Year 2000 Iowa Greenhouse Gas Emissions Inventory

Center for Energy & Environmental Education
University of Northern Iowa
Cedar Falls, Iowa

A report for the Iowa Department of Natural Resources
Funded by the U.S. Environmental Protection Agency
January, 2005

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Page numbers and some graphics in this PDF version may differ from the Microsoft Word electronic version and printed copies of this document. Corrections have been made to figure ES-8 on page 8 by lengthening bar for energy efficiency to represent an offset of 5.3 million MTCE; the executive summary description of potential emissions savings from energy efficiency from 2.3 to 5.3 million MTCE on page 9; and figure 37 on page 91 by lengthening bar for energy efficiency to represent an offset of 5.3 million MTCE.

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Executive Summary

Balance between Emissions and Capture of Greenhouse Gases in Iowa in Year 2000

Overview. Iowa was among the first states to accept the challenge of quantifying its atmospheric burden of greenhouse gases, creating a baseline inventory for 1990 (Iowa Department of Natural Resources, 1996). The intent of this 2000 inventory is to update estimates of greenhouse gas emissions and gauge progress made toward greenhouse gas mitigation in the decade of the 1990s. When possible, the previously reported 1990 emissions were recalculated to take into account new methodologies introduced in the 2000 inventory.

Overall, it appears that total greenhouse gas emissions have increased from 22.8 million MTCE[1] in 1990 to 32.8 million MTCE in 2000. A precise comparison, however, is difficult to make because of differences in methodology and data availability for the two years in question, particularly with respect to emissions from agricultural soils. Offsetting increases in emissions in the 1990s were increases in the amounts of carbon sequestered in forests, croplands, and landfills, and recovered in landfills and wastewater treatment plants. These increased carbon savings narrow the apparent increase in net emissions (emissions minus sequestration and recovery) from 21.1 million MTCE in 1990 and 26.2 million MTCE in 2000.

The overall analysis is summarized in Figure ES-1. As one can observe, fossil fuel combustion was by far Iowa's greatest source of greenhouse gases in 2000, and growth in their consumption, 26 percent between 1990 and 2000, was the major reason why emissions increased in the 1990s. Most of the rise in demand was for coal and petroleum, which grew by 28 and 37 percent, respectively.

Iowa's energy picture is diversifying with the development of new sources of energy such as natural gas-fired power plants, wind power, and biomass-derived fuels. Even so, fossil fuels still dominate the market, and energy forecasts indicate the transition away from them will likely be slow. Despite spectacular recent development in wind-generated electricity, it still comprises only 1 percent of total electricity generation in Iowa, while nuclear power, another emissions-free source of electric power, has grown to provide one-tenth of the total demand.

Energy use increased in all four economic end-use sectors -- industrial, commercial, transportation, and residential. The industrial sector experienced the greatest increase at 36 percent. The residential sector saw the smallest increase at 3 percent owing to energy efficiency programs, improved building energy codes, and technological advances.

[1] MTCE stands for "metric ton of carbon equivalents." It is the standard unit used in greenhouse gas inventories, and applied in order to equate the impact of different greenhouse gases that vary in their "greenhouse effect" potency and chemical composition (some do not even contain carbon). For further details, see page 18.

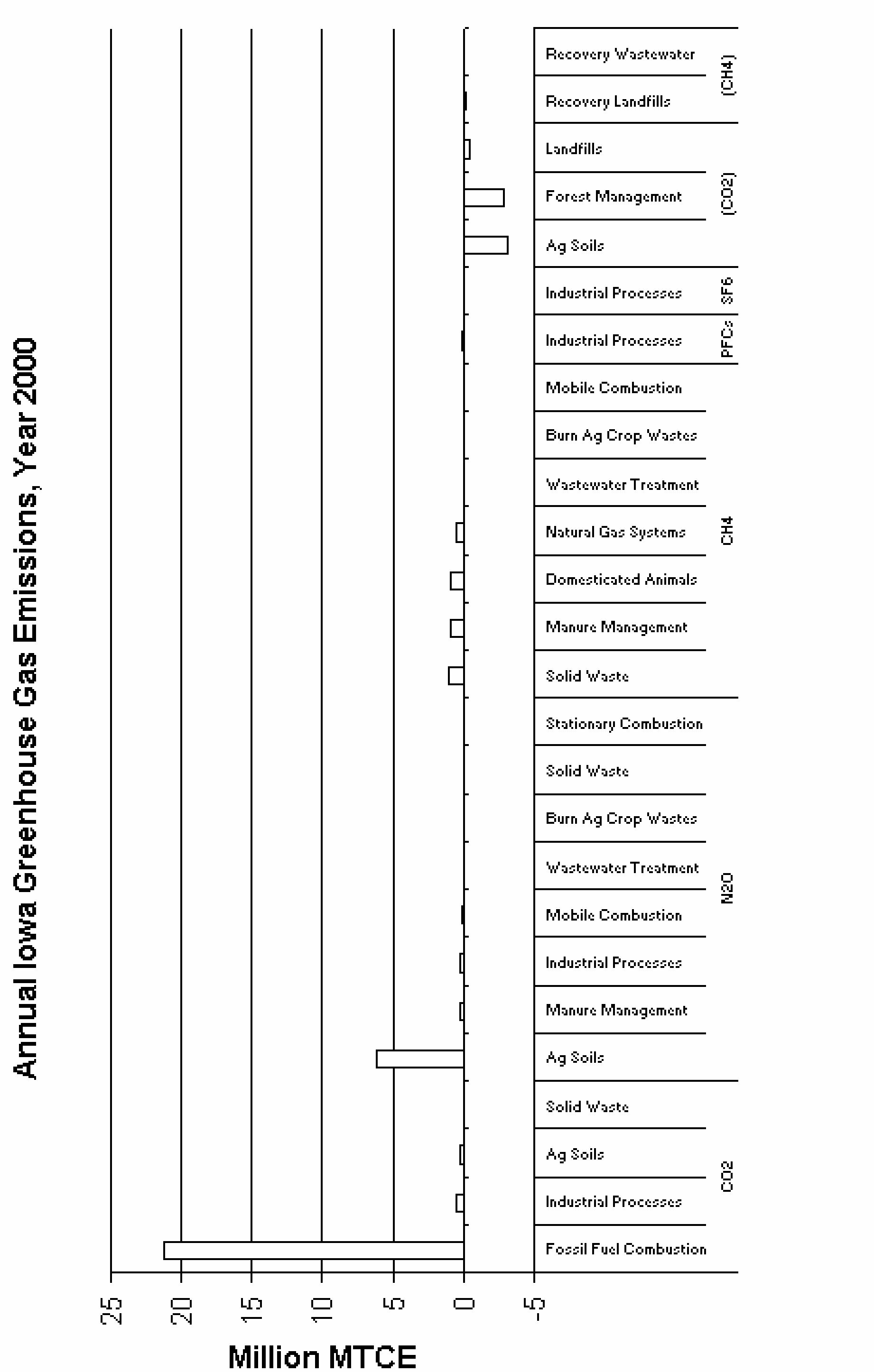


Figure ES-1. CO_2 from fossil fuel combustion and N_2O from agricultural soils make up 84 percent of all emissions. Agricultural soils and forests also sequestered large amounts of carbon.

