Residential Fuel Combustion	5,887.00		25.50
Solvent Use	7.30		
Mobile Sources	142,302.00		76.65
Prescribed Burning	514.65		1,208.15
Natural Sources		345,874.00	
Miscellaneous	839.50		29.20
Unspecified Sources			33,528.90

Source: Taken from Development of an Emissions Inventory for Assessing Visual Air Quality in the Western United States, 1994

SECTION II

Methane Emissions from Natural Gas and Oil Systems

In 1998, emissions from oil and gas systems accounted for 15.4% of the state's methane emissions at an estimated 89,641.85 short tons median emissions. The national emissions increased to 7,672,522 short tons of methane in 1998 from 683,572 short tons of methane in 1990. This is the reason for the decrease in Colorado's proportion of national emissions, decreasing from 12% in 1990 to 1.2% of the total national emissions in 1998.

The emissions of methane from gas and oil systems have increased since 1990 due mainly to a dramatic rise in gas production, with a gas production increase of approximately 437 MMBTU over eight years. However, oil production has decreased since 1990, but the emission factor of oil production is much less than that of gas production thus less of a factor in methane emissions from oil and gas systems. Emission factors have been reduced slightly since 1990, possibly due to better technologies to prevent venting from oil and natural gas systems.

Emissions of methane from oil and gas systems in Colorado accounted for 9% of the state's methane emissions budget in 1990, at an estimated median range of 47,294.80 tons of methane. Considerable uncertainty surrounds these estimates due to a general lack of comprehensive emissions data. The total budget for the nation for 1990 was estimated to be between 110,253.5 and 683,572.22 short tons. Colorado's emissions accounted for about 12% of the nation's figure.

Emissions from natural gas and oil systems are primarily methane, although smaller quantities of non-methane volatile organic carbon, carbon dioxide and carbon monoxide are also emitted. For the purposes of this inventory, the terms natural gas or gas are used to refer to both natural gas (extracted from the ground) and the "synthetic", or "substitute" natural gas (comprised mostly of methane) produced from other petroleum-based products or sources. Depending on its origin and how it is processed, commercially distributed natural gas also will include various amounts of non-methane hydrocarbons (e.g., ethane, butane, propane, and pentane), carbon monoxide, carbon dioxide, and nitrogen. Oil is used to refer to both oil extracted directly from the ground and various other synthetic processes such as oil shale or tar sands.

The information needed to estimate emissions from natural gas and oil systems is based on production by sector. The required data include: the amount of oil produced, refined, transported and stored at oil facilities, and the amount of natural gas produced, processed and distributed to consumers. Data for the amount of natural gas and oil produced and gas consumed are available from the Colorado Oil and Gas Commission's Production department. Consumption data for gas is also available from the State of Colorado Oil and Gas Commission.

The following tables summarize what segment of the oil and gas systems are considered major sources of methane (*Table 1.2.1*). *Table 1.2.2a and 1.2.2b* describe the calculation used to determine methane emissions from these sources, and total methane emissions for 1990 and 1998 respectively.

Table 1.2.1: Emissions Sources From Natural Gas Systems

Segment	Major Emissions Sources	Other Potential Emission Sources
Oil and Gas Production - Oil and Gas Wells - Gathering Lines - Treatment Facilities	 - Venting - Normal operation: fugitive emissions; deliberate releases from pneumatic devices and process vents.	 - Combustion in gas turbines - IC engines - Routine maintenance - System upsets and accidents
Natural Gas Processing, Transportation and Distribution - Gas Plants - Underground Storage - Reservoirs - Transmission Pipelines - Distribution Pipelines	- Normal operations: fugitive emissions, deliberate releases from pneumatic devices and process vents	- Combustion in gas turbines - IC engines, - Routine maintenance ***source**: State's Workbook

Table 1.2.2(a): **Emissions of Methane from Oil and Gas Systems (1998)**

Sector	MMBtu	Emissions (tons methane)		
Oil and Gas Production		**Low**	**High**	**Median**
Oil Production	130,344,792.00	45.62	755.99	404.06
Gas Production	704,552,072.00	37,658.31	68,764.28	53,193.68
Oil and Gas Venting and Flaring				
Oil Venting and Flaring	130,344,792.00	228.10	1062.31	645.21
Gas Venting and Flaring	704,552,072.00	1,232.97	5,742.10	3,487.53
Oil Transportation, Refining, and Storage		Data for this sector are unavailable.		
Natural Gas Processing, Transport, and Distribution				
Gas Process, Transport, and Distribution	312,163,000.00	20,665.19	42,797.54	31,731.37
Totals		**59,830.19**	**119,122.22**	**89,461.85**

Source: State of Colorado Oil and Gas Commission

Table 1.2.2(b): Emissions of Methane from Gas and Oil Systems (1990)

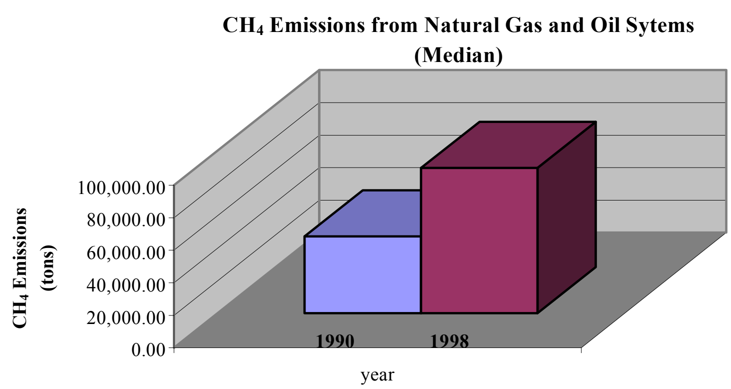
Sector	MMBtu	Emissions (tons methane)		
Oil and Gas Production		**Low**	**High**	**Median**
Oil Production	164,598,200.00	57.60	954.67	510.25
Gas Production	270,691,000.00	14,468.43	26,419.44	20,437.17
Oil Venting (Oil Produced)	164,598,200.00	288.05	1,341.47	814.76
Gas Venting (Gas Produced)	270,691,000.00	473.71	2,206.13	1,339.92
Oil Transportation, Refining, and Storage		Data for this sector is unavailable.		
Natural Gas Processing, Transport and Distribution				
Gas Consumption	238,000,000.00	15,755.60	32,629.80	24,192.70
TOTALS:		**31,043.39**	**63,551.51**	**47,294.80**

Source: State of Colorado Oil and Gas Commission

***assumes: 1,000 Btu = 1 cf**

***1 thousand cubic feet = 1.0 million Btu (MMBtu)**

Figure 1.2.1: Comparison of Natural Gas and Oil System Emissions, 1990 and 1998



Forecast (1990)

Methane emissions from gas and oil systems were estimated to grow from the 1990 level of 51,034 tons to 63,037 tons by 2015. This is almost a 24% change over the 25-year period. An increase of 89% percent between 1990 and 1998 indicates a much more significant increase than expected.

SECTION III
Methane Emissions from Coal Mining

According to the EPA, the amount of methane emitted from coal mines throughout the U.S. has steadily decreased from 24.0 MMTCE in 1990 to 18.8 MMTCE in 1997, amounting to a 27.6% decrease. The opposite trend is true for Colorado, which has had a 78% increase in methane emissions. Colorado coal mine methane emissions amounted to approximately 5% of the national total in 1999. Colorado's coal production was 2.7% of national coal production as reported by the Energy Information Administration (EIA). In contradiction to what was found, the 1990 inventory noted that Colorado coal mine methane emissions tend to be lower than most states due to the fact that the Rocky Mountain region's coal mines are relatively less gassy than coal mines found in the Appalachian region or other regions. As noted before, the amount of methane recovered was not determined and could play a factor in determining the percent of

Colorado's coal mine emissions.

In 1998, the number of active underground and surface coal mines has decreased and the coal production has increased. More coal production from less mines equals more production per mine and more methane emitted from each mine. In fact, the methane emitted from coal mines has increased since 1990. Also, the portion of methane emitted by underground mines has increased since 1990, emitting 80% of total emissions from coal mines. It should be noted that in 1990 an emissions coefficient was used to calculate the emissions from underground mines, however in 1999 actual emissions were obtained by daily averages of each mine. It was undetermined if any underground mines recovered methane liberated from the mining of coal.

In 1990, Colorado's annual production averaged about 19 million tons. Approximately 60% of this figure was mined from underground sources. While not as gassy as Appalachian or Warrior Basin mines, Rocky Mountain mines produce a significant amount of methane. Currently, methane is not recovered from any underground mining operation in Colorado. The State's total methane production accounted for 102,947 short tons. This figure represents 24% of Colorado's methane budget. The nation as a whole emitted 28 million short tons of methane from coal mining. Colorado's contribution of methane from coal mining amounts to less than 1% of this total. *Table 1.3.2a and 1.3.2b* present the calculations for methane emissions by mine type in 1999 and 1990 respectively.

Table 1.3.1(a): Underground Coal Mine Production (1999)

Name of Mine	County	Short Tons
Bowie # 2 Mine	Delta	1,748,007
Deserado	Rio Blanco	1,336,659
Foidel Creek Mine	Routt	8,555,948
King Coal Mine	La Plata	245,719
Roadside South Portal	Mesa	284,540
Sanborn Creek Mine	Gunnison	962,226
Southfield	Fremont	242,917
West Elk Mine	Gunnison	7,094,972
Total		**20,470,268**

Table 1.3.1(b): Underground Coal Mine Production (1990)

Name of mine	County	Short tons
Orchard Valley Mine	Delta	600,952
Southfield	Fremont	302,165
Twin Pines #2	Fremont	29,201
McLean Canyon	Garfield	196,803
O.C. Mine #2	Gunnison	4,784
Bear #3	Gunnison	385,853
Mt. Gunnison	Gunnison	559,251
King Coal Mine	La Palata	165,516
Golden Eagle	Las Animas	1,551,193
Raton Creek	Las Animas	20,929
Roadside	Mesa	183,212
Eagle Mine #5	Moffat	2,245,810
Coal Basin	Pipkin	477,927
Desperado	Rio Banco	1,498,739
Fidel Creek Mine	Routt	2,720,096
Total		**10,942,431**

Source: Colorado Dept. of Natural Resources, Division of Minerals and Geology.

Table 1.3.2(a): Surface Coal Mine Production (1999)

Name of Mine	County	Short Tons
Colowyo Coal Mine	Moffat	5,569,385
New Horizon Mine	Montrose	359,405
Seneca Strip	Routt	1,363,463
Trapper Strip	Moffat	2,219,053
Total		**9,511,306**

Table 1.3.2(b): Surface Coal Mine Production (1990)

Name of Mine	County	Short Tons
Mary Strip	Jackson	61,145
Colowyo Coal Co.	Moffat	4,085,500
Trapper Strip	Moffat	2,336,690
Seneca Coal	Routt	1,454,928
Edna Mine	Routt	239,748
Total		**8,178,011**

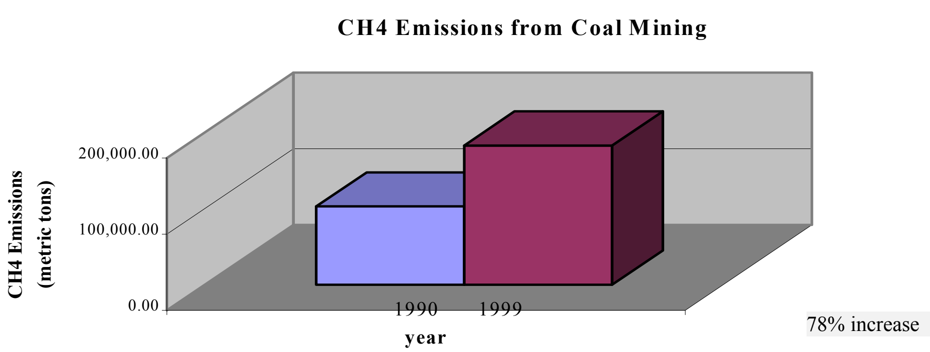
Table 1.3.3(a): Methane Emissions from Coal Mines (1999)

Type of Mine	Coal Production (short tons)	Emissions Coefficient (cf/ton)	Methane Emitted		
			cubic feet	short tons	MTCE
Underground	20,470,268.00	NA	7,686,452,145.00	147,579.88	845,230.23
Surface	9,511,306.00	30.60	291,045,963.60	5,588.08	32,004.46
Underground (post-mining)	20,470,268.00	73.40	1,502,517,671.00	28,848.34	165,222.30
Surface (post-mining)	9,511,306.00	5.00	47,556,530.00	913.08	5,229.49
Total	**29,981,574.00**		**9,527,572,310.60**	**182,929.38**	**1,047,686.48**

Table 1.3.3(b): Methane Emissions From Coal Mines (1990)

Type of Mine	Coal Production (short tons)	Emissions Coeffecient (cf/ton)	Methane Emitted		
			cubic feet	short tons	MTCE
Underground	10,942,431.00	390.00	4,267,548,090.00	81,936.92	469,275.09
Surface	8,178,011.00	30.60	250,247,136.60	4,804.74	27,518.06
Underground (post-mining)	10,942,431.00	73.40	803,174,435.40	15,420.95	88,319.99
Surface (post-mining)	8,178,011.00	5.00	40,890,055.00	785.09	4,496.42
Total	**19,120,442.00**		**5,361,859,717.00**	**102,947.70**	**589,609.56**

Figure 1.3.1: Comparison of Methane Emissions from Coal Mining, 1990 and 1999



Forecast (1990)

Coal mining grew by 13% between 1990 and 1992 and was expected to grow by 34% between 1990 and 2015. A more dramatic increase than what was expected was observed between 1990 and 1999 (increasing 77.7%).

PART II

EMISSIONS FROM PRODUCTION PROCESSES AND AREA SOURCES

Overview

Part II of the inventory presents emissions data from production processes and area sources. Some production processes release emissions as a by-product of the process itself or directly from the production process. For example, in the industrial sector, raw materials are chemically transformed from one state to another. This transformation often results in the release of greenhouse gases such as carbon dioxide, nitrous oxide, hydrofluorocarbons, and perfluorinated carbons. The production processes addressed in this section include:

- **Section I**: Carbon Dioxide Emissions from Cement Production and Other Production Processes
- **Section II**: Ozone Depleting Compounds (ODC) Emissions from Air Conditioning and Refrigeration Processes
- **Section III**: Methane Emissions from Landfills
- **Section IV**: Methane Emissions from Municipal Wastewater

Data

Calculating emissions from production processes varies by the process. For example, in **Section I**, calculating carbon dioxide emissions from cement production requires annual clinker and masonry cement production data. This data is considered to be proprietary information by the industry and cannot be obtained through federal or state agencies. Enough information was gathered through state commodity records to derive adequate inventory data. The Colorado Department of Natural Resources, Division of Minerals and Geology supply other data, such as lime manufacturing. Limestone and dolomite data is from the Federal Bureau of Mines Annual Report, titled "Crushed Stone, 1990".