Slow population growth and fast energy growth drove up per capita energy use in Iowa in the 1990s. This ratio started to flatten out in the late 1990s, however, because the electric utilities began burning coal emitting less carbon per unit of energy produced. With a decentralized farm economy and a strong dependence on coal, Iowa exceeded U.S. average per capita carbon consumption. As shown in Figure ES-2, it was the 13th highest state in overall carbon emissions per capita from fossil fuel consumption. Its best performance was in the transportation sector, where it ranked the 31st from the top, thus placing Iowa's per capita transportation energy consumption below the national average.

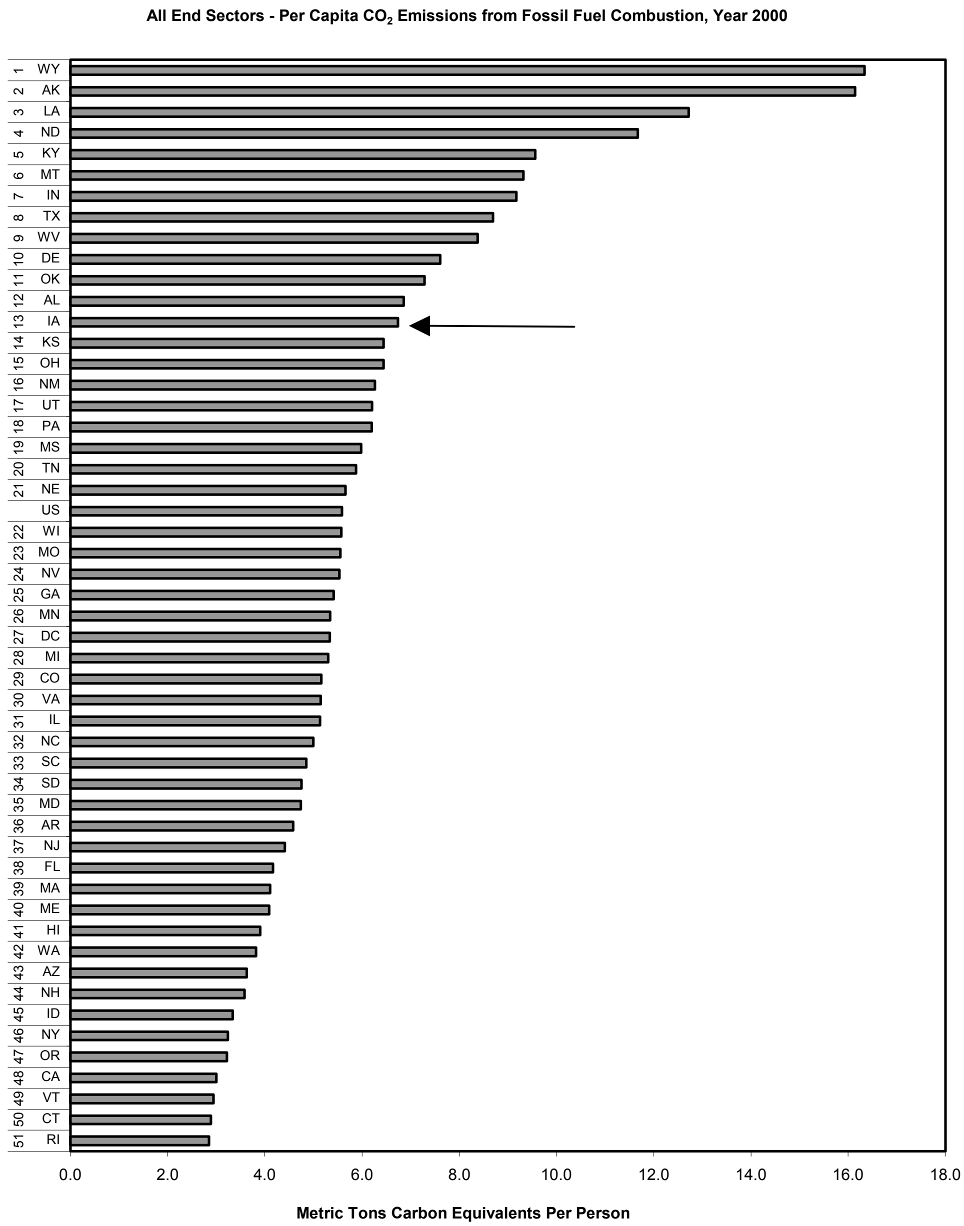


Figure ES-2. Iowa ranked as the 13th highest per capita carbon emitting state from fossil fuel combustion in all end use sectors, possessing annual emissions of 6.74 MTCE per person. The national average was 5.59 MTCE per person.

Energy use. In this report, the fluxes of greenhouse gases are grouped into five categories; energy, agriculture, industry, wastes, and forest management/land-use change. As shown in Figure ES-3, energy-related activities contributed 67 percent of total greenhouse gas emissions, the largest share by far of all the categories. Carbon dioxide (CO_2) emissions from combustion of fossil fuels made up two-thirds of all greenhouse gas emissions in Iowa, totaling 21.3 million MTCE. This amount was up from 17 million MTCE in 1990. The largest fraction came from electricity generation. Fugitive emissions and storage leaks from natural gas transmission and distribution systems comprised the second largest source in this category, adding another 553,278 MTCE. Compared to carbon dioxide, emissions of methane (CH_4) and nitrous oxide (N_2O) from mobile combustion were rather insignificant (14,212 MTCE and 172,033 MTCE, respectively). Nitrous oxide emissions from stationary combustion sources were estimated to be 61 MTCE.