Section II presents data on ozone depleting compound emissions from air conditioning and refrigeration processes. Present and future data is based on surveys from refrigerant suppliers who sell ODC refrigerants for existing, and new air conditioning and refrigeration equipment.

In **Section III**, emissions data from landfills are provided. Estimates of actual waste in place in Colorado landfills are not readily available, so the estimates were based on past and present state population numbers. In the final section of **Part II**, wastewater treatment systems are analyzed and methane estimates calculated. Informational needs for this calculation include: pounds of biochemical oxygen demand (BOD) generated per capita; state population data; the fraction of total methane undergoing anaerobic treatment, and; the amount of methane currently being recovered by wastewater treatment facilities. The information on biochemical oxygen demand comes from the Wastewater Treatment Division of the Colorado Department of Public Health and Environment. Demographic data was obtained from the State Demographers office and methane recovery information was obtained directly from municipalities via a telephone survey. The 1998 population estimates were obtained from the U.S. Census Bureau.

Methodology

The emission methodologies used for **Sections I, III and IV** comes directly from the *State's Workbook*. In **Section I** various methodologies were used to determine carbon dioxide emissions from production processes. For cement production processes, carbon dioxide emissions is calculated as follows:

Total CO_2 Emissions = Total Clinker Production (tons) 0.507 (tons CO_2/ton of clinker)*

Total CO_2 Emissions = Total Masonry Cement Production (tons) 0.0224 (tons CO_2/ton of masonry cement)*

For lime manufacturing, the following calculation was used:

*Total CO_2 Emissions (tons) = Total Lime Production (tons) * 0.785 (tons CO_2/ton of lime produced) - (amount CO_2 recovered)*

The methodology used for limestone and dolomite production is as follows:

*Total CO_2 Emissions (tons) = Crushed Stone Used (tons) * 0.12 tons C/tons Stone * 44/12 (CO_2 equivalent)*

Data for CFC emissions in 1998 were based on national emissions reported by the EPA. In Section II, the methodology for determining present and future data on ozone depleting compound emissions will be limited to emissions from air conditioning and refrigerant sources utilizing ODC refrigerants. Those sources include stationary air conditioning and refrigeration equipment, and motor vehicle air conditioning sources. Previous inventories have examined numerous sources of ODC emissions, however; with the exception of air conditioning and refrigeration usage, most significant usage has been replaced by non-ODC chemicals by 2000.

Surveys will be developed in order to contact all major refrigerant suppliers to the State of Colorado. Annual refrigerant sales will be monitored and tracked, and utilized as the basis for estimating ODC emissions from air conditioning and refrigeration sources. An analysis will be made on the number of new air conditioning and refrigeration units sold, compared to the number of existing units. By comparing new air conditioning and refrigeration equipment sales to the existing units in operation and their respective refrigerant operating charges, an assumption can be made that the remaining portion of refrigerant sales represent existing equipment usage.

In **Section III**, methane emissions from landfill were calculated as recommended in EPA's State Workbook. The general steps applied include:

1) Obtain required data (estimates of total waste in place in landfills in the state: such data was unavailable for the state of Colorado, so the amount was estimated based on current state population and past annual population growth rates): 2) Estimate waste in place at MSW Landfills, 3) estimate fraction of waste in place at Large versus Small MSW landfills, (86 % to 14%) 4) Classify state as arid or non-arid based on annual rainfall (Colorado is clearly classified as an arid state –0.27), 4) estimate methane generated from waste in place at small MSW landfills, 5) estimate methane generated from waste in place at large MSW landfills; methane generated at large landfills used an equation from Vol. VIII different than that from Vol. I or II, which was applied to both years of the inventory - 1990 and 1998, 6) estimate methane generated from Industrial landfills, 7) adjust for flaring and recovery, and 8) adjust for oxidation.

*Methane generated at small landfills = WIP * 0.27* CH_4 *generation rate * 0.0077 conversion to tons * Oxidation factor*

Methane generated at large landfills = N * (417,957 + 0.16 W_{avg} (tons))

N = # of large landfills

W_{avg} *= WIP / N*

*Methane generated at industrial landfills = 0.07 * (Methane generated at small and large MSW landfills)*

A possibly more accurate methane emission estimate than what is presented in this inventory was provided by EPA's Landfill to Methane Outreach Program (LMOP) that did a study on the possibility to collect methane from landfills and use it for energy.

Section IV presents estimated emission data from wastewater treatment facilities. To estimate methane emissions from municipal wastewater, the following steps are required: 1) obtain the required data on state population, 2) estimate BOD, 3) estimate gross annual methane emissions, and 4) estimate net annual methane emissions. Corrections have been made to the 1990 data for the fraction of wastewater treated anaerobically for comparison with 1998 data. The following simplified equation has been used for estimating methane emissions from wastewater treatment:

*Net Methane Emissions = Methane Emissions - (15 % * Methane Emissions)*

*Methane Emissions = Pop. * BOD Generation Rate (0.18 lbs/capita/day) * FRACTION OF WASTEWATER TREATED ANAEROBICALLY* (15%) ** Methane Emission Factor (0.22 lbs. methane/ lbs. BOD)*

*Methane Recovered = 15 % * Methane Emissions*

SECTION I

Greenhouse Gas Emissions From Production Processes

Greenhouse gases are by-products of various production processes. Emissions are produced directly from the process itself and are not a result of the energy that may be consumed during the process. Carbon dioxide emitted during the production of cement processing, for example, is a major non-energy source of industrial carbon dioxide emissions. A number of other production processes also emit carbon dioxide as well as other greenhouse gases. *Table 2.1.1 (a) and (b)* summarize carbon dioxide emissions estimated from production processes in Colorado in 1998 and 1990. Brief descriptions of each process are provided after the tables. The comparison of 1990 data with 1999 was determined to be incompatible due to inconsistent data, which can possibly be attributed to inconsistent data sources. No comparison between 1990 and 1998 should be drawn.

Table 2.1.1(a): Carbon Dioxide Emissions from Production Processes (1997-1999)

	Tons	**Emission factor**	**Tons CO_2**
CO_2 from Cement Manufacture (1999)			
masonry	248,980	0.0224	5,577.15
clinker	1,721,056.00	0.507	872,575.40
CO_2 From Lime Manufacture (1998)			
	37,195.20	0.785	35,761.11
CO_2 From Limestone Usage (1997)		**Tons C / Ton limestone**	*** 44 CO_2 / 12 C**
	1,623,888.00	0.12	714,510.72
Total (tons)			**1,628,424.38**

Sources: - various cement producers throughout CO and Airs Facility Subsystem Quick Look Report (1999)

- United States Geologic Survey (USGS) *State Mineral Data Report* (1998) <www..us.gs.gov>

Table 2.1.1(b): Carbon Dioxide Emissions from Production Processes (1990)

	Tons	Emission factor	Tons CO_2
CO_2 from Cement Manufacture			
masonry	800,000.00	0.0224	17,920.00
clinker	1,704,000.00	0.507	863,928.00
CO_2 From Lime Manufacture			
	36,900.00	0.785	28,966.50
CO_2 From Limestone Usage		**Tons C / Ton limestone**	**$* 44\ CO_2 / 12\ C$**
	3,108.05	0.12	1,367.54
Total (tons)			**912,182.04**

Source: Colorado commodity records and Colorado Dept. of Natural Resources.

Note: The significant increase in total emissions due mainly from increased limestone usage.

Carbon Dioxide Emissions from Cement Production

Carbon dioxide emitted during the production of cement is believed to represent the most significant non-energy-related source of industrial carbon dioxide emissions. Cement is produced in most states, and is used in every state.

In 1999, carbon dioxide emissions from cement manufacture declined slightly since 1990 from 881,848 tons to 878,452 tons. The percent of production process carbon dioxide emissions from cement production declined to 54%, while the percent of emissions from limestone usage increased to 43.8% of the total emissions from production processes. The U.S. emissions of carbon dioxide from cement manufacture in 1999 were approximately 43,246,619 short tons, attributing Colorado to 2.0% of national emissions. Carbon dioxide emissions from cement production for the base year 1990 were 881,848 tons, accounting for 96.7% of carbon dioxide emissions from production processes in 1990. Furthermore, the nation's total carbon dioxide emissions from this source were 36,052,900 short tons in 1990. In 1990, Colorado's carbon dioxide emissions from this source accounted for 2.5% of the nation's total.

Carbon Dioxide Emissions from Lime Manufacturing

Lime is a manufactured product with many chemical, industrial and environmental uses. In 1990, lime ranked fifth in total production of all chemicals in the United States. In Colorado, 37,195 tons of lime was manufactured in 1998 compared to 36,900 tons in 1990. Lime's major uses are in steel making, construction, pulp and paper manufacturing, and in water and sewage treatment. Lime is manufactured by heating limestone (mostly calcium carbonate--$CaCO_3$) in a kiln, creating quicklime (CaO) and carbon dioxide. The carbon dioxide is quickly driven off as a gas and usually exits the stack into the atmosphere. In 1998, lime production activities statewide emitted 35,761 tons of carbon dioxide increasing from 1990 levels of 28,966 tons, accounting for 2.19% in 1998 and 3.17% in 1990 of carbon dioxide from production processes. No carbon dioxide recovery operations were identified in the state to recover the gas from this specific process. This figure amounts to less than one percent of the carbon dioxide emitted from this particular process nationwide.

Carbon Dioxide Emissions from Limestone and Dolomite Use

Limestone is a basic raw material used by a wide variety of industries, including construction, agriculture, chemical and metallurgical industries. When limestone is heated during the process, carbon dioxide is driven off as a by-product.

Carbon dioxide emissions from crushed carbonate rock usage in the state were calculated as 714,510 tons in 1997 and when compared to the 1990 emissions of 1,367 tons it is indicative of a dramatic increase in limestone usage. This increase (and related carbon dioxide emissions) can be attributed to change, or it can be attributed to inconsistent data and data source. In 1997, the national carbon dioxide emissions amounted to 10 million tons, attributing Colorado to 7.1% of national emissions. In 1990, Colorado emissions accounted for less than 1% of national emissions. The 1990 figure accounted for less than one percent of Colorado carbon dioxide emissions from production processes in 1990, increasing to 43.8% of emissions from production processes in 1997.

Emissions From Other Production Processes

Other industrial processes in Colorado may emit greenhouse gases, but due to the lack of agreed-upon methodology to estimate their magnitude, they are not included in this inventory. Examples of these processes and related greenhouse gas emissions are summarized in *Table 2.1.2*.

Table 2.1.2: Other Emissions from Production Processes

Process	NO_x	NMVOC	CH_4	CO	CO_2	N_2O
Agricultural Liming					X	
Ferro-Alloy Production					X	
Silicum Carbide Production					X	
Coke Production				X	X	
Nitrogen Fertilizer Production	X					
Petroleum Product Processing	X	X	X	X	X	X
Sulphur Recovery Plants						
Colliery Coke Production		X	X			
Metallurgical Coke Production		X	X			
Sulfuric Acid Production						
Ammonia Production		X	X			
Sodium Carbonate						
Urea Production						
Titanium Dioxide						
Ethylene Production	X					
Propylene Production		X				
1,2 Dichlorothane Production		X				
Vinylchloride Production		X				
Polyethylene Low Density Production		X				

Polyvinylchoride Production		X				
Polypropylene Production		X				
Styrene Butadiene		X				
ABS Resins		X				
Ethylene Oxide		X				
Formaldehyde Production		X				
Ethylbenzene Production		X				
Styrene Butadiene Latex		X				
Styrene Butadiene Rubber		X				
Phthalic Anhydride Production		X				
Acrylonitrile Production		X			X	
Chipboard Production		X				
Paper Pulp Production		X				
Bread Production					X	
Wine Production		X			X	
Beer Production		X			X	
Spirits Production		X			X	
Paint Applications: Wood Products		X				
Paint Applications: Construction and Buildings		X				
Paint Applications: Vehicles Refinishing		X				
Paint Applications: Domestic Use		X				
Metal Degreasing		X				
Dry Cleaning		X				
Polymers Processing		X				
Elastomers Processing		X				
Rubber Processing			X			
Plastics Processing		X				
Pharmaceutical Processing		X				
Paints Processing		X				
Inks Processing		X				
Glues Processing		X				
Printing Industry (solvent use only)		X				
Domestic Solvent Use		X				

*taken from the State's Workbook

Forecast
In the original forecast no change was expected in greenhouse gas emissions from production processes from 1990-2015, but an increase of 78.5% was observed between 1990~2000.

SECTION II
Ozone Depleting Compounds

Ozone Depleting Compounds such as Chlorofluorocarbons (CFCs) and other halocarbons are extremely potent greenhouse gases because of the high GWP attributed to the substances. CFCs are man-made gases, i.e. none exist naturally. In the U.S., CFCs have been used since the 1920s in various industrial processes. They are generally colorless, odorless, and non-toxic. In addition, the chlorine atoms of these molecules are non-reactive and non-volatile, remaining in the atmosphere for 50 to 100 years before being destroyed in reactions catalyzed by the sunlight. CFCs molecules are composed of carbon, fluorine, and chlorine.

Often there is lag time between the production of CFCs and their escape into the atmosphere. Some halocarbons, such as those used as aerosols, coolants, and fire retardants, may not be released for decades.

Thus, regulated production phase-out of these substances (as was done in 1987 at the Montreal Protocol which now incorporates 175 nations) will not prove to be immediately effective.

Data to support the inventory of ODCs emitted in Colorado will be supplied to the GHG Inventory as they become available. Surveys are currently being developed in order to determine current refrigerant sales.

Forecast (1990)
The production and consumption of CFCs are regulated under an international agreement known as the Montreal Protocol of 1987 and in the U.S. under the Clean Air Act of 1990. Class I Ozone Depleting Substances (ODSs) were to be phased-out Jan. 1, 1996 and Jan. 1, 1994 for halons. Emissions in 2015 were expected to be from reserves existing in systems that used Class I ODSs before the phase-out on production and distribution.

SECTION III
Methane Emissions from Landfills

The total amount of methane generated from landfills in the state has increased by approximately 20,000 tons in the past 8 years. Landfill gas recovery and energy conversion programs used by two landfills in the state have reduced the amount emitted in 1998. Other proposed Landfill Gas-to-Energy (LFGTE) projects are being considered under EPA's Landfill Methane Outreach Program (LMOP). Table 2.3.2 is an estimate by LMOP of potential methane recovery and energy savings from the combustion of methane for electrical generation. LMOP estimates that the current amount of methane recovered is 6,938 tons/year.