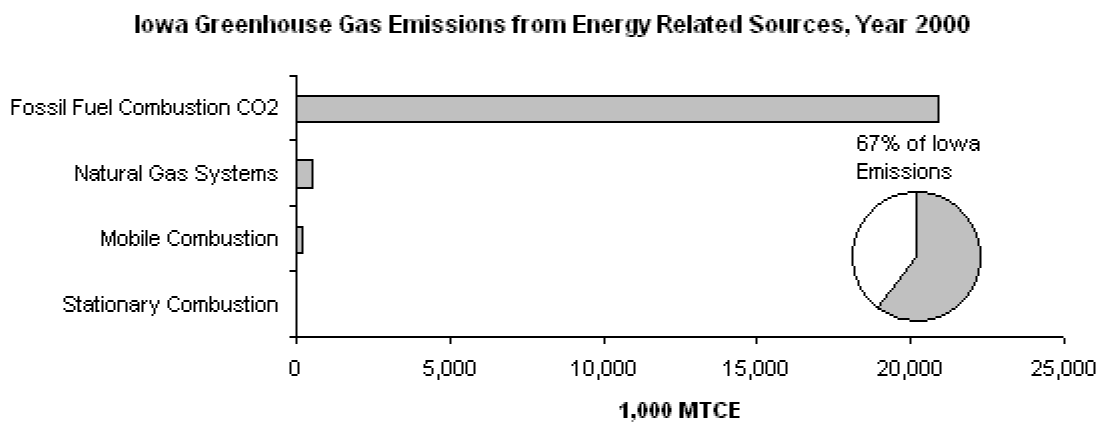


Figure ES-3. The leading source of energy sector emissions was CO_2 generated from fossil fuel combustion.

Agriculture. Agricultural activities, with 27 percent of overall emissions, made up the second largest category of greenhouse gas emissions. Figure ES-4 illustrates the contributing sources, the largest of which is soil nitrogen amendment through cropping practices, comprising 6.3 million MTCE (19 percent of total emissions). This activity includes application of synthetic and organic fertilizers, incorporation of crop residues into the soil, growth of nitrogen fixing crops and deposition of manure directly onto pastures. This source is a factor of six higher than the estimates published in the 1990 inventory, but the dramatic rise is likely an artifact owing to improvements in the method of estimation. Previously, only the fraction of emissions from application of fertilizers was quantified. Also new to the methodology is the estimate of carbon dioxide from field lime ($CaCO_3$) applications, calculated to release 222,545 MTCE.

Emissions from manure management increased slightly from 1990, masking the large shifts that occurred in animal populations. The substantial rise in numbers of swine and layer chicken in the past decade pushed emissions upward, while the large drop in cattle populations served to hold down the overall increase. Emissions of nitrous oxide rose from 854,941 MTCE in 1990 to 989,376 MTCE in 2000. Methane also increased from 220,845 MTCE to 235,916 MTCE. The lower ruminant cattle population decreased emissions from enteric fermentation in domesticated animals from 1.2 million to 0.9 million MTCE.

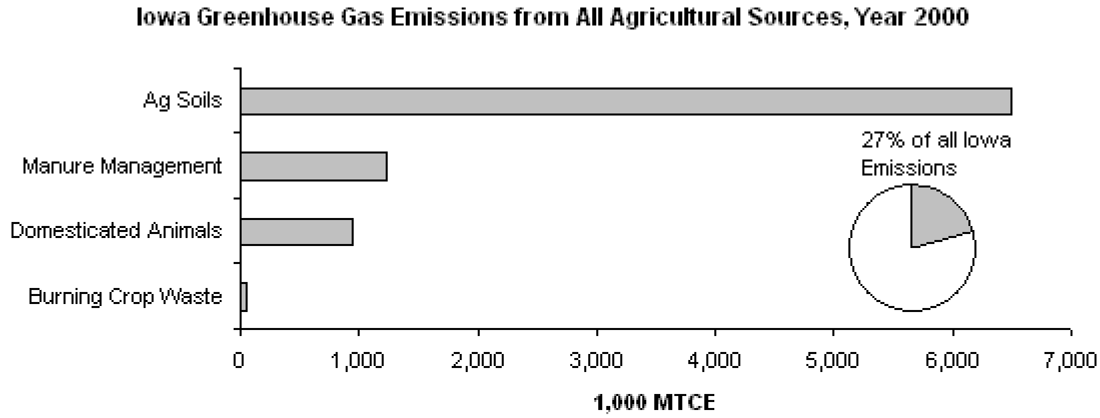


Figure ES-4. Emissions from agricultural soils dominated the agricultural source category. Burning crop wastes was not a significant source of emissions.

Burning of agricultural crop residues was identified as a large emitter of carbon dioxide in the 1990 inventory. However, full carbon cycle analysis indicates that biogenic sources of carbon dioxide such as crop residue burning do not produce significant net greenhouse gas emissions. Based on this reevaluation we calculated the 2000 emissions and recalculated the 1990 emissions and found them to be of minimal importance. Moreover, the method of calculating gross emissions from this source, based on average national values, may be overestimated for Iowa because burning agricultural fields is rather uncommon in the state. Total mass burned may have increased in 2000 relative to 1990 because of the increase in crop yield, but the emissions are still rather miniscule. Methane and nitrous oxide are estimated to have increased from 21,375 and 13,245 MTCE to 26,558 and 17,431 MTCE, respectively. The total represents about 0.1 percent of Iowa's entire greenhouse gas burden.

Industrial processes. As shown in Figure ES-5, emissions from non-energy related industrial processes are minor compared to the energy and agriculture categories, estimated to contribute only about 0.9 million MTCE (3 percent) to the total emissions. Cement clinker manufacture and limestone ($CaCO_3$) use in industry are the largest emitters of carbon dioxide (total of over 400,000 MTCE). Lime (CaO) manufacture, reported to be a major CO_2 emitter in the 1990 inventory (over 500,000 MTCE), is estimated to be much smaller in 2000 (34,000 MTCE). The latter conclusion is tenuous, however, because the current estimate came from an anonymous government source using proprietary data, and an undisclosed method of calculation by the U.S. Environmental Protection Agency (EPA).

Nitric acid production, based on its synthesis in fertilizer production, is the largest emitter of nitrous oxide, accounting for 229,000 MTCE. In the 1990 inventory, this gas was unreported because of lack of activity data.

Substitutes for ozone depleting substances include hydrofluoro- and perfluorocarbons (HFCs and PFCs). Emissions of HFCs and PFCs were estimated to have risen sharply between 1990 and 2000 with the increase in their use as substitutes for ozone-depleting chlorofluocarbons (CFCs), going from 2,740 MTCE to 163,916 MTCE in the ten-year period. In contrast, emissions of sulfur hexafluoride (SF_6) were estimated to be dropping in its use in electrical transformers because of increased environmental awareness about its potency as a greenhouse gas.

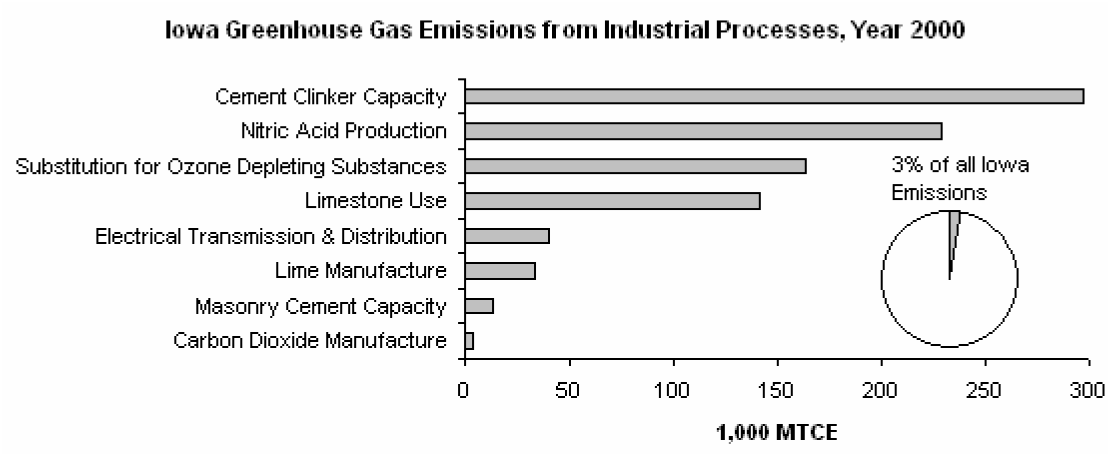


Figure ES-5. Industrial emissions were dominated by cement clinker production, and a few other processes.

Waste treatment. Sources of emissions from treatment of wastes are provided in Figure ES-6. At about 1.1 million MTCE (3 percent of the total), they are comparable in magnitude to industrial emissions, but net emissions are significantly lower at about 0.5 million MTCE owing to methane recovery and carbon sequestration in landfills. Wastewater and sludge treatment at sewage treatment plants release methane and nitrous oxide emissions totaling an estimated 65,000 MCTE. Of this total about 23,000 MCTE are recovered as methane, yeielding net emissions of about 41,000 MTCE. These numbers may underestimate emissions somewhat because they are based on only treatment of human wastes, rather than considering all organic matter removed during municipal wastewater treatment.

Methane emissions from solid waste disposal (landfills), the most significant source by far, increased slightly between 1990 and 2000. Undoubtedly, they would have risen higher had it not been for initiatives set in place to reduce landfill usage through source reduction and recycling. The amount of carbon that remains buried and unoxidized in landfills is considered to be sequestered, crediting Iowa with an annual savings of over 413,377 MTCE. The large expansion of methane recovery and flaring at landfills provided Iowa with an additional 150,000 MTCE in carbon credits.

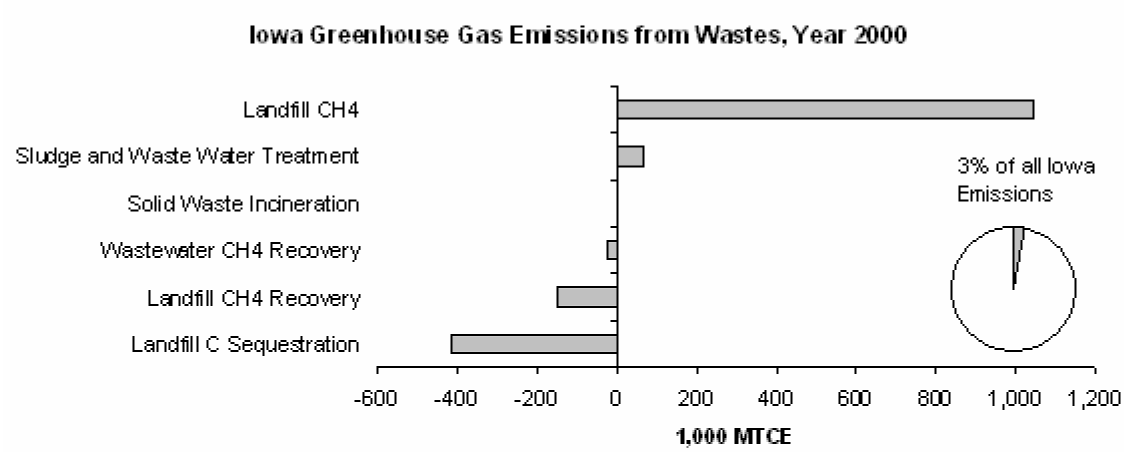


Figure ES-6. Landfills are the largest source of emissions, as well as the largest source of carbon capture among waste management practices.

Forest management/Land-use change. Figure ES-7 gives the magnitudes of carbon sequestration in the category "forest management/land-use change." These agricultural and forest "sinks" for carbon serve to offset emissions of greenhouse gases from the other four categories. During the 1990s, forests (biomass plus soil) were estimated to be sinking 2.9 million MTCE per year. Using a different method of estimation for forest carbon flux, Ney et al. (2001) reported that Iowa forests were sinking 1.2 million MTCE annually. The expansion of forestland may account for some of the difference between estimates. With regard to carbon sequestration in agricultural soils, the U.S. Department of Agriculture/Natural Resource Conservation Service estimated that Iowa agricultural soils absorb 3.1 million MTCE annually, mostly as a consequence of adopting conservation tillage and to a lesser degree due to increased crop yields (Brenner et al., 2001).