Landfill gas emissions represent one of the major anthropogenic sources of methane emissions both in the United States and internationally. Organic landfill material such as yard waste, household garbage, food waste and paper can decompose and produce methane. This decomposition process is a natural mechanism through which microorganisms derive energy for their growth. Methane production typically begins one or two years after waste is placed in a landfill and may occur over the next 10 to 60 years.

Most of the landfill gas is emitted directly into the atmosphere. At some landfills, the gas is captured and either flared or used as an energy source. It was reported in 1990 that Colorado has 114 active landfills, and 83 closed landfills throughout the state (9 are major landfills with over 1.1 million tons of waste in place: the others are smaller). No data has been collected by the state that catalogues known methane recovery or flaring operations at Colorado landfills.

Large municipal solid waste facilities had an estimated 4,1054.62 tons of waste in place in 1990. Small landfills stored 6,683.31 tons. Industrial landfills are estimated to have 78,999.39 tons of waste in place. This makes Colorado's net emissions of methane from large, small, and industrial landfills 84,529.35 tons for the base year 1990: just less than one percent of the nation's total. The estimated range of U.S. emissions from methane from landfill is 8,100 to 11,800 thousand tons. Colorado's proportion of the emitted methane from landfill nationwide is less than one percent. *Table 2.3.1* provides the total methane emissions from small, large and industrial landfills in Colorado in 1990.

Table 2.3.1(a): Methane Emissions from Landfills (1998)

Type of Landfill	WIP (tons)	Methane Generation (tons/year)	MTCE
Small (MSW)	6,351,385.09	11,884.08	61,747.08
Large (MSW)	39,015,651.29	86,707.18	450,511.59
Industrial*		6,211.25	32,272.29
Total		**104,802.51**	**544,530.97**

Methane Generation = 104,802.51 tons= 544,530.97 MTCE
Methane Recovered = 6,938.00 tons
(1999)Methane Emitted = 97,864.51 tons = 508,482.64 MTCE

Table 2.3.1(b): MethaneEmissions from Landfills (1990)

Type of Landfill	WIP (tons)	Methane Generation (tons/year)	MTCE
Small Landfills	5,723,511.79	10,709.26	55,642.98
Large Landfills	35,107,115.29	65,051.96	337,995.79
Industrial Landfills		5,303.29	27,554.73
Total		**81,064.51**	**421,193.50**

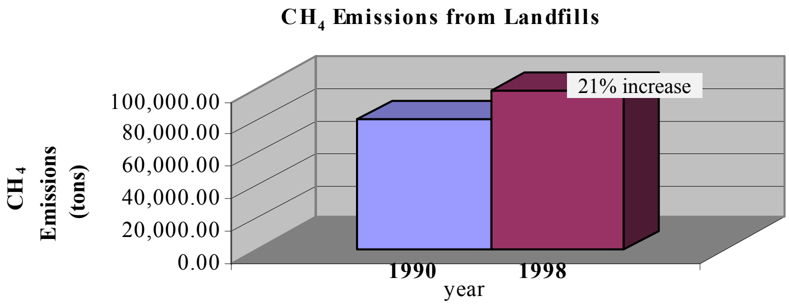
Table 2.3.2: Estimated Potential for Methane Recovery from Landfills (1998)

Category	No. of Landfills	Est. Capacity Potential		Est. CH_4 Generation (mmscf/d)	CH_4 Reduction Potential (tons/yr)	CO_2 Equivalent (tons/yr)
		Electricity (MW)	Gas Capacity (mmBtu/hr)			
Current	1	23	230	7	42,555	893,661
Candidate	9	70	696	22	128,797	2,704,735
Shutdown	1	5	54	2	10,053	211,105
Other	15	67	673	22	124,441	2,613,255
Unknown WIP	2					
Total	**28**	**165**	**1,653**		**305,846**	**6,422,756**

Source: EPA/LMOP – LFGTE

The amount of methane emitted from landfills in Colorado is greatly underestimated according to estimates by EPA/ LMOP. Although the figures are obscured between methane emissions calculated from *EIIP Vol.VIII* and the figures from the potential reduction produced by the EPA/LMOP due to the difficulty in estimating the amount of emissions, the idea is that landfill methane can be used for energy. According to Glenn Mallory of the Solid Waste Division of CDPHE, there are currently no solid waste incineration facilities operating in the state of Colorado, thus no emissions of carbon dioxide or nitrous oxide from waste incineration were assumed.

Figure 2.3.1: Comparison of Methane Emissions from Landfills, 1990 and 1998



Forecast (1990)

It was reported in 1990 that if current population trends continue, and if no appreciable increase occurs in the overall recycling trends, the amount of methane emissions expected from landfill in Colorado was expected to increase by 28% by 2015. Current population increases reflect this increase in methane emissions from landfills.

SECTION IV

Methane Emissions from Wastewater Treatment Systems

Disposal and treatment of industrial and municipal wastewater can produce methane. Wastewater can be treated using aerobic and/or anaerobic technologies, or if untreated, can degrade under either aerobic or anaerobic conditions. Methane is produced when organic material in treated and untreated wastewater degrades anaerobically (without the presence of oxygen). Highly organic wastewater streams such as waste streams from food processing or pulp and paper plants rapidly deplete available oxygen in the water stream as their organic matter decomposes. The organic content, otherwise known as the 'loading' of these wastewater streams, is measured in terms of biochemical oxygen demand, or BOD. BOD represents the amount of oxygen taken up by the organic matter in the wastewater during decomposition. Wastewater with relatively high BOD concentrations will produce more methane than wastewater with lower BOD concentrations. Most industrial wastewater has a low BOD content, while food processing facilities such as fruit, sugar, meat processing plants, and breweries can produce waste streams with high BOD content.

The BOD factor of 0.18 lbs/capita/day was obtained from the Colorado Department of Public Health and Environment. The EPA default value is 0.136 lbs/capita/day. The amount of methane emitted from wastewater treatment facilities has increased since 1990 as expected. The amount of methane emitted in 1990 did not take into account the fraction of BOD removed as sludge (15% removal - EPA default). The amount of methane recovered is assumed to be 15% of the total, however this can be misleading since it does not take into account the amount flared or the amount used for boilers. It should be noted that in an informal conversation with Jim Tallent from the Littleton/Englewood Wastewater Treatment Facility, there was indication that minimal amounts of methane (0.5% of total) are released from wastewater treatment facilities. Assuming the emission factor (0.22) takes into account these factors, the amount estimated is a reasonable indication of methane being released from wastewater treatment facilities. The minimal percent of methane from wastewater facilities leads to the assumption that methane is combusted or recovered for energy uses.

For the base year 1990, methane emissions from wastewater treatment totaled 3,571.29 tons. That figure represents 1.8% of the total methane budget. During the base year 1990, methane emissions from wastewater treatment for the nation as a whole totaled about 0.9 MMTCE. Methane from this source in Colorado represents about ½ percent of the nation's total. Methane produced from wastewater treatment in Colorado is summarized in *Table 2.4.1*.

Table 2.4.1: 1998 and 1990 Methane Emissions from Wastewater Treatment Systems

Type of Treatment	Population	BOD (lbs BOD/day)	Quantity of BOD treated anaerobically (lbs BOD/yr)	CH_4 Emissions (lbs)	CH_4 Recovered (lbs)	Net CH4 Emissions (tons)
Wastewater (1998)	4,056,133	730,103.94	39,973,190.72	**8,794,101.96**	**1,319,115.29**	**3,737.49**
Wastewater (1990)	3,294,394	592,990.92	32,466,252.87	**7,142,575.63**	**1,071,386.35**	**3,035.60**

Sources: State Demographers Office – population CDPHE Wastewater Treatment Division – BOD factor (0.18)

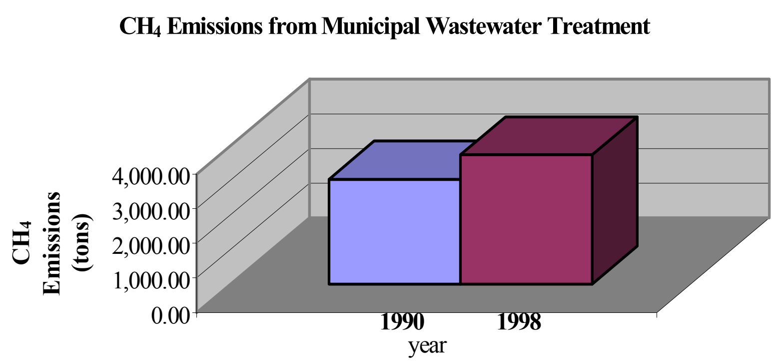


Figure 2.4.1: Comparison of Methane Emissions from Wastewater Treatment Systems, 1990 and 1998 Forecast (1990)

Methane emissions from wastewater treatment facilities were estimated to increase by 42.16% from 1990 to 2015. As with landfills, an increase in population is accompanied with an increase in methane emissions from wastewater treatment systems. This is apparent from the increase in population between 1990 and 1998.

PART III
EMISSIONS FROM AGRICULTURE AND LAND USE CHANGES

Overview

Part III of the inventory presents data on greenhouse gas emissions from agriculture, forests, and land use changes. Each section presents the following sector information:

Section I: Methane Emissions from Domestic Animals
Section II: Methane Emissions from Animal Manure Management Systems
Section III: Methane Emissions from Fertilizer Use
Section IV: Greenhouse Gas Emissions Due to Forest and Land Use Changes

In **Section I**, methane emissions from ruminant domestic animals (cud-chewing animals, e.g., cows, sheep, deer) are presented. In ruminant and non-ruminant herbivores, methane is produced as part of the digestive process. Although wild animals do emit methane, only animals managed by humans for the production of animal products, including meat, hides, fiber and draft power are included. In addition to the methane emitted directly from the digestive tracts of animals, animal waste (manure) also contributes to the overall methane budget. Emissions from animal wastes are considered in **Section II**.

In **Section III**, nitrous oxide is presented as a greenhouse gas, causing global warming and damaging stratospheric ozone. Nitrous oxide is naturally produced in soils by microbial processes, and in the absence of anthropogenic interference, remains in balance with nitrogen sinks. Commercial nitrogen fertilizers, however, provide an additional nitrogen source to soils, increasing emissions of nitrous oxide from soils.

Forests and land-use changes can alter the amount of bio-mass and produce a net change of greenhouse gas emissions between the atmosphere and land surfaces. An inventory of greenhouse gas emissions due to land-use changes in Colorado’s forest is presented in **Section IV**.

Data

In **Section I**, the amount of methane emitted from individual ruminant and non-ruminant animals is a result of the age or weight of the animal and the amount of feed energy that the animal consumes. This percentage can vary depending on the amount and type of feed consumed by the animal, and will often range from 4 to 9 percent of the gross energy consumed. The number of head for each type of animal determines the overall emissions. The population data for 1998 was obtained from Colorado Agriculture Statistics Service (1999) and the 1997 U.S. Census of Agriculture.

In **Section II**, animal population data and manure management system data were used to estimate methane emissions from animal manure for the Colorado inventory. The 1990 data on cattle, swine, and other hoofed animals and poultry was given by the Colorado Department of Agriculture and are estimated figures. The 1992 data is from agricultural census figures, which is taken every 5 years. The data for this section was also from the most recent CASS and the U.S. Census of Agriculture publications.

In **Section III**, emissions of nitrous oxide from fertilizer was calculated based on annual fertilizer consumption, by fertilizer type, for three consecutive years centered on the 1990 base year (1989-1991). This method was used to avoid distortion due to unusual annual variations from economic, climatic, or other variables. Colorado fertilizer consumption data was obtained from Steve Bornmann of the Colorado Department of Agriculture, in Denver, Colorado.

In **Section IV**, data sources for Colorado forest and land use changes were provided by the US Forest Service - Colorado State Forester, and the Natural Resources Conservation Service (formerly the US Soil Conservation Service). Dr. Dennis Lynch of Colorado State University provided the data compiled for 1999.

Methodology

In **Section I**, estimating methane emissions from domestic livestock animals requires two basic steps: 1) obtain data on animal populations (in number of head), and 2) multiply the animal populations by an appropriate emissions factor (which reflects the percentage of feed energy that is converted to methane by the animal and the total feed energy intake of the animal). The only emission factor change between the 1992 and 1998 versions of the workbook is for mature dairy cattle. The adjustments to the 1990 inventory have been made. The resulting figure is then divided by 2000 to obtain a figure in short tons of methane. The equation is as follows:

$$\textit{Tons } CH_4 = \frac{\textit{Animal Population * Emissions Factor (lbs methane/head)}}{2000}$$

In **Section II**, the following methodology was used to estimate methane emissions from manure management systems: 1) collect the data, 2) calculate the amount of volatile solids produced, from the number of animals and an average animal mass figure (provided by EPA), 3) estimate methane emissions from each of the manure management systems (again using averaged figures provided by EPA), and 4) converting the emitted methane figures from cubic feet to tons, and 5) summing the total methane emissions across all animal types and manure management systems. Both the typical animal mass and the annual pounds of volatile solids per pound of animal mass are animal-specific constants that are provided by EPA. The potential amount of methane produced by each type of domestic animal is calculated as follows:

$$\textit{Potential } CH_4 \textit{ Emissions} = \textit{number of animals} * \textit{typical animal mass (pounds/head)} * \textit{annual pounds of volatile solids per lb. of mass} * \textit{Maximum Potential Emissions (in } ft^3\ CH_4 \textit{ /lb-VS)}$$

In **Section III** the methodology for calculating nitrous oxide emissions from the application of fertilizers to agricultural soils is adopted from the 1992 version of the State's Workbook, and can be summarized as follows: 1) obtain the data, 2) calculate the average annual nitrogen consumption by fertilizer type, 3) estimate nitrous oxide emissions, 4) convert to units of N_2O by multiplying by 44/28.

Based on this methodology, the annual nitrogen consumption figures are used to calculate the amount of nitrogen released into the atmosphere as nitrous oxide. In the previous version of the inventory, an emissions coefficient of 1.17% was used to determine the potential emissions, however in the Vol. 8 of the *State's Workbook* an emission factor of 1.25% was used. Changes to the 3-year average have been made. The following formula is used for each fertilizer type to calculate the estimates for nitrogen emissions:

$$\textit{Tons } N_2O \textit{ Emissions} = \textit{tons N content} * \textit{(1.25\%) emissions coefficient} * 44/28$$

In **Section IV**, estimating greenhouse gas emissions and uptake of carbon due to forest and land use changes in Colorado is organized into 3 major sections: forest lands, woodlands and grasslands. The methodologies used for each of these sectors were based on the *State's Workbook*. Some of the land use changes that contribute to anthropogenic emissions and carbon uptake include forest conversion, logging, forest degradation or mortality, timber stand management, flooding of lands, wetland drainage and conversion of grasslands. For each of these land use activities, the following methodologies were used:

Commercial Harvest

An average emissions factor of .496 pounds of carbon per cubic foot of tree volume is used to estimate releases due to loss of forest biomass from commercial tree harvest. This figure is an average value for Colorado forest trees. Accordingly, the above ground carbon released as a result of loss of forest biomass in Colorado is estimated by multiplying the net lost biomass (an estimated 770,100,000 cubic feet) by 0.496 pounds of carbon per cubic foot and dividing by 2,000 pounds per ton. Multiplying by 44/12 yields equivalents, resulting in 700,277.6 tons of CO_2 emitted in 1990 from commercial harvest of forest conifers.