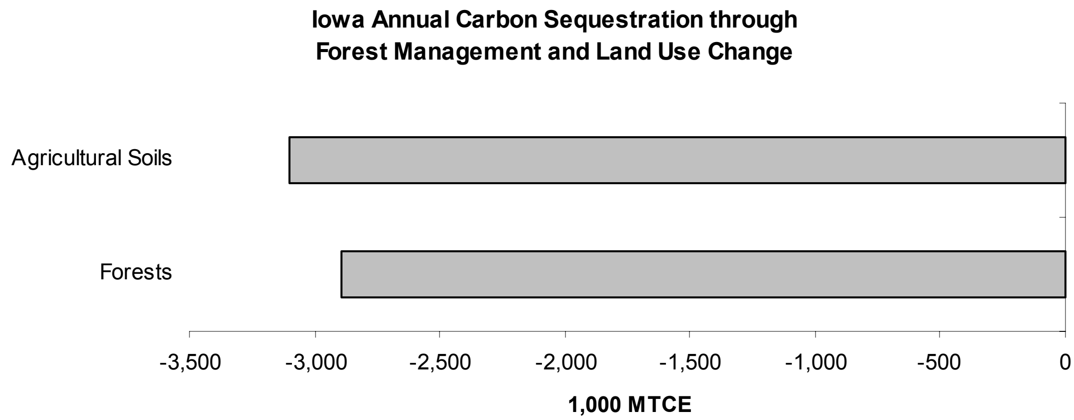


Figure ES-7. Forests in Iowa cover a small part of the state but sequester almost as much carbon as agricultural soils.

Solutions for Mitigating Greenhouse Gas Emissions

Iowa has numerous options to reduce emissions of greenhouse gases. These include the development of renewable energies, enhancement of energy efficiency and recycling, and carbon sequestration. It was determined that initiatives such as these currently offset 8.7 million MTCE annually. The potential impacts of these options are summarize in Figure ES-8, and explored in more detail below.

Wind – annual emission reduction potential of 10 to 39 million MTCE. Jumping from a nameplate capacity of less than 0.5 MW in 1998 to 194 MW in 1999 to 471 in 2004, wind is the fastest growing renewable energy source in the state, with plans to expand capacity to 781 MW by 2006. At that point, Iowa wind will deliver nearly 2 million MWh of electricity and avoid 541,000 MTCE in carbon emissions annually. Wind power appears to possess the largest potential by far of any measure Iowa could undertake to offset greenhouse gas emissions. Estimates of the state's remaining untapped wind potential are huge, suggesting that Iowa could supply up to four times its electricity demand in 2000, with an offset in emissions of between 9.5 to 38.7 million MTCE per year. Less conservative estimates suggest the potential is 12 times the state's electricity demand, providing offsets up to 132.1 MTCE.

Potential to Offset Greenhouse Gas Emissions in Iowa by Use of Renewable Energies, Energy Efficiency, Recycling/Source Reduction, and Carbon Sequestration in Soils

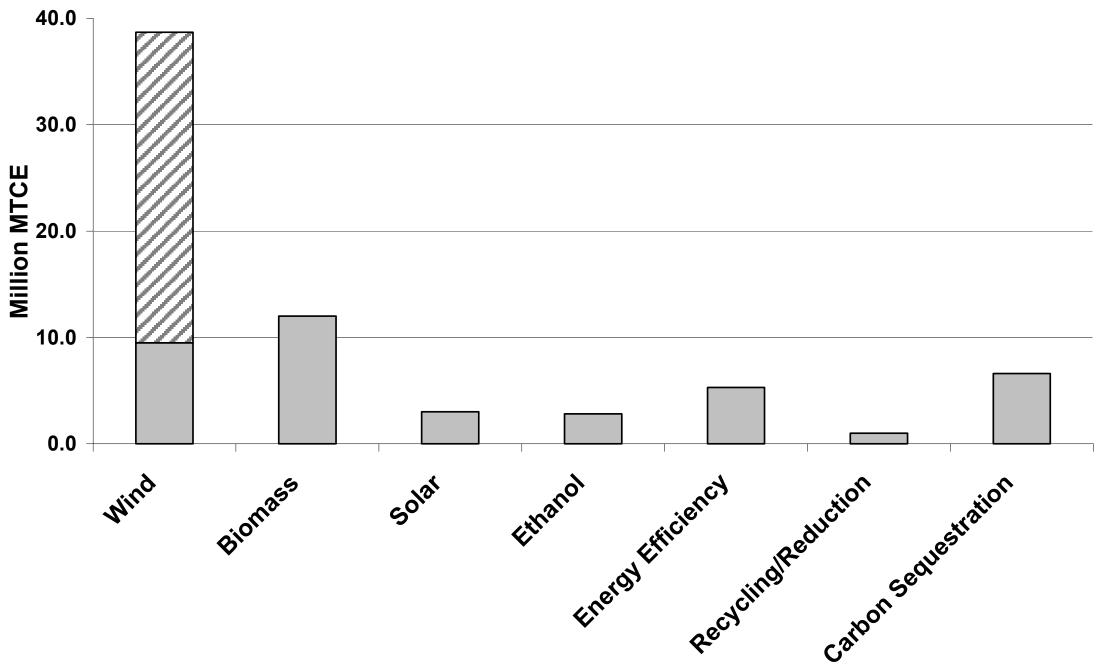


Figure ES-8. Wind and biomass energy, and carbon sequestration appear to offer the greatest potential for offsetting greenhouse gas emissions. Gray area under wind signifies emissions offset if wind-generated electricity were to equal state's total electricity consumption in 2000; combined gray/hatched area corresponds to emission offsets if wind-generated electricity were to produce four times the state's year 2000 consumption.

Biomass – annual emission reduction potential of 12 million MTCE. Energy from biomass represents a large potential for greenhouse gas emission reductions. The most promising resources available for development are corn stover and dedicated energy crops. Expansion of methane recovery from landfills, wastewater and livestock also represent feasible options to capture energy from biomass and abate CH_4 emissions. All together, biomass resources can offset 12 million MTCE of carbon dioxide, primarily through replacement of coal-fired electricity.