[770,100,000.496/2000]*44/12 = 700,277.6 tons CO_2*

Land Development

In 1990, an estimated 297 acres of Colorado forestland was cut for commercial land development. No re-growth will occur on these lands. Total above-ground releases of carbon are estimated by the following formula:

*Tons carbon released = (acres of converted land * pounds of carbon/acre * carbon coefficient)/2000 * 0.496)*

*[(297 acres of forest * 13,411 # carbon/acre) * .496]2000*44/12=3,621.93 tons carbon released*

Carbon releases that result from soil disturbances during the conversion of Colorado forestland are estimated by multiplying the area of forest cleared (297 acres) by 71,571 tons of carbon per acre and by 0.50 (the proportion of carbon released from soil when disturbed). The amount of carbon that was released from soil disturbance during forestland conversion was 5,314.15 tons of carbon in 1990.

*(297 acres of forest*71,571 tons carbon/acre)*.50 (proportion of carbon released from soil)/2000 *44/12 = 19,845 CO_2 released*

Releases of nitrogen resulting from soil disturbances during conversion of Colorado forestland to commercial development are estimated by multiplying the forest area cleared (297 acres) by 0.00154 tons of nitrogen per acre. The result is an estimated 0.457 tons of nitrogen released.

*297 acres of forest * .00154 tons of nitrogen/acre = .46 tons nitrogen released*

Other Harvest

The Forest Service estimates that 2,348 cubic feet of wood were cut in 1990 for firewood and Christmas trees. Emission of carbon dioxide released from that loss of biomass is 5.48 tons.

All previously computed emissions were summed to obtain an estimate of total releases due to land-use changes in Colorado forests. This summation resulted in an estimated 723,387.0 tons of carbon dioxide and 0.457 tons of nitrogen released.

(2,348 cubic feet of wood.496/2000)*44/12 = 2.1 tons CO2 emitted from loss of biomass*

1999

In 1999, approximately 21.96 million cubic feet of biomass were lost from Colorado forests. This loss includes harvests and development. The same methodology used in the previous 1998 inventory was used in the 2000 inventory to estimate carbon dioxide from land use changes and were as follows:

*[21,960,000 cf *.496/2000]*44/12 = 19,968.96 tons CO_2*

SECTION I

Methane Emissions from Domestic Animals

The methane emissions from domesticated animals have decreased since 1990, due primarily to a decreased population of sheep. The number of sheep has decreased by almost half, thus less methane produced. The number of beef cattle head has increased since 1990 by 393,000 head, however the methane emission factor from feedlots was not assumed to be 142.0. Feedlot cattle were not treated as a separate group but were divided into different types of cattle. The decrease in emissions from the previous inventory of 1990 are misleading since feedlot cattle were treated as a separate group, thus producing an over estimate of beef cattle emissions.

Figure 3.1.1(a): 1999 Methane Emissions from Domesticated Animals

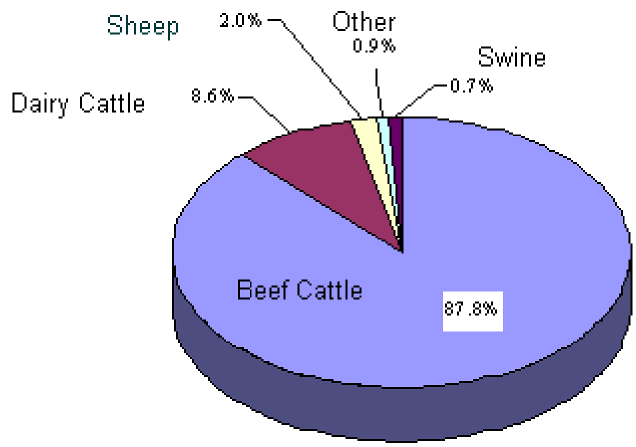
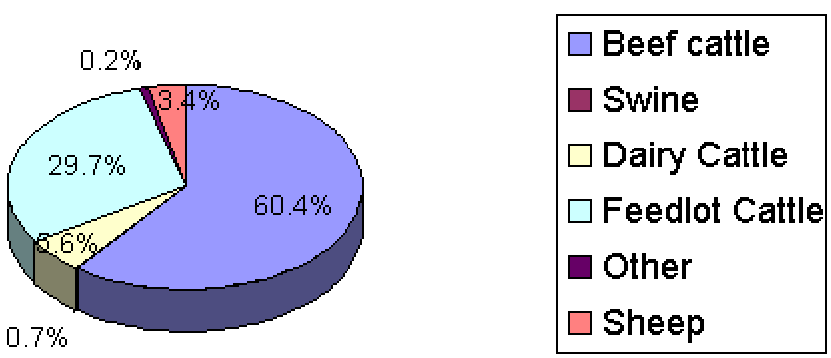


Figure 3.1.1(b): 1990 Methane Emissions from Domesticated Animals

Sources: Colorado Agricultural Statistics - 1990 & 1999 and Annual Colorado Livestock Inventory.



If feedlot cattle were factored in by type and added to the total methane emissions for 1999, the methane emissions would be similar to that of 1990. Dairy cattle emissions have risen due to an increase in the number of head. Hogs and pigs have increased dramatically, but since these animals have a low emissions factor, their influence on methane emissions data from domesticated animals is minimal. Mules, burrows, donkeys, horses, and goats have all increased in number, emitting more methane.

In 1990, total methane emission from enteric fermentation in domesticated animals was 214,850 tons. This level of emissions is over 30% of the nation's total and 43.4% of Colorado's methane budget. The major type of domesticated animals found in Colorado is cattle. Cattle are also the largest producer of methane in this sector. In Colorado, 3,594,000 beef and feedlot cattle contribute 26.8% of the nation's methane total. Annually, 193,602 tons of methane is emitted from cattle alone. *Figure 3.1.1* shows a breakdown of methane emissions by animal type. *Table 3.1.1* provides a summary of the type of domestic animals inventoried and the total methane produced by the animal in 1990. Due to inconsistencies in methodology used for 1990 and 1999 a graphical comparison was determined to be unnecessary.

<u>Table 3.1.1(a)</u>: 1999 Population of Domestic Animals and Methane Emissions

Animal	No. of Head	Emission Factor (lbs CH_4/year)	CH_4 Produced (tons/year)
Dairy Cattle (tot.)	**173,000**		**16,805.20**
Mature Cows	83,000	***307.30	12,752.95
Replacement (0-12 mo.)*	45,000	45.50	1,023.75
Replacement (12-24 mo.)	45,000	134.60	3,028.50
Beef Cattle (tot.)	**3,087,000**		**172,640.50**
Bulls	50,000	220.00	5,500.00
Mature Cows	827,000	152.00	62,852.00
Replacement (0-12 mo.)*	140,000	49.90	3,493.00
Replacement (12-24 mo.)	140,000	142.70	9,989.00
Yearling System Steer	1,544,000	104.70	80,828.40
Weanling System Steer**	386,000	51.70	9,978.10
Sheep (tot.)	**440,000**	**17.60**	**3,872.00**
Ewes (1 year old +)	185,000	“	1,628.00
Rams (1 year old +)	6,000	“	52.80
Replacement	29,000	“	255.20
Market	220,000	“	1,936.00
Hogs & Pigs (tot.)	**870,000**	**3.30**	**1,435.50**
Breeding	180,000	“	297.00
< 60 lbs.	335,000	“	552.75
60–119 lbs.	120,000	“	198.00
120–179 lbs.	120,000	“	198.00
180 lbs. +	115,000	“	189.75
Mules, Burrows, Donkeys	**4,900**	**48.50**	**118.83**
Horses	**82,000**	**39.60**	**1,623.60**
Goats	**13,000**	**11.0**	**71.50**
		Total	**196,567.13**

* Replacements 0-12 mo. were included in 1999 emissions inventory but not in 1990
- They are assumed to be the same number as replacements 12-24 mo.

** Weanling system steers are cattle in feedlots that are less than 14 mo. old

*** The emission factor for mature dairy cows has increased since 1990 (262.5)

Sources: EPA’s *States Workbook: Methodologies for Estimating Greenhouse Gas Emissions Vol. VIII*
<www.nass.usda.gov/co/>

Table 3.1.1(b): 1990 Population of Domestic Animals and Methane Emissions

Animal	Number of Head 1990	Emissions Factor (lbs CH4 /year)	CH_4 Produced (tons/year)
Dairy Cattle	**106,000**		
Mature Cows	76,000	307.30	11,677.40
Replacement (12-24 mo.)	30,000	134.60	2,019.00
Beef Cattle	**2,694,000**		
Bulls	45,000	220.00	4,950.00
Mature Cows	1,299,000	152.00	98,724.00
Replacement (12-24 mo.)	130,000	142.70	9,275.50
Yearling System Steer	320,000	104.70	16,752.00
Feedlot Cattle	900,000	142.00	63,900.00
Sheep (tot.)	**840,000**	**17.60**	**7,392.00**
Ewes one yr. old & older	375,000	"	
Rams one yr. old & older	13,000	"	
Replacement lambs	67,000	"	
Market sheep & lambs	385,000	"	
Hogs & Pigs (tot.)	**230,000**	**3.30**	**379.50**
Breeding	35,000	"	
Market Under 60 lbs.	70,000	"	
Market 60-119 lbs.	50,000	"	
Market 120-179 lbs.	40,000	"	
Market 180 lbs & over	35,000	"	
Mules, Burros, and Donkeys	**1,838**	**48.50**	**44.57**
Horses and Ponies	**69,381**	**39.60**	**1,373.74**
Goats	**11,746**	**11.00**	**64.60**
		Total	**216,552.32**

Source of data: Steve Sakry, Colorado Agricultural Statistics - 1996 (received via fax 22-Mar-96). And on 1-Apr-96, via written communication from Dr. David Anderson, Agricultural Economist, Livestock Marketing Information Center, Lakewood, Colorado (data from the Annual Colorado Livestock Inventory)

Forecast (1990)

According to the Livestock Marketing Information Center, the cyclic nature of the cattle industry, makes fo recasting of animal populations a difficult task. However, based on current trends, it was expected that cattle populations will increase by 9% through the year 2015. Hog populations, on the other hand, are expected to rise more dramatically in Colorado, due to the fact that a major slaughterhouse has been recently built in the region. Hog populations were expected to grow by 25% by the year 2015. Sheep and goat populations, however, are expected to remain flat, as are horse, pony, burro, and mule populations. When factored together, methane emissions from domesticated animals are estimated to increase by almost 9% by 2015. Forecasted methane emissions are tabulated in *Table 3.1.2.* As was expected the hog population increased but to a larger extent than expected (increasing 278%). The sheep population has decreased by 91%, contributing the decrease in emissions from domesticated animals. Cattle and other domesticated animals increased in population size. The major reason for the decrease in methane emissions was from a change in methodology used for beef cattle that could not be used for data from 1990.

Table 3.1.2: Forecasted Methane Emissions from Domesticated Animals in 2015

Animal	Number of Head Estimated 2015	Emissions Factor	CH_4 Produced (tons/year)
Dairy Cattle	**115,540**		
Mature Cows	82,840	262.50	10,872.75
Replacement (12-24 mo.)	32,700	134.60	2,200.71
Beef Cattle	**2,936,460**		
Bulls	49,050	220.00	5,395.50
Mature Cows	1,415,910	152.00	107,609.16
Replacement (12-24 mo.)	141,700	142.70	10,110.30
Yearling System Steer	348,800	104.70	18,259.68
Feedlot Cattle	981,000	142.00	69,651.00
Sheep	**840,000**	**17.60**	**7,392.00**
Ewes one yr. old & older	375,000		
Rams one yr. old & older	13,000		
Replacement lambs	67,000		
Market sheep & lambs	385,000		
Hogs & Pigs	**287,500**	**3.30**	**474.38**
Breeding	35,000		
Market Under 60 lbs.	70,000		
Market 60-119 lbs.	50,000		
Market 120-179 lbs.	40,000		
Market 180 lbs & over	35,000		
Mules, Burros, and Donkeys	**1,838**	**48.50**	**44.57**
Horses and Ponies	**69,381**	**39.60**	**1,373.74**
Goats	**11,746**	**11.00**	**64.60**
Total			**233,448.39**

Source: Colorado Agricultural Statistics - 1990 & 1999 and Annual Colorado Livestock Inventory: Steve Sakry, Colorado Agricultural Statistics - 1996 (received via fax 22-Mar-96). And, on 1-Apr-96 via written communication from Dr. David Anderson, Agricultural Economist, Livestock Market Information Center, Lakewood, Colorado (data from the Annual Colorado Livestock Inventory).

Several different types of animals are managed in Colorado for the production of animal products - each with different types of manure management systems in place. The manure management systems that are used in Colorado can be described as follows:

SECTION II

Methane Emissions from Animal Manure Management Systems

<u>Definitions</u>

Pasture/Range Manure from grazing pasture and range animals is not managed, but is naturally applied directly to the soil.

Daily Spread The manure is collected in solid form, usually by scraping. The collected manure is stored until mechanically applied to fields.

Solid Storage In a solid storage system, the solid manure is collected as in the daily spread system. The collected manure is stored in bulk for a period of time prior to disposal.

Drylot In dry climates, animals may be kept on unpaved feedlots where manure is piled and allowed to dry until it is removed.

Deep Pit Stacks With caged layers, manure collects in solid form in pits (several feet deep) below the cages. Removal of manure only occurs once per year.

Litter Broilers and young turkeys may be grown on beds of litter such as shavings, sawdust, or peanut hulls. Manure, or litter pack is removed periodically between flocks.

Paddock Horses are frequently kept in paddocks where they are confined to a limited area. The manure is either scraped and removed or treated similarly to manure on pasture or drylot.

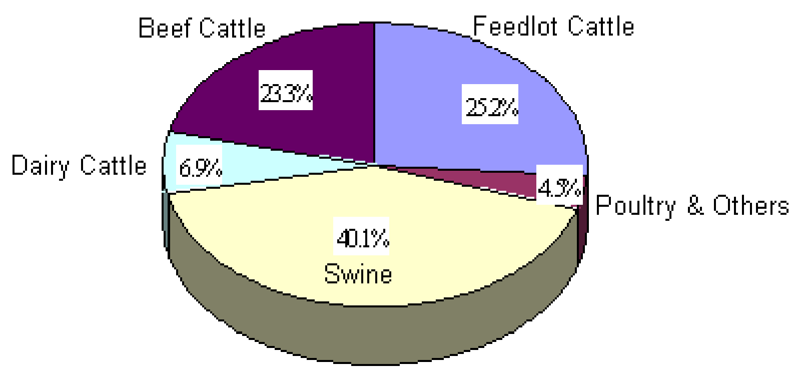
Liquid/Slurry These systems are generally characterized by large concrete-lined tanks built into the ground. Manure is stored in the tank for six or more months, or until it can be applied to fields. To facilitate handling as a liquid, water usually must be added to the manure, reducing its total solids concentration to less than 12%. Slurry systems may or may not require addition of water.