Solar – annual reduction potential of 3 million MTCE. Solar power in Iowa is a feasible option as a clean, renewable energy resource. The fastest growing market for photovoltaic (PV) technologies is in customer-sited, grid-connected, roof-mounted systems in the residential and commercial sectors (National Renewable Energy Laboratory, 2003). The more than 940,000 single family homes in Iowa provide up to 58.4 million square meters of roof space for mounting PV panels with a generation potential of 13.6 million MWh of electricity, or 22 percent of year 2000 electricity consumption. Avoided emissions would be 3 million MTCE, equivalent to 32 percent of emissions from year 2000 electricity production. However over the short term, Iowa's achievable potential for PV may continue to be modest when compared to wind and biomass development that currently show greater balance between costs and benefits.

Ethanol – annual emission reduction potential of 2.8 million MTCE. Iowa has embraced the benefits of ethanol fuels; more than half of year 2000 motor fuel purchases were ethanol blends of either E10 (10 percent ethanol) or E85 (85 percent ethanol) (Iowa Department of Natural Resources, 2002a). Because the use of ethanol brings feedstock and fuel production to the state, the result is higher in-state emissions from the agriculture and energy use categories that must be balanced against gains from reduced fuel combustion emissions. Consuming 93 million gallons of ethanol in 2000, the state offset gasoline combustion emissions by 149,915 MTCE. There is great potential in Iowa to further replace gasoline with ethanol. Analysis shows that if all gasoline sold in the state were blends of E10 or E85, gasoline emission offsets would be 237,716 MTCE and 2,831,305 MTCE respectively.

Energy efficiency programs – annual emission reduction potential of 5.3 million MTCE. Energy efficiency programs have focused on demand-side management, including residential tune-ups and weatherization, energy-efficient equipment rebates, new construction, and recycling. Since 1990, Iowa's programs are estimated to have offset more than 1 million MWh of electricity and about 283,000 MTCE emissions. Great potential still exists to enhance energy efficiency in the state, and Iowa is committed to expanding its progress. The Iowa Department of Natural Resources (IDNR) is an active partner in programs that encourage energy efficiency installments across all sectors. A study through the U.S. Department of Energy's Oakridge National Laboratory examined the potential for demand-side energy management to reduce consumption in the state by the year 2020 (Hadley, 2001). Using an economic simulation model with a moderate energy efficiency policy scenario and an industrial market assessment survey, the study found that Iowa could reduce projected energy use across all energy sectors by 5 percent by 2020.

A detailed study commissioned by Iowa's four investor owned utilities (Global Energy Partners, LLS, 2002) explored emission reductions through the implementation of 258 demand side management energy efficiency measures specific to 26 segments of Iowa's end use sectors. Interestingly, the residential sector had the greatest technical savings potential through lighting, cooling and water heating. Ideally, by year ten of a plan working toward implementing these measures, Iowa could be saving up to 5.3 million MTCE annually.

Recycling and source reduction – annual emission reduction potential of 979,731 MTCE. A report prepared by the Tellus Institute (1999) analyzed emission reductions due to recycling and source reduction activities in the state. The analysis employed state landfill use reduction goals as the basis for the avoided emissions from resource extraction and manufacturing. In 1995, Iowa attained a 33 percent reduction in waste relative to the 1988 baseline, resulting in annual greenhouse gas emission reductions estimated at 575,589 MTCE. Projections for future scenarios show that if Iowa were to reach the 50 percent waste diversion goal, it could avoid nearly 1 million MTCE annually. If diversions were to drop to 25 percent, avoided emissions would accordingly decline to 374,023 MTCE.

Carbon sequestration – annual emission reduction potential of 6.4 million MTCE. Carbon sequestration is one of the most promising options to reduce net greenhouse gas emissions. As a major agricultural state, Iowa can exploit the opportunity to reduce soil carbon emissions and thus store more soil carbon through adoption of conservation tillage.

The Iowa Carbon Storage Project has created a county level database that provides modeled predictions of soil carbon storage resulting from changes in crop rotations, tillage regimes, and enrollment in the Conservation Reserve Program (Brenner et al., 2001). This database can help focus carbon sequestration initiatives by indicating where the greatest potential for carbon storage exists. Most of the 4.3 million hectares (10.6 million acres) of agricultural land are still managed by conventional tillage practices. If three-quarters of this area were to convert to "no-tillage" management, 4.4 million MTCE could be returned to the soil annually.

Reforestation was an option featured in the Iowa Greenhouse Gas Action Plan (Iowa Department of Natural Resources, 1996). Converting between 200,000 and 1 million acres of land to forest would store an estimated 224,000 to 1.1 million MTCE per year, respectively. The inclusion of 200,000 acres of hybrid poplar tree as buffer strips could sequester and estimated additional 817,000 MTCE in Iowa's riparian environments. An initiative to establish switchgrass as a biofuel for cofired electricity generation would restore carbon to the lands in which they are grown. Building 100 MW of capacity from switchgrass could sequester an estimated 81,400 MTCE annually. Taken together, no-till management, reforestation, planting of poplar buffer strips and development of bioenergy crops can restore between 5.5 million and 6.4 million MTCE per year.

Conclusions. Any comprehensive solution for mitigation of greenhouse gas emissions in Iowa must focus considerable effort on reductions in fossil-fuel derived combustion. Generation of electricity by coal and gasoline consumption dominate fossil fuel use and continue to grow. Although Iowa has made considerable improvements in energy efficiency and enormous strides in development of renewable energies, efforts thus far have been unable to keep pace with growth in fossil fuel use.

No one strategy will reverse this trend. Rather, an array of coordinated actions can serve to reign in net greenhouse gas emissions. It is even possible that Iowa could one day become a net "negative emissions" state, in which sequestration and capture of greenhouse gases exceeds their in-state emissions. This would require far greater investment in renewable sources of energy generation, implementation of more aggressive energy efficiency measures, expanded recycling and source reduction programs, and continued development of land-use activities that sequester/capture carbon in landfills, forests and croplands.

Chapter 1: Fundamentals

Comparing the 1990 and 2000 Inventories

Responding to mounting concern over global climate change, Iowa was among the first states to complete an independent state level greenhouse gas inventory in 1992. Later, fulfilling a need to provide a uniform methodology for comparison between states, the U.S. Environmental Protection Agency (EPA) provided the first state workbook for estimating emissions. The methodology was based on guidelines offered by the Intergovernmental Panel on Climate Change (IPCC) for country level greenhouse gas analysis. In 1996, Iowa completed a baseline inventory for activities and emissions for the year 1990, using the EPA State Workbook (Iowa Department of Natural Resources, 1996).