Anaerobic Lagoon Anaerobic lagoon systems are generally characterized by automated flush systems that use water to transport the manure to treatment lagoons that are usually greater than six feet deep. The manure resides in the lagoon for periods ranging from 30 to 200 days depending on the lagoon design and other local conditions. Water from the lagoon is often recycled as flush water. Periodically, the lagoon water may be used for irrigation on fields with the treated manure providing fertilizer value.

The manure management systems that contribute the most methane are anaerobic lagoons and “other”, accounting for 73% of the methane emissions from manure management systems. The major reason for the high emissions from anaerobic lagoons is due to the process in which the manure is decomposed (anaerobically) facilitates the production of methane. The reason “other” manure management system portion is high, is that these systems must also facilitate the production of methane. There has been an increase in emissions from anaerobic lagoons, indicating an increase in reliance on these types of systems as well as an increase in animal populations. The rest of the manure management systems have relatively low emissions, and there has not been any significant increase in emissions from any type of system (except for storage which had an increase).

In 1990, total methane emission from animal manure was 13,332.53 tons. Methane emissions from manure management systems accounted for roughly 1.7% of Colorado's methane budget in 1990. The bulk of methane emissions from animal manure management comes from the large population of cattle, and is a result of the way that the cattle are managed and the manner in which their wastes are handled. *Figure 3.2.1* depicts methane emissions from the various manure management systems inventoried in Colorado in 1990 and 1999.

Figure 3.2.1(a): 1999 Methane Emissions from Animal Manure



Sources: Colorado Agriculture Statistics 1990 & 1999 and 1987 & 1997 Agriculture Census

Figure 3.2.1(b): 1990 Methane Emissions from Animal Manure

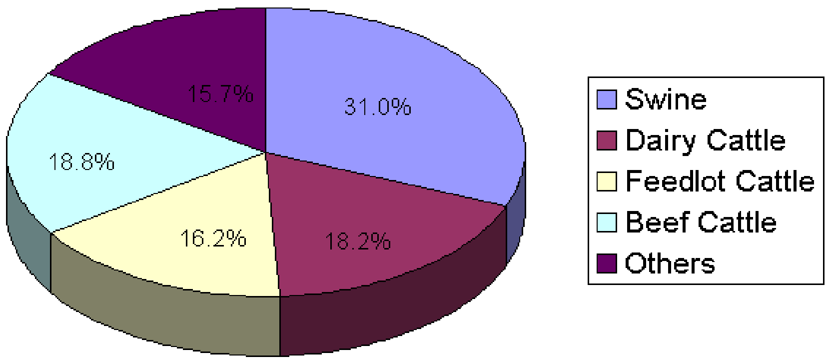


Table 3.2.1(a): Manure Management Systems Methane Emissions per Animal (1999)

Animal	Number of Head	CH_4 Emissions (tons)
Feedlot Cattle	1,160,000	10,846.49
Beef Heifer	150,000	625.80
Beef Steer	990,000	4,130.28
Beef Cows	837,000	4,846.53
Beef Bulls	50,000	416.94
Dairy Cows	83,000	2,199.80
Dairy Heifer	45,000	763.20
Swine - Breeder	180,000	7,621.10
Swine - Market	690,000	9,650.90
Layers	3,737,000	897.50
Broilers	130,000	12.01
Turkeys*	102,000	27.60
Sheep - Breeder	210,000	133.80
Sheep - Market	230,000	146.50
Goats	13,000	3.20
Mules, Donkeys, Burros	4,900	11.60
Horses	82,000	291.90
	Total	**43,048.87**

Source: <www.nass.usda.gov/co/> and Colorado Agriculture Statistics Service (CASS)

* Number of turkeys was estimated due to a single operation had over 100,000 and did not disclose how many for privacy reasons.

- The number of turkeys for smaller operations totaled 2,000.

**Turkey, mule (donkey and burro), and horse populations were taken from the 1997 NASS *Census of Agriculture* and were assumed to have relatively the same populations in 1999

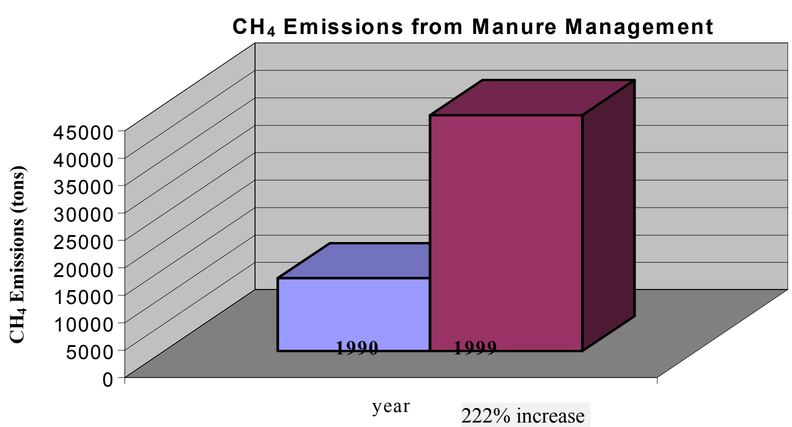
***Goat population was provided by CASS

Table 3.2.1(b): Manure Management Systems Methane Emissions per Animal (1990)

Animal Type	Number of Head	CH_4 Emissions (tons)
Feedlot Cattle	900,000	2,163.49
Beef Heifer	130,000	139.43
Beef Steer	320,000	343.22
Beef Cows	1,299,000	1,933.73
Beef Bulls	45,000	96.47
Dairy Cows	76,000	1,920.10
Dairy Heifer	30,000	508.86
Swine - Breeder	195,000	1,453.74
Swine - Market	35,000	2,675.59
Layers	3,495,250	1,276.50
Broilers	65,000	6.00
Turkeys	915,000	209.83
Sheep - Breeder	455,000	133.02
Sheep - Market	385,000	213.63
Goats	11,476	2.91
Mules, Donkeys and Burros	1,838	4.36
Horses	69,381	251.65
	Total	**13,332.53**

Source: Steve Sakry, Colorado Agricultural Statistics and Dr. David Anderson, Livestock Marketing Information Center, 1996.

Figure 3.2.2: Comparison of Methane Emissions from Manure Mgt. Systems, 1990 and 1999



Note: The dramatic increase of 222% is mainly from the inclusion of "other" manure management systems, and it can also be attributed to an increase in most animal populations.

Table 3.2.2(a): Manure Management Systems Methane Emissions per System (1999)

Manure System	Methane (tons)	Percent of Total
Lagoon	15,273	36.93
Other	15,168	36.68
Pasture	4,017	9.71
Pit Storage	3,775	9.13
Drylot	1,512	3.66
Slurry	925	2.24
Deep Pit	570	1.38
Spread	78	0.18
Litter	35	0.09
Total	**41,353**	**100.00**

Table 3.2.2(b): Manure Management Systems Methane Emissions per System (1990)

Manure System	Methane (tons)	Percent of Total
Lagoon	5,067	38.01
Pasture	3,819	28.64
Storage	1,890	14.18
Drylot	1,347	10.10
Slurry	769	5.77
Litter	214	1.61
Other	162	1.21
Spread	64	.48
Total	**13,332**	**100.00**

Source: Climate Change and Colorado: A Technical Assessment Examining Climate Change, 1998.

Forecast (1990)

Methane emissions from manure management systems were expected to increase over 12% by 2015, yet in 1999 the methane emissions have increased more than 3x the amount reported in 1990.

SECTION III

Nitrous Oxide Emissions from Fertilizer Use

As of 1999, the amount of nitrous oxide emissions has increased by 525.34 tons since 1990. This amount does not include the nitrogen in manure and other organic fertilizers applied to soils for agricultural purposes, nor does it include nitrogen fixing crops. It was determined that the amount of nitrous oxide from these two sources was insignificant.

For the year 1990, Colorado's annual consumption of nitrogen from fertilizer was in the range of 132,128 tons. Anhydrous ammonia and nitrogen solutions were the most commonly applied fertilizers. Anhydrous ammonia and urea were the fertilizers with the highest proportion of nitrogen. The following tables provide a summary of the estimated nitrous oxide emissions.

Table 3.3.1(a): Nitrous Oxide Emissions from Fertilizer Use (1999)

Fertilizer	Nitrogen Content	Fertilizer Consumption (Tons material) 1999	Fertilizer Consumption (Tons N) 1999	Emission Coefficient	Tons N_2O-N Emissions	N_2O Emissions (tons/yr)
Anhydrous Ammonia	0.82	92,675.00	75,993.50	0.0125	949.92	1,492.73
Urea - Form.	0.38	445.00	169.10	0.0125	2.11	3.32
Nitrogen Solutions - 32%	0.32	175,815.00	56,260.80	0.0125	703.26	1,105.12
Nitrogen Solutions - 28%	0.28	11,656.00	3,263.68	0.0125	40.80	64.11
Ammonium Nitrate	0.34	22,675.00	7,596.13	0.0125	94.95	149.21
Ammonium Sulfate	0.21	8,470.00	1,778.70	0.0125	22.23	34.94
Urea	0.46	39,410.00	18,128.60	0.0125	226.61	356.10
Urea Solution	0.20	1,604.00	320.80	0.0125	4.01	6.30
Calcium Nitrate	0.16	60.00	9.60	0.0125	0.12	0.19
Ammonium Thiosulfate	0.12	31,658.00	3,798.96	0.0125	47.49	74.62
Magnesium Nitrate	0.07	249.00	17.43	0.0125	0.22	0.34
Other	0.16	10,114.00	1,618.24	0.0125	20.23	31.79
Total Tons N2O		**394,831.00**	**168,955.54**		**2,111.94**	**3,318.77**

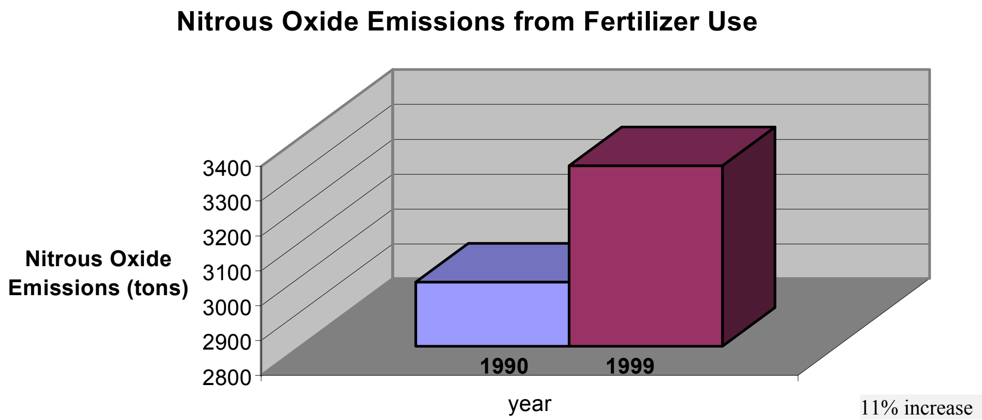
Source: Steve Bornnman, Colorado Department of Agriculture, 2000.

Table 3.3.1(b): Nitrous Oxide Emissions from Fertilizer Use (1990)

Fertilizer	N Content	Fertilizer Consumption (Tons material) 1990	Fertilizer Consumption (Tons N) 1990	Emissions Coefficient	Tons N_2O-N Emissions	N_2O Emissions (tons/yr)
Anhydrous Ammonia	0.82	91,082.00	74,687.24	0.0125	1,052.91	1,654.58
Aqua Ammonia	0.21	1,381.00	283.11	0.0125	1.99	3.12
Nitrogen Solutions	0.35	100,010.00	35,003.50	0.0125	431.77	678.49
Ammonium Nitrate	0.34	29,807.00	9,985.35	0.0125	126.02	198.02
Ammonium Sulfate	0.21	15,864.00	3,331.44	0.0125	42.30	66.47
Urea	0.46	37,861.00	17,416.06	0.0125	215.73	339.01
Sodium Nitrate	0.16	0.00	0.00	0.0125	0.05	0.08
Other	0.16	20,909.00	3,345.44	0.0125	28.43	44.67
Total Tons N2O		**296,914.00**	**144,052.13**		**1,899.19**	**2,984.44**

Source: Steve Bornnman, Colorado Department of Agriculture, 1996.

Figure 3.3.1: Comparison of Nitrous Oxide Emissions from Fertilizer Use, 1990 and 1999



Forecast (1990)
In 1990 methane emissions from the application of fertilizers to agricultural soils was 893,898 tons per year (carbon equivalent applied). This sector was anticipated to remain unchanged through the year 2015, however an increase of 10.1% has been observed from 1990 to 1999.

SECTION IV
Greenhouse Gas Emissions Due To Forest and Land Use Changes

Forest woodlands comprise about 21.5 million acres in Colorado. Colorado forest lands are estimated to sequester an average of 3.58 tons of carbon dioxide per acre, bringing its carbon sink capability to 76,918,806 tons annually. Yearly growth is approximately 6.7 tons of dry matter/acre/year in the forests.

An additional 34 million acres in Colorado is classified as land without trees. This land is mostly farm and rangeland: little is known about the carbon sequestration potential of grazed grassland. *Table 3.4.1* provides an acreage breakout of timberline and woodland by tree types. The total carbon sequestration capability of the Colorado forest(s) is also provided.

Table 3.4.1: Tree Species in Colorado Forests

Tree Species	Acres
Timberline Trees	
Douglas Fir	1,805,600
Ponderosa Pine	2,771,900
Lodge Pole Pine	2,244,200
Limber Pine	65,600
Sub-Alpine Fir	347,000
White Fir	121,300
Spruce	
Blue, Engleman	4,431,800
Aspen	3,556,800
Cottonwood	
Narrow Leaf, Plains	108,300
Total Timberland Species	**15,452,500**
Woodland Trees	
Pure Juniper	452,400
Oak	727,000
Riparian	
Willow, Cottonwood	3,800
Other Western Hardwoods	
Oak, Ash, Hackberry	12,500
Total Woodland Species	**6,033,200**
TOTAL FOREST SPECIES	**21,485,700**
Carbon Sink Capability of all Colorado Forest Species (based on a sequester rate of 3.58 tons CO_2 per acre):	**76,918,806**

Source of data: Tom Ostermann, Forest Management Division Supervisor, Colorado State Forest Service, Fort Collins, Colorado, 1996. According to Mr. Ostermann, the data was taken from a 1982-83 inventory of forest land conducted by Robert E. Benson and Allen W. Greene of the Intermountain Inventory Group and published in the "Resource Bulletin: INT-48 U.S. Forest Service System". October 1987. (Publisher: Intermountain Research Station, Ogden, Utah.)

In an informal conversation with Dr. Dennis Lynch of Colorado State University in July 2000, there was indication that the forests of Colorado are growing faster than the harvest or mortality rates. The average growth rate of Colorado's forests was 24.97 cf/acre, and when compared to the 1.25 cf/acre cut rate (from all types of anthropogenic activities) and the 7.63 cf/acre mortality rate, the forests of Colorado are growing faster than dying. The smaller amount of CO_2 released in 1999 compared to 1990 from land use changes can be attributed to a decrease in commercial harvests. The data to calculate much of these figures was incomplete or unavailable. The quality assurance of CO_2 released from land use changes is insufficient due to missing or incomplete data. A graphical comparison of carbon dioxide emissions between 1990 and 1999 was determined to be unnecessary due to inconsistencies in data and data source.

Land-use changes that alter the amount of biomass on land produce a net exchange of greenhouse gas emissions between the atmosphere and the land surface. Biomass includes organic material both above ground and below ground, both living and dead. Various land-use change activities that contribute to anthropogenic emissions and uptake include: forest conversion, logging, forest degradation or mortality, timber stand management, flooding of lands, wetland drainage, and conversion of grasslands.

Total carbon and nitrous oxide emissions due to land-use changes in Colorado forestlands were the second largest single category of carbon dioxide equivalent emissions in 1990. The major cause of these land-use emissions is commercial logging within Colorado forests. In Colorado, 30.7% of the growing stock biomass is in forests owned by the federal government. Conserving this resource requires joint effort between private ownership, US Forest Service and Colorado State Forest Service to continue to practice sound forest management and replant harvested trees. No reliable data exist with regard to the acreage or net increase/decrease in Christmas tree farms, tree nurseries or other enterprises of that type.

Methane Emissions Due to Conversion of Grasslands to Development

Data are not available for estimating how much grassland is converted to farmland, urban lands, or other type of land use in Colorado. Specific data on grasslands is not available. However, the annual number of building permits was available from the U.S. Bureau of the Census. According to this data, the U.S. Fish and Wildlife Service estimated that each building permit represented 0.5 acres of land: therefore, in 1990, a total of 5,498 acres of Colorado lands were converted to other uses: in this case, urbanization. In 1999, 49,313 permits were issued amounting to 24,656.5 acres of land developed. Qualitatively, much of this land is likely to be grassland, because of the state's growth demographics. *Tables 3.4.2a* and *3.4.2b* summarizes carbon dioxide emissions from all land use changes in Colorado forests.

Table 3.4.2(a): 1999 Summary of Emissions from Land Use Changes in Colorado Forests

CO_2 Released (tons)	Forest Sink Capability (tons)	N Released (tons)
19,968.96	76,918,806.00	0.06313

Source: Dr. Dennis Lynch Colorado State University, 2000.

Table 3.4.2(b): 1990 Summary of Emissions from Land Use Changes in Colorado Forests

Forest/Land Use Changes	CO_2 Released (tons)	Forest Sink Capability (tons)	N Released (tons)
Commercial Harvest	700,277.60		
Forest Developed	3,621.90		
Soil Disturbances	19,485.00		0.457
Other Harvests	2.14		
Total	**723,386.64**	**76,918,806.00**	**0.457**

Source: Tom Ostermann, Forest Management Division Supervisor, Colorado State Forest Service, 1996.

Table 1.1.2(a): Carbon Dioxide Emissions from Residential Fossil Fuel Use, 1997 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions Tons CO2
Distillate Fuel	69,000.00	barrels	5.825	401,925.00	44.00	8,842.35	0.99	8,753.93	32,097.73
Liquified Petroleum Gas	2,100,000.00	barrels	4.011	8,423,100.00	37.80	159,196.59	0.99	157,604.62	577,883.62
Kerosene	19,000.00	barrels	5.67	107,730.00	43.50	2,343.13	0.99	2,319.70	8,505.55
Bituminous Coal	23,000.00	tons	23.89	549,470.00	56.00	15,385.16	0.99	15,231.31	55,848.13
Anthracite	0.00	tons	21.668	0.00	62.10	0.00	0.99	0.00	0.00
Natural Gas	116.00	bcf*	1.03	119,480,000.00	31.90	1,905,706.00	0.995	1,896,177.47	6,952,650.72
Total tons CO2 Emissions			* billion cubic feet	128,962,225.00					**7,626,985.76**

Table 1.1.2(b): Carbon Dioxide Emissions from Residential Fossil Fuel Use, 1990 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions Tons CO2
Distillate Fuel	27,000.00	barrels	5.825	157,275.00	44.00	3,460.05	0.99	3,425.45	12,559.98
Liquified Petroleum Gas	1,697,000.00	barrels	4.011	6,806,667.00	37.80	128,646.01	0.99	127,359.55	466,985.00
Kerosene	22,000.00	barrels	5.67	124,740.00	43.50	2,713.10	0.99	2,685.96	9,848.53
Bituminous Coal	20,000.00	tons	23.89	477,800.00	56.00	13,378.40	0.99	13,244.62	48,563.59
Anthracite	0.00	tons	21.668	0.00	62.10	0.00	0.99	0.00	0.00
Natural Gas	92.00	bcf*	1.03	94,760,000.00	31.90	1,511,422.00	0.995	1,503,864.89	5,514,171.26
Biomass	93,380.03	tons		1,610,000.00	0.475	382.38	0.90	344.14	1,261.84
Total tons CO2 Emissions			* billion cubic feet	103,936,482.00					**6,053,390.21**

Table 1.1.3(a): Carbon Dioxide Emissions from Commercial Fossil Fuel Use, 1997 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Gasoline	37,000.00	barrels	5.253	194,361.00	42.80	4,159.33	0.99	4,117.73	15,098.35
Distillate Fuel	1,186,000.00	barrels	5.825	6,908,450.00	44.00	151,985.90	0.99	150,466.04	551,708.82
Residual Oil	0.00	barrels	6.287	0.00	47.40	0.00	0.99	0.00	0.00
Liquified Petroleum Gas	371,000.00	barrels	4.011	1,488,081.00	37.80	28,124.73	0.99	27,843.48	102,092.77
Kerosene	5,000.00	barrels	5.67	28,350.00	43.50	616.61	0.99	610.45	2,238.30
Bituminous Coal	42,000.00	tons	23.89	1,003,380.00	56.00	28,094.64	0.99	27,813.69	101,983.54
Anthracite	0.00	tons	21.668	0.00	62.10	0.00	0.99	0.00	0.00
Natural Gas	69.00	bcf	1.03	71,070,000.00	31.90	1,133,566.50	0.995	1,127,898.67	4,135,628.45
Total tons CO2 Emissions				80,692,622.00					**4,908,750.24**

Table 1.1.3(b): Carbon Dioxide Emissions from Commercial Fossil Fuel Use, 1990 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Gasoline	263,000.00	barrels	5.253	1,381,539.00	42.80	29,564.93	0.99	29,269.29	107,320.71
Distillate Fuel	437,000.00	barrels	5.825	2,545,525.00	44.00	56,001.55	0.99	55,441.53	203,285.63
Residual Oil	0.00	barrels	6.287	0.00	47.40	0.00	0.99	0.00	0.00
Liquified Petroleum Gas	299,000.00	barrels	4.011	1,199,289.00	37.80	22,666.56	0.99	22,439.90	82,279.62
Kerosene	10,000.00	barrels	5.67	56,700.00	43.50	1,233.23	0.99	1,220.89	4,476.61
Bituminous Coal	38,000.00	tons	23.89	907,820.00	56.00	25,418.96	0.99	25,164.77	92,270.82
Anthracite	0.00	tons	21.668	0.00	62.10	0.00	0.99	0.00	0.00
Natural Gas	66.00	bcf	1.03	67,980,000.00	31.90	1,084,281.00	0.995	1,078,859.60	3,955,818.52
Total tons CO2 Emissions				74,070,873.00					**4,445,451.91**

Table 1.1.4(a): Carbon Dioxide Emissions from Industrial Fossil Fuel Use, 1997 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Distillate Fuel	4,066,000.00	barrels	5.825	23,684,450.00	44.00	521,057.90	0.99	515,847.32	1,891,440.18
Liquified Petroleum Gas	1,502,000.00	barrels	4.011	6,024,522.00	37.80	113,863.47	0.99	112,724.83	413,324.38
Other Liquids	1,782,000.00	barrels	5.825	10,380,150.00	44.00	228,363.30	0.99	226,079.67	828,958.78
Lubricants	239,000.00	barrels	6.065	1,449,535.00	44.60	32,324.63	0.99	32,001.38	117,338.41
Kerosene	5,000.00	barrels	5.67	28,350.00	43.50	616.61	0.99	610.45	2,238.30
Bituminous Coal	780,000.00	tons	23.89	18,634,200.00	56.00	521,757.60	0.99	516,540.02	1,893,980.09
Asphalt and Road Oil	2,574,000.00	barrels	6.636	17,081,064.00	45.50	388,594.21	0.99	384,708.26	1,410,596.97
Natural Gas	103.00	bcf	1.03	106,090,000.00	31.90	1,692,135.50	0.995	1,683,674.82	6,173,474.35
Total tons CO2 Emissions				183,372,271.00					**12,731,351.45**

Table 1.1.4(b): Carbon Dioxide Emissions from Industrial Fossil Fuel Use, 1990 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Distillate Fuel	2,683,000.00	barrels	5.825	15,628,475.00	44.00	343,826.45	0.99	340,388.19	1,248,090.01
Liquified Petroleum Gas	974,000.00	barrels	4.011	3,906,714.00	37.80	73,836.89	0.99	73,098.53	268,027.93
Other Liquids	1,444,000.00	barrels	5.825	8,411,300.00	44.00	185,048.60	0.99	183,198.11	671,726.42
Lubricants	244,000.00	barrels	6.065	1,479,860.00	44.60	33,000.88	0.99	32,670.87	119,793.19
Kerosene	18,000.00	barrels	5.67	102,060.00	43.50	2,219.81	0.99	2,197.61	8,057.89
Bituminous Coal	729,000.00	tons	23.89	17,415,810.00	56.00	487,642.68	0.99	482,766.25	1,770,142.93
Asphalt and Road Oil	3,257,000.00	barrels	6.636	21,613,452.00	45.50	491,706.03	0.99	486,788.97	1,784,892.90
Natural Gas	66.00	bcf	1.03	67,980,000.00	31.90	1,084,281.00	0.995	1,078,859.60	3,955,818.52
Total tons CO2 Emissions				136,537,671.00					**9,826,549.78**

Table 1.1.5(a): Carbon Dioxide Emissions from Transportation Fossil Fuel Use, 1997 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Gasoline	43,026,000.00	barrels	5.253	226,015,578.00	42.80	4,836,733.37	0.99	4,788,366.04	13,799,814.40
Distillate Fuel	8,437,000.00	barrels	5.825	49,145,525.00	44.00	1,081,201.55	0.99	1,070,389.53	3,924,761.63
Liquified Petroleum Gas	67,000.00	barrels	4.011	268,737.00	37.80	5,079.13	0.99	5,028.34	18,437.24
Lubricants	403,000.00	barrels	6.065	2,444,195.00	44.60	54,505.55	0.99	53,960.49	197,855.14
Aviation Gasoline	143,000.00	barrels	5.048	721,864.00	41.60	15,014.77	0.99	14,864.62	54,503.62
Jet Fuel	7,174,000.00	barrels	5.67	40,676,580.00	43.50	884,715.62	0.99	875,868.46	3,211,517.68
Natural Gas	12.00	bcf	1.03	12,360,000.00	31.90	197,142.00	0.995	196,156.29	719,239.73
Ethanol	64,827,000.00	gallons	0.764	49,527,828.00	41.80	1,035,131.61	0.99	1,024,780.29	3,757,527.73
Total tons CO2 Emissions				331,632,479.00					**21,926,129.44**

Table 1.1.5(b): Carbon Dioxide Emissions from Transportation Fossil Fuel Use, 1990 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Gasoline	34,688,000.00	barrels	5.253	182,216,064.00	42.80	3,899,423.77	0.99	3,860,429.53	14,154,908.28
Distillate Fuel	7,175,000.00	barrels	5.825	41,794,375.00	44.00	919,476.25	0.99	910,281.49	3,337,698.79
Liquified Petroleum Gas	75,000.00	barrels	4.011	300,825.00	37.80	5,685.59	0.99	5,628.74	20,638.70
Lubricants	412,000.00	barrels	6.065	2,498,780.00	44.60	55,722.79	0.99	55,165.57	202,273.74
Aviation Gasoline	167,000.00	barrels	5.048	843,016.00	41.60	17,534.73	0.99	17,359.39	63,651.08
Jet Fuel	6,109,000.00	barrels	5.67	34,638,030.00	43.50	753,377.15	0.99	745,843.38	2,734,759.06
Natural Gas	9.00	bcf	1.03	9,270,000.00	31.90	147,856.50	0.995	147,117.22	539,429.80
Ethanol	28,000,000.00	gallons	0.764	21,392,000.00	41.80	447,092.80	0.99	442,621.87	1,622,946.86
Total tons CO2 Emissions				292,953,090.00					**19,430,412.60**

*Total does not inlcude ethanol

Table 1.1.6(a): Carbon Dioxide Emissions from Utilities Fossil Fuel Use, 1997 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Petroleum Coke	0.00	barrels	6.02	0.00	61.40	0.00	0.99	0.00	0.00
Kerosene	0.00	barrels	5.67	0.00	43.50	0.00	0.99	0.00	0.00
Bituminous Coal	17,116,000.00	tons	23.89	408,901,240.00	56.00	11,449,234.72	0.99	11,334,742.37	41,560,722.03
Anthracite	0.00	tons	21.668	0.00	62.10	0.00	0.99	0.00	0.00
Natural Gas	6.00	bcf	1.03	6,180,000.00	31.90	98,571.00	0.995	98,078.15	359,619.87
Other Oil	38,000.00	tons	5.825	655,172.41	44.00	14,413.79	0.99	14,269.66	52,322.07
Total tons CO2 Emissions				415,736,412.41					**41,972,663.97**

Table 1.1.6(b): Carbon Dioxide Emissions from Utilities Fossil Fuel Use, 1990 (tons)