Major findings of the inventory included:

- Iowa's net greenhouse gas emissions were estimated at 21.5 MTCE.[2]
- Fossil fuel combustion was the main source of greenhouse emissions, contributing 70 percent of net emissions.
- Compared to other states, Iowa ranked 15th highest for carbon dioxide emissions per capita from fossil fuel combustion.
- Methane from domesticated livestock was the second largest source (2.1 million MTCE).
- Fertilizer application was estimated to be only 4 percent of gross emissions (1.1 million MTCE).
- Burning of agricultural crop wastes was estimated to be 7 percent of gross emissions (since believed to be a vast overestimation).
- Forests were estimated to be sequestering roughly 6.9 million MTCE.

Since the 1990 inventory, the EPA has turned over the task of designing the state level inventory methodology to the Emission Inventory Improvement Program (EIIP). The program has developed volumes of methodologies to help states estimate emissions of various air pollutants. Greenhouse gases are addressed in volume VIII (Emission Inventory Improvement Program, 1999). The methods in volume VIII are based on IPCC guidelines as well as methods from the EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1996* (Environmental Protection Agency, 1998b), and reflects improvements culled from state energy and environmental officials. Because volume VIII represents the most current methods available for state greenhouse gas emission inventories, it was the method of choice for this project.

One goal of the year 2000 inventory is to compare emissions with the baseline estimates provided for 1990. The inventory is divided into five categories that encompass activities involved with energy, agriculture, industrial processes, waste management, and forest and land-use management. Each category summarizes the results of analysis based on activity data and emission factors provided by EIIP, volume VIII. An appendix is provided for each category to provide detailed calculations for the derivation of the emission estimates reported here.

There are a number of reasons why emission estimates change over time. A reported

[2] See page 18, for meaning of "MTCE."

reduction or increase does not necessarily mean the situation has improved or degraded. Apparent changes in emissions can be brought on by changes in the methods and assumptions in estimating emissions. In comparing the 1990 and 2000 inventories, the 1990 estimates were recalculated in those cases where methodologies had been updated. Such was the case for Iowa's second largest source of emissions, agricultural soils. The previous inventory quantified direct nitrous oxide emissions only from application of commercial fertilizers. In EIIP, volume VIII, this represents just one-third of direct emissions from agricultural soils. The current method also accounts for indirect emissions from nitrogen application and emissions from animals allowed to graze on fields. Clearly, it is pertinent to determine the comparability of methods of estimation.

On the other hand changes may reflect real changes in level of activity of a particular source. Such was the case for industrial limestone consumption. The 1990 inventory reported consumption of 23 million metric tons of calcite and dolomite. Sources for year 2000 indicate only one million metric tons were used by the industry. This reduction in activity led to a very different estimate of emission.

The Natural Greenhouse Effect: Protector against "Iceball" Earth

The natural greenhouse effect is a well understood phenomenon. (For a detailed explanation, see the IPCC's latest report *Climate Change 2001 The Scientific Basis* (Baede et al., 2001). The sun emits radiation to Earth in the form of visible, near-infrared (IR) and ultraviolet (UV) light with a flux rate of 342 Watts/m^2. A portion of this radiation (107 Watts/m^2) is reflected back to space by the clouds, atmosphere and Earth's surface; this reflected light does not play a role in Earth's overall heat balance (Spiro and Stigliani, 2003). Some of the solar energy not reflected is absorbed by the atmosphere (67 W/m^2) and the remainder by Earth's surface (168 W/m^2). By the laws of physics Earth's heat balance must be in steady state, i.e., the incoming solar radiation must be balanced by outgoing radiation from Earth's surface and atmosphere, which in this report we shall name "earthshine." While the incoming sunlight is mostly in the visible light range, outgoing earthshine is in the IR range with a flux of 235 W/m^2 to balance the sum of solar fluxes of 67 and 168 W/m^2.

If sunlight and earthshine were the only factors at play in the heat balance, the global average temperature at Earth's surface would be about –18 ^oC (0 ^oF). The result would be a so-called "iceball" Earth, which would be inhospitable to most life on the planet. In actuality, the global average surface temperature is much warmer at +14 ^oC (57 ^oF). We owe this warming effect to the natural "greenhouse effect." It occurs because some of the earthshine emitted to the atmosphere is intercepted by certain gases in the atmosphere (the "greenhouse" gases) that first absorb the radiation and subsequently re-emit it. A portion of the re-emitted radiation is reflected back to earth's surface, thereby heating it and raising its temperature. The overall heat balance is maintained because the surface is heated at the expense of the atmosphere, which is cooled by the greenhouse effect. The main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and water (H_2O). Thus, the current debate about the greenhouse effect is not whether it is good or bad; clearly we owe our existence to it. Rather, it is whether or not, by increasing the concentrations of greenhouse gases in the atmosphere, we are creating too much of a good thing? Scientists estimate that the increase in greenhouse gas concentrations in the atmosphere due to human activities has raised the radiation flux back to Earth by 2.43 W/m^2, resulting in an increase in temperature of about 0.6 ^oC. The year to which temperature and flux increases are compared is 1750, which serves as a pre-industrial baseline when little anthropogenic radiative impact is assumed. Though the current magnitude of radiative change is small in comparison to the total radiation entering and leaving the atmosphere, growth in this imbalance could have severe impacts on the Earth's climate systems.

Among the greenhouse gases cited above, water is not a major issue because its concentration is regulated by the hydrological cycle and out of our control. The focus of policy debate is on the other three natural greenhouse gases, and a few additional ones that are not found in nature, but rather are synthetic industrial gases that by coincidence also exhibit a greenhouse effect. In this latter category, the major ones are the chlorofluorocarbons (CFCs) formerly used in foam insulations, aerosol sprays, and air conditioners. They are being phased out due to strong international cooperation between nations and industries that produce them. However, their long lifetimes in the atmosphere (45 – 1,700 years) and their radiative efficiency mark them as important players in perturbing the radiation imbalance long after we have ceased emitting them to the atmosphere. There are other greenhouse-active, synthetic gases with very small low current emissions, that may be more abundant in the future. Moreover, there are drivers of climate change other than greenhouse gases that may serve to heat or cool the climate. Among these are trophospheric aerosols, land-use change, solar irradiance and stratospheric aerosols (Ramaswamy, et al. 2001). Uncertainty over the net impact of all these agents is a favored argument among critics of those advocating actions to mitigate climate change.

Global Warming Potentials (GWP)

Scientists have adopted the parameter global warming potential (GWP) as an index for assessing the relative potency of well mixed greenhouse gases over a particular time horizon. Specifically, it quantifies the capacity of a gas to trap IR radiation in comparison to CO_2, which has been designated as the reference gas and assigned a GWP value of 1. Molecular radiative properties (i.e., radiative efficiency, abundance) control the absorption of radiation per kilogram of gas at any instant, but the atmospheric lifetime determines the duration over which this absorption can take place (Ramaswamy, et al., 2001). Both factors are considered in the quantification of GWP. Values can be assigned only to those greenhouse gases with atmospheric lifetimes long enough to allow homogeneous mixing in the troposphere (so-called "well mixed" gases). This is not the case for gases with regionally distinct patterns of accumulation such as water and tropospheric ozone.

As shown n Table 1, greenhouse gases have atmospheric lifetimes ranging from a few years to millennia. On timescales important to humans, say one or two generations, gases with extremely long lifetimes represent essentially irreversible emissions, having the potential to build up in the atmosphere without an efficient removal mechanism. Fortunately, the gases with the longest lifetimes are emitted in the lowest quantities and have minimal or no natural sources. Halting the buildup of these essentially synthetic chemicals can be accomplished through bans on production, as is the case currently with the CFCs. On the other hand, more abundant gases with relatively shorter lifetimes and large human-derived emissions are the most promising targets for quelling future greenhouse forcing, because greater reductions by mass can be achieved.

Table 1. Atmospheric lifetimes (years) and Global Warming Potentials of well mixed greenhouse gases based on a 100-year time horizon.			
Gas	**Atmospheric Lifetime**	**GWP [a] Year 1996**	**GWP [b] Year 2001**
CO_2	50-200	1	1
CH_4 [c]	12	21	23
N_2O	114	310	296
CFC-11	45	4,000	4,600
HFC-23	260	11,700	12,000
HFC-125	29	2,800	3,400
HFC-134a	13.8	1,300	1,300
HFC-143a	52	3,800	4,300
HFC-152a	1.5	140	120
HFC-227ea	33	2,900	35,00
HFC-236fa	220	6,300	9,400
HFC-4310mee	15	1,300	1,500
CF_4	50,000	6,500	5,700
C_2F_6	10,000	9,200	11,900
C_4F_{10}	2,600	7,000	8,600
C_6F_{14}	3,200	7,400	9,000
SF_6	3,200	23,900	22,200

Source: Intergovernmental Panel on Climate Change, 2001.
[a] GWP used in this inventory represents figures from the second IPCC assessment report in 1996.
[b] GWP was updated in Third Assessment Report of the 2001 IPCC.
[c] Methane GWP includes direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor; the indirect effect due to the production of CO_2 is not included.

Quantification of GWP for different time horizons (e.g., 20, 100, 500 years) is useful for analysis of shorter term impacts, such as the response of cloud cover to surface temperature change or longer term impacts such as sea level rises (Ramaswamy et al., 2001). The United Nations Framework Convention on Climate Change (UNFCC) has established the 100-year time horizon as the foremost measure for member countries in assessing global warming impacts of greenhouse gases (Environmental Protection Agency, 2001). These figures have been recently revised in the IPCC third assessment report on climate change (Intergovernmental Panel on Climate Change, 2001). Table 1 shows the earlier and revised GWPs and atmospheric lifetimes for a range of greenhouse gases. In this inventory, we employ the GWPs cited in the second IPCC assessment report published in 1996. This was done to conform to the 1996 values cited in the EPA national greenhouse gas inventory for 2000, in compliance with the UNFCC reporting guidelines. Supplemental analysis of the U.S. inventory showed these revised values did not have a significant overall effect on U.S. emission trends, showing only a 0.7 percent increase in year 2000 emission estimates when new GWP values replaced the 1996 values (Environmental Protection Agency, 2001).

Some gases, namely methane, carbon monoxide, nitric oxides and CFCs, can exert an indirect effect on the global radiative budget. This category consists of both greenhouse and non-greenhouse gases that are chemically reactive in the atmosphere and in some measure exert controls on the abundances of the direct greenhouse gases (Ehhalt et al., 2001).

Methods for quantification of indirect GWPs are highly uncertain because such reactions can be difficult to predict owing to a number of processes and conditions that contribute to the indirect effects of various molecules. Complex and highly uncertain models have been employed to estimate indirect effects of several gases. However, these values remain unused for inventorying gases (Ramaswamy, et al., 2001).

The Greenhouse Gases

Carbon dioxide (CO_2). Atmospheric concentrations of carbon dioxide have risen by 32 percent since preindustrial times, from around 280 ppm by volume (ppmv) in 1750 to about 370 ppmv today (Albritton et al., 2001). The IPCC states that such a rapid increase has not occurred for at least the past 20,000 years and is a consequence of anthropogenic carbon dioxide emissions, mostly from burning fossil fuels and clearing of forested land. Radiative forcing[3] for this gas is estimated at 1.46 W/m^2, corresponding to 60 percent of the total forcing from anthropogenic changes in concentrations of all long lived and well mixed greenhouse gases.

Carbon is naturally cycled through the terrestrial, ocean and atmospheric reservoirs as organic matter, minerals and gases. Lifetimes in these environmental compartments range from weeks to centuries and longer. The carbon cycle is of particular importance to life on the planet. Carbon dioxide is the primary vehicle of carbon exchange between the atmosphere and other reservoirs. Growth and decomposition of biomass represent a full cycle of carbon exchanged between the atmosphere and biosphere. During photosynthesis plants fix carbon dioxide to organic carbon, the building block for a vast array of vegetative structures that comprise plant biomass. Eventually this biomass is transformed by direct microbial decomposition on land or sea, by herbivore consumption, or by combustion (e.g., forest fires, burning wood for fuel). In each case the organic carbon is reoxidized to carbon dioxide and returned to the atmosphere. In nature, this cycling is assumed to occur in a steady state with no net increase or decrease in atmospheric carbon dioxide, and thus with no net climate forcing. The aerobic decomposition of grass clippings, the harvesting and consumption of crops, the burning of prairies and forests for maintenance, and even *sustainable* harvest of wood and grasses for fuel and products are not sources of emissions that need to be counted in inventories like this one.

In contrast, emissions that result in the loss of long-stored carbon from land and sea