Type of Fuel	Units of Fuel		Conversion Factor to Million btu	Fuel Consumption Million btu	Carbon Content Coefficient	Total Carbon Converted to Tons	Fraction Oxidized	Total Carbon Oxidized	CO2 Emissions tons CO2
Petroleum Coke	0.00	barrels	6.02	0.00	61.40	0.00	0.99	0.00	0.00
Kerosene	0.00	barrels	5.67	0.00	43.50	0.00	0.99	0.00	0.00
Bituminous Coal	15,924,000.00	tons	23.89	380,424,360.00	56.00	10,651,882.08	0.99	10,545,363.26	38,666,331.95
Anthracite	0.00	tons	21.668	0.00	62.10	0.00	0.99	0.00	0.00
Natural Gas	5.00	bcf	1.03	5,150,000.00	31.90	82,142.50	0.995	81,731.79	299,683.22
Biomass	1,694.94	tons	17.24	29,223.10	0.475	6.94	0.9	6.25	22.90
Total tons CO2 Emissions				385,603,583.10					**38,966,038.07**

Table 1.1.7: Forecast for Carbon Dioxide Emissions From Fossil Fuel Use Through 2015

	1990 Total Tons of CO2 Emissions from Energy Production & Consumption	Total % of CO2 Emissions	1997 Total Tons of CO2 From Energy Production & Consumption	2015 CO2 Projections
Residential	6,053,390.21	7.39%	7,626,985.76	7,460,803.68
Commercial	4,445,451.91	5.42%	4,908,750.24	5,746,191.50
Industrial	9,826,549.78	11.99%	12,731,351.45	13,007,403.65
Transportation	19,430,412.60	27.66%	21,926,129.44	35,819,110.08
Utilities	38,966,038.07	47.54%	41,972,663.97	55,378,533.80
Total	**78,720,580.81**		**89,165,880.86**	**117,412,042.71**
Difference in inventories additional tons (from 1990)			**10,445,300.05**	**42,691,431.90**

	1997 Total tons CO2 Emissions from Coal Use - All Sectors	1997 Total tons CO2 Emissions from Petroleum Use - All Sectors	1997 Total tons CO2 Emissions from Natural Gas Use - All Sectors	1997 Total tons CO2 Emissions Ethanol/Biomass Use - All Sectors
Residential	55,848.13	618,486.90	6,952,650.72	0.00
Commercial	101,983.54	671,138.24	4,135,628.40	0.00
Industrial	1,893,980.09	4,663,897.02	6,173,474.35	0.00
Transportation	0.00	21,205,889.71	719,239.73	3,757,527.73
Utilities	41,560,722.03	52,322.07	359,619.87	0.00
Total	**43,612,533.79**	**27,211,733.94**	**18,340,613.07**	**3,757,527.73**

	1990 Total tons CO2 Emissions from Coal Use - All Sectors	1990 Total tons CO2 Emissions from Petroleum Use - All Sectors	1990 Total tons CO2 Emissions from Natural Gas Use - All Sectors	1990 Total tons CO2 Emissions Ethanol/Biomass Use - All Sectors
Residential	48,563.59	489,393.51	5,515,433.10	0.00
Commercial	92,270.82	397,362.57	3,955,818.52	0.00
Industrial	1,770,142.93	4,100,588.34	3,955,818.52	0.00
Transportation	0.00	20,513,929.65	539,429.80	1,622,946.86
Utilities	38,666,331.95	0.00	299,683.22	22.90
Total	**40,577,309.29**	**25,501,274.07**	**14,266,183.16**	**1,622,969.76**

Part I-Section II: Methane Emissions from Oil and Gas Systems, 1998

Sector Oil and Gas Production	Bbl or MCF	Conversion Factor to MBTU	MMBTU	Emissions Factor lbs CH4/MMBTU Median	Calculation Median	Conversion to tons CH4 Median
Oil Production	22,473,240.00	Bbls 5.8	130,344,792.00	0.0062	808,137.71	404.07
Gas Production	704,552.00	Mcf 1000	704,552,000.00	0.151	106,387,352.00	53,193.68
Oil Venting (Oil Produced)	22,473,240.00	Bbls 5.8	130,344,792.00	0.0099	1,290,413.44	645.21
Gas Venting (Gas Produced	704,552.00	Mcf 1000	704,552,000.00	0.0099	6,975,064.80	3,487.53
Natural Gas Processing, Transport and Distribution	312,163.00	Mcf 1000	312,163,000.00	0.2033	63,462,737.90	31,731.37
						89,461.85

Source: State of Colorado Oil & Gas Commission

Part I-Section II: Methane Emissions from Oil and Gas Systems, 1990

Sector Oil and Gas Production	Bbl or MCF	Conversion Factor to MBTU	MMBTU	Emissions Factor lbs CH4/MMBTU Median	Calculation Median	Conversion to tons CH4 Median
Oil Production	28,379,000.00	Bbls 5.8	164,598,200.00	0.0062	1,020,508.84	510.25
Gas Production	270,691.00	Mcf 1000	270,691,000.00	0.151	40,874,341.00	20,437.17
Oil Venting (Oil Produced)	28,379,000.00	Bbls 5.8	164,598,200.00	0.0099	1,629,522.18	814.76
Gas Venting (Gas Produced	270,691.00	Mcf 1000	270,691,000.00	0.0099	2,679,840.90	1,339.92
Natural Gas Processing, Transport and Distribution	238,000.00	Mcf 1000	238,000,000.00	0.2033	48,385,400.00	24,192.70
						47,294.81

Source: State of Colorado Oil & Gas Commission

Part I-Section III: Calculations for Estimating Methane Emissions from Coal Mines (sample 1999)

Type of Mine	Coal Production (short tons)	Emissions Coefficient (cf/ton)	Methane Emitted (mcf methane)	CH4 (metric tons)	Conversion to tons (tons CH4)	MTCE
Underground	20,470,268.00	****************************	7,686,452,145.00	147,579.88	133,884.47	766,792.86
Post-Mining Underground	20,470,268.00	73.4	1,502,517,671.20	28,848.34	31,733.17	181,744.54
Surface	9,511,306.00	30.6	291,045,963.60	5,588.08	6,146.89	35,204.92
Post-Mining Surface	9,511,306.00	5	47,556,530.00	913.09	1,004.39	5,752.44

Source: Colorado Dept. of Natural Resources

Calculations for Estimating Methane Emissions from Coal Mines (sample 1992)

Type of Mine	Coal Production (short tons)	Emissions Coefficient (cf/ton)	Methane Emitted (mcf methane)	Conversion to tons (metric tons CH4)
Underground	10,942,431.00	**390**	**4,267,548,090.00**	81,936.92
Post-Mining Underground	10,942,431.00	**73.4**	**803,174,435.40**	15,420.95
Surface	8,178,011.00	**30.6**	**250,247,136.60**	4,804.75
Post-Mining Surface	8,178,011.00	**5**	**40,890,055.00**	785.09
				102,947.71

Amount of MSW Landfill in Colorado - 1998

Population (1998)	30 year period (1968-1998) (*24.8 year multiplier)	lbs./person/day (902)	Waste in place in tons (convert to tons)
4,056,133.00	100,592,098.40	90,734,072,756.80	45,367,036.38

Total Methane from Landfills - 1998

	Waste in Place (tons)	%at landfills small=14%, large=86%	Large LF (ft3 CH4/day) (equation)	Small LF (ft3 CH4/day) (*0.27)	Conversion factor tons/year	Oxidation factor (*0.9)	Tons CH4 from Landfills	MTCE
Small Landfills	45,367,036.38	6,351,385.09	*********************************	1,714,873.98	0.0077	0.90	**11,884.08**	**61,747.80**
Large Landfills	45,367,036.38	39,015,651.29	12,511,859.21	***************************	0.0077	0.90	**86,707.18**	**450,411.59**
Industrial Landfills	3,175,692.55					0.90	**6,211.25**	**32,272.29**
							104,802.51	**544,530.97**

Amount of MSW Landfill in Colorado - 1990

Population (1990)	30 year period (30 years)	#/person/day (1460)	Percentage ending up in landfills (.70)	Growth rate adjustment (0.8095)	Waste in place in tons (convert to tons)
3,294,394.00	98,831,820.00	144,294,457,200.00	101,006,120,040.00	81,764,454,172.38	40,882,227.09

Total Methane from Landfills - 1990

	Waste in Place	%at landfills small=14%, large=86%	CH4/ton CH4 Factor (0.27)	Conversion factor tons/year	CH4 (tons/year)	Oxidation Factor	Tons CH4 from Landfills	
Small Landfills	40,882,227.09	5,723,511.79	1,545,348.18	.0077	11,899.18	0.9	**10,709.26**	**Small**
Large Landfills	40,882,227.09	35,158,715.30	12,511,859.21	.0077	96,341.32	0.9	**65,051.96**	**Large**
Industrial Landfills	97,416.45						**5.303.29**	**Industrial**
							81,064.51	**Total All Landfills**

Methane Emissions from Wastewater Treatment

Year	Population	BOD Generated (.18 BOD factor)	per year (365 days/year)	Fraction of Wastewater BOD Treated Anaerobically (15% EPA default)	CH4 emissions (.22 #CH4)	CH4 recovered (15% EPA default)	Net CH4 Emissions (tons)
1990	3,294,394.00	592,990.92	216,441,685.80	32,466,252.87	7,142,575.63	1,071,386.34	3,035.59
1993	3,566,000.00	641,880.00	234,286,200.00	35,142,930.00	7,731,444.60	1,159,716.69	3,285.86
1995	3,721,000.00	669,780.00	244,469,700.00	36,670,455.00	8,067,500.10	1,210,125.02	3,428.69
1998	4,056,133.00	730,103.94	266,487,938.10	39,973,190.72	8,794,101.96	1,319,115.29	3,737.49
2010	4,548,000.00	818,640.00	298,803,600.00	44,820,540.00	9,860,518.80	1,479,077.82	4,190.72
2020	5,049,000.00	908,820.00	331,719,300.00	49,757,895.00	10,946,736.90	1,642,010.54	4,652.36

Source: Colorado Dept. of Public Health & Environment, Wastewater Treatment Division. Demographic data: State Demographers Office.

Year	Population	BOD Generated (.18 BOD factor)	per year (365 days/year)	CH4 emissions (.22 #CH4)	CH4 recovered (15% EPA default)	Net CH4 Emissions (tons)
1990	3,294,394.00	592,990.92	216,441,685.80	47,617,170.88	7,142,575.63	3,571.29
1993	3,566,000.00	641,880.00	234,286,200.00	51,542,964.00	7,731,444.60	3,865.72
1995	3,721,000.00	669,780.00	244,469,700.00	53,783,334.00	8,067,500.10	4,033.75
2000	4,018,000.00	723,240.00	263,982,600.00	58,076,172.00	8,711,425.80	4,355.71
2010	4,548,000.00	818,640.00	298,803,600.00	65,736,792.00	9,860,518.80	4,930.26
2020	5,049,000.00	908,820.00	331,719,300.00	72,978,246.00	10,946,736.90	5,473.37

Methane Emissions from Domesticated Animals

Animal	Population 1990	Population 1999	Population Estimated 2015	Emissions Factor	Total Methane Produced 1990 (tons per year)	Total Methane Produced 1999 (tons per year)	Estimated Emissions 2015 (tons per year)
Dairy Cattle	**106,000**	**173,000**	**115,540**		**13,696.40**	**16,805.20**	**14,929.08**
Mature Cows	76,000	83,000	82,840	**307.3**	11,677.40	12,752.95	12,728.37
Replacement (0-12 mo.)	NA	45,000	NA	**45.5**	NA	1,023.75	NA
Replacement (12-24 mo.)	30,000	45,000	32,700	**134.6**	2,019.00	3,028.50	2,200.71
Beef Cattle	**2,694,000**	**3,087,000**	**2,936,460**		**193,601.50**	**172,640.50**	**211,025.64**
Bulls	45,000	50,000	49,050	**220**	4,950.00	5,500.00	5,395.50
Mature Cows	1,299,000	827,000	1,415,910	**152**	98,724.00	62,852.00	107,609.16
Replacement (0-12 mo.)	NA	140,000	NA	**49.9**	NA	3,493.00	NA
Replacement (12-24 mo.)	130,000	140,000	141,700	**142.7**	9,275.50	9,989.00	10,110.30
Yearling System Steer	320,000	1,544,000	348,800	**104.7**	16,752.00	80,828.40	18,259.68
Feedlot Cattle	900,000	NA	981,000	**142.0**	63,900.00	NA	69,651.00
Weanling System Steer	NA	386,000	NA	**51.7**	NA	9,978.10	NA
Sheep	**840,000**	**440,000**	**840,000**	**17.6**	**7,392.00**	**3,872.00**	**7,392.00**
Ewes one yr. old & older	375,000	185,000			3,300.00	1,628.00	
Rams one yr. old & older	13,000	6,000			114.40	52.80	
Replacement lambs	67,000	29,000			589.60	255.20	
Market sheep & lambs	385,000	220,000			3,388.00	1,936.00	
Hogs & Pigs	**230,000**	**870,000**	**287,500**	**3.3**	**379.50**	**1,435.50**	**474.38**
Breeding	35,000	180,000			57.75	297.00	
Market Under 60 lbs.	70,000	335,000			115.50	552.75	
Market 60-119 lbs.	50,000	120,000			82.50	198.00	
Market 120-179 lbs.	40,000	120,000			66.00	198.00	
Market 180 lbs & over	35,000	115,000			57.75	189.75	
Mules, Burros, & Donkeys	**1,838**	**4,900**	**1,838**	**48.5**	**44.57**	**118.83**	**44.57**
Horses and Ponies	**69,381**	**82,000**	**69,381**	**39.6**	**1,373.74**	**1,623.60**	**1,373.74**
Goats	**11,746**	**13,000**	**11,746**	**11**	**64.60**	**71.50**	**64.60**
Total tons/yr					**216,552.32**	**196,567.13**	**233,488.39**

Corresponds to Table 3.1.2
Source of data: Steve Sakry, Colorado Agricultural Statistics - 1996 (received via fax 22-Mar-96). And on 1-Apr-96, via written communication from Dr. David Anderson, Agricultural Economist, Livestock Marketing Information Center, Lakewood, Colorado (data from the Annual Colorado Livestock Inventory).
Methodology: 1990 animal population data was multiplied by a growth factor provided by the Colorado Livestock Marketing Information Center (SKBusch). Cattle are estimated to grow by 9% by 2015. Hogs are expected to grow by 25% by 2015 due to the expanded facility in the Greeley, CO., area. All other categories are expected to remain constant. The following methodology was used:
Tons CH4 = Estimated 2015 Animal Population * Emissions Factor (lbs gas/head)/2000.

Animal Type	Population (1999)	Typical Animal Mass (lbs/head)	Volatile Solids (lbs VS/ lb mass)	Total Volatile Solids (lbs/yr)	CH4 Producing Capacity (ft3/lb-VS)	Max Potential Emissions (ft3/yr)
Feedlot Cattle	1,160,000	915.00	2.60	2,759,640,000.00	5.29	14,598,495,600.00
Beef Heifer	150,000	794.00	2.60	309,660,000.00	2.72	842,275,200.00
Beef Steer	990,000	794.00	2.60	2,043,756,000.00	2.72	5,559,016,320.00
Beef Cows	837,000	1,102.00	2.60	2,398,172,400.00	2.72	6,523,028,928.00
Beef Bulls	50,000	1,587.00	2.60	206,310,000.00	2.72	561,163,200.00
Dairy Cow	83,000	1,411.00	3.65	427,462,450.00	3.84	1,641,455,808.00
Dairy Heifer	45,000	903.00	3.65	148,317,750.00	3.84	569,540,160.00
Swine - Breeder	180,000	399.00	3.10	222,642,000.00	5.77	1,284,644,340.00
Swine - Market	690,000	101.00	3.10	216,039,000.00	7.53	1,626,773,670.00
Layers	3,737,000	3.50	4.40	57,549,800.00	5.45	313,646,410.00
Broilers	130,000	1.50	6.20	1,209,000.00	4.81	5,815,290.00
Turkeys*+	102,000	7.50	3.32	2,539,800.00	4.81	12,216,438.00
Sheep - Breeder	210,000	154.00	4.40	142,296,000.00	3.04	432,579,840.00
Sheep - Market	230,000	154.00	4.40	155,848,000.00	5.77	899,242,960.00
Goats*	13,000	141.00	3.48	6,378,840.00	2.72	17,350,444.80
Mules, Donkeys*	4,900	661.00	3.65	11,821,985.00	5.29	62,538,300.65
Horses*	82,000	992.00	3.65	296,905,600.00	5.29	1,570,630,624.00
Totals	**8,693,900.00**			**9,406,548,625.00**		**36,520,413,533.45**

Methane Emissions (ft3/yr)	Methane Emissions (lbs/yr)	Methane Emissions (tons/yr)
525,253,871.69	21,692,984.90	10,846.49
30,305,061.70	1,251,599.05	625.80
200,013,407.19	8,260,553.72	4,130.28
234,698,580.83	9,693,051.39	4,846.53
20,190,651.94	833,873.92	416.94
106,530,481.94	4,399,708.90	2,199.85
36,963,156.38	1,526,578.36	763.29
369,065,472.44	15,242,404.01	7,621.20
467,355,807.65	19,301,794.86	9,650.90
66,091,571.52	2,729,581.90	1,364.79
581,529.00	24,017.15	12.01
1,132,708.13	46,780.85	23.39
3,698,557.63	152,750.43	76.38
7,688,527.31	317,536.18	158.77
156,154.00	6,449.16	3.22
562,844.71	23,245.49	11.62

14,402,682.82	594,830.80	297.42
2,084,691,066.88	**86,097,741.06*** numbers in	

Animal Type	Population (1990)	Typical Animal Mass (lbs/head)	Volatile Solids (lbs VS/ lb mass)	Total Volatile Solids (lbs/yr)	CH4 Producing Capacity (ft3/lb-VS)	Max Potential Emissions (ft3/yr)
Feedlot Cattle	900,000	915.00	2.60	2,141,100,000.00	5.29	11,326,419,000.00
Beef Heifer	130,000	794.00	2.60	268,372,000.00	2.72	729,971,840.00
Beef Steer	320,000	794.00	2.60	660,608,000.00	2.72	1,796,853,760.00
Beef Cows	1,299,000	1,102.00	2.60	3,721,894,800.00	2.72	10,123,553,856.00
Beef Bulls	45,000	1,587.00	2.60	185,679,000.00	2.72	505,046,880.00
Dairy Cow	76,000	1,345.00	3.65	373,103,000.00	3.84	1,432,715,520.00
Dairy Heifer	30,000	903.00	3.65	98,878,500.00	3.84	379,693,440.00
Swine - Breeder	35,000	399.00	3.10	43,291,500.00	5.77	249,791,955.00
Swine - Market	195,000	101.00	3.10	61,054,500.00	7.53	459,740,385.00
Layers*	3,495,250	3.50	4.40	53,826,850.00	5.45	293,356,332.50
Broilers*	65,000	1.50	6.20	604,500.00	4.81	2,907,645.00
Turkeys*	915,000	7.50	3.32	22,783,500.00	4.81	109,588,635.00
Sheep - Breeder	455,000	154.00	3.36	235,435,200.00	3.04	715,723,008.00
Sheep - Market	385,000	154.00	3.36	199,214,400.00	5.77	1,149,467,088.00
Goats	11,746	141.00	3.48	5,763,527.28	2.72	15,676,794.20
Mules, Donkeys	1,838	661.00	3.65	4,434,450.70	5.29	23,458,244.20
Horses	69,381	992.00	3.65	251,214,724.80	5.29	1,328,925,894.19
Totals	**8,428,215.00**			**8,327,258,452.78**		**30,642,890,277.10**

Methane Emissions (ft3/yr)	**Methane Emissions** (lbs/yr)	**Methane Emissions** (tons/yr)
104,769,375.75	4,326,975.22	2,163.49
6,752,239.52	278,867.49	139.43
16,620,897.28	686,443.06	343.22
93,642,873.17	3,867,450.66	1,933.73
4,671,683.64	192,940.53	96.47
92,983,237.25	3,840,207.70	1,920.10
24,642,104.26	1,017,718.91	508.86
70,398,866.68	2,907,473.19	1,453.74
129,568,632.70	5,351,184.53	2,675.59
61,816,046.38	2,553,002.72	1,276.50
290,764.50	12,008.57	6.00
10,161,058.24	419,651.71	209.83
6,441,507.07	266,034.24	133.02
10,345,203.79	427,256.92	213.63
141,091.15	5,827.06	2.91
211,124.20	8,719.43	4.36

12,186,250.45	503,292.14	251.65
645,642,956.03	**26,665,054.08**	**13,332.53**

*** numbers in these categories based on 1987 Agriculture Census data (SKBusch).**

** Methane Conversion Factor

*** Waste System Usage

Methane Conversion Factors (MCF) and Waste System % Usage

MCF** Pasture Range	**MCF** Lagoon	**MCF** Drylot	**MCF** Daily Spread	**MCF** Pit <30 days Storage	**MCF** Pit >30 days Storage	**MCF** Liquid Slurry	**MCF** Other	**MCF** Litter	**WS***** An. La.**	**WS** Drylot	**WS** Liquid Slurry	**WS** Spread	**WS** Pasture	**WS** Pit <30 days Storage	**WS** Pit >30 days Storage	**WS** Litter	**WS** Other
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.900	0.100	0.000	0.250	0.000	0.000	0.720	0.000	0.000	0.000	0.030
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.900	0.100	0.000	0.250	0.000	0.000	0.720	0.000	0.000	0.000	0.030
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.900	0.100	0.000	0.250	0.000	0.000	0.720	0.000	0.000	0.000	0.030
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.900	0.100	0.000	0.250	0.000	0.000	0.720	0.000	0.000	0.000	0.030
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.900	0.100	0.000	0.250	0.000	0.000	0.720	0.000	0.000	0.000	0.030
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.050	0.000	0.100	0.850	0.000	0.000	0.000	0.000	0.000
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.050	0.000	0.100	0.850	0.000	0.000	0.000	0.000	0.000
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.100	0.100	0.240	0.250	0.000	0.000	0.000	0.210	0.240	0.000	0.060
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.100	0.100	0.240	0.250	0.000	0.000	0.000	0.210	0.240	0.000	0.060
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.040	0.000	0.080	0.000	0.000	0.000	0.880	0.000	0.000
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.000	0.000	0.000	0.000	0.080	0.000	0.000	0.920	0.000
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.000	0.000	0.000	0.000	0.950	0.000	0.000	0.000	0.050
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.000	0.000	0.000	0.000	0.950	0.000	0.000	0.000	0.050
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.000	0.100	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
0.009	0.900	0.010	0.002	0.091	0.182	0.182	0.009	0.100	0.000	0.170	0.000	0.000	0.830	0.000	0.000	0.000	0.000

N2O Emissions from Fertilizer Use (1999)

Fertilizer	Nitrogen Content	Fertilizer Consumption (tons material) 1999	Fertilizer Consumption (Tons N) 1999	Emission Coefficient	Tons N2O-N Emissions	N2O Emissions (tons/yr)
Anhydrous Ammonia	0.82	92,675.00	75,993.50	0.0125	949.92	1,492.73
Urea - Form.	0.38	445.00	169.10	0.0125	2.11	3.32
Nitrogen Solutions - 32%	0.32	175,815.00	56,260.80	0.0125	703.26	1,105.12
Nitrogen Solutions - 28%	0.28	11,656.00	3,263.68	0.0125	40.80	64.11
Ammonium Nitrate	0.34	22,675.00	7,596.13	0.0125	94.95	149.21
Ammonium Sulfate	0.21	8,470.00	1,778.70	0.0125	22.23	34.94
Urea	0.46	39,410.00	18,128.60	0.0125	226.61	356.10
Urea Solution	0.20	1,604.00	320.80	0.0125	4.01	6.30
Calcium Nitrate	0.16	60.00	9.60	0.0125	0.12	0.19
Ammonium Thiosulfate	0.12	31,658.00	3,798.96	0.0125	47.49	74.62
Magnesium Nitrate	0.07	249.00	17.43	0.0125	0.22	0.34
Other	0.16	10,114.00	1,618.24	0.0125	20.23	31.79
TOTAL Tons N2O		**394,831.00**	**168,955.54**		**2,111.94**	**3,318.77**

Data Source: Steve Bornmann, Colorado Department of Agriculture, Denver, Colorado - 22-Mar-1996 and July 2000
Methodology: Taken from 1998 Version of state's workbook
Tons material (fertilizer consumption) * nitrogen content = Tons Nitrogen in fertilizer consumed. Than multiplied by 1.25% emission coefficient = Tons N2O-N emissions.
To derive N2O emissions the Tons N2O is converted to N2O emissions by multiplying the total N2O-N figure by 44/28 to find the total N2O emissions by fertilizer type.

N20 Emissions From Fertilizer Use (1989 - 1991)

Fertilizer	Nitrogen Content	Fertilizer Consumption (Tons N) 1989	1990	1991	3-yr avg.	Emission Coefficient	Tons N2O-N Emissions	N2O Emissions (tons/yr)
Anhydrous Ammonia	0.82	96,587.80	74,687.24	81,424.36	84,233.13	0.0125	1,052.91	1,654.58
Aqua Ammonia	0.21	151.04	220.96	0.00	158.87	0.0125	1.99	3.12
Nitrogen Solutions	0.35	20,765.43	21,002.10	20,406.75	34,541.27	0.0125	431.77	678.49
Ammonium Nitrate	0.34	10,278.20	10,134.38	10,282.62	10,081.27	0.0125	126.02	198.02
Ammonium Sulfate	0.21	3,695.16	3,331.44	3,124.59	3,383.73	0.0125	42.30	66.47
Urea	0.46	18,809.40	17,416.06	15,550.30	17,258.59	0.0125	215.73	339.01
Sodium Nitrate	0.16	12.32	0.00	0.00	4.11	0.0125	0.05	0.08
Other	0.16	1,032.48	3,345.44	2,444.32	2,274.08	0.0125	28.43	44.67
TOTAL Tons N2O		**151,331.83**	**130,137.62**	**133,232.94**	**151,935.05**	**0.0125**	**1,899.19**	**2,984.44**

Tree Acreage of Colorado's Forests

	TIMBERLAND (total acres)
Douglas Fir	1,805,600
Ponderosa Pine	2,771,900
Lodge Pole Pine	2,244,200
Limber Pine	65,600
Engleman Spruce	
Sub-Alpine Fir	347,000
White Fir	121,300
Spruce	
Blue, Engleman	4,431,800
Aspen	3,556,800
Cottonwood	108,300
Narrow Leaf, Plains	
Total Timberland Species	**15,452,500**

	WOODLAND (total acres)
Pinon-Juniper	4,837,500
Pure Juniper	452,400
Oak	727,000
Riparian	3,800
Willow, Cottonwood	
Other Western Hardwoods	12,500
Oak, Ash, Hackberry	
Total Woodland Species	**6,033,200**
TOTAL FOREST SPECIES	**21,485,700**

Carbon Sink Capability of all Colorado Forest Species (based on a sequester rate of 3.58 tons CO_2 per acre):

76,918,806

Source of data: Personal communication with Tom Ostermann, Forest Management Divsion Supervisor, Colorado State Forest Service, Fort Collins, Colorado on 18-Apr-96. According to Mr. Ostermann, the data was taken from a 1982-83 inventory of forest land conducted by Robert E. Benson and Allen W. Greene of the Intermountain Inventory Group and published in the "Resource Bulletin: INT-48 U.S. Forest Service System", October 1987. (Publisher: Intermountain Research Station, Ogden, Utah.)

Methodology: Total acreage figures were taken directly from 'information provided by Tom Ostermann of the Colorado State Forest Service in Fort Collins, Colorado. The estimation of forest land sequestration of carbon dioxide was taken from the State's Workbook. Calculating the resulting carbon sink capability of forest lands was accomplished by multiplying the estimated 3.58 tons of CO_2 per acre sequestered

The numerical equation looks like this:
76,918,806 tons annual carbon sink capability of forests = 21,485,700 acres of forest land * 3.58 tons CO_2 sequestered

per acre

by forest lands with total acreage in Colorado.

The equation for calculating the carbon sink capability of forest lands is derived from the following: Total Forest Acreage * Estimated sequestration rate.

Greenhouse Gas Emissions Due to Forest and Land Use Changes

Carbon	Net Loss Biomass		Emission Factor	Calculation	Conversion to tons	Tons CO2
Loss from Land Use Changes	21,960,000.00	cf	0.496	10,892,160.00	5,446.08	19,968.96
						19,968.96
Nitrogen						
Soil Disturbances	0.06313					

Source: Dr. Dennis Lynch, Colorado State University, 2000.
Corresponds to 3.4.2

Greenhouse Gas Emissions Due to Forest and Land Use Changes

Carbon	Net Loss Biomass		Emission Factor	Calculation	Conversion to tons	Tons CO2
Commercial Harvest	770,100,000.00	cf	0.496	381,969,600.00	190,984.80	700,277.60
Land Development	3,983,067.00	#carbon/acre	0.496	1,975,601.23	987.80	3,621.94
Soil Disturbances	21,256,587.00	#carbon/acre	0.5	10,628,293.50	5,314.15	19,485.20
Other Development	2,348.00	cf	0.496	1,164.61	0.58	2.14
						723,386.88
Nitrogen						
Soil Disturbances	0.45738					

Source: Tom Ostermann, Colorado State Forest Service, 1996.
Corresponds to 3.4.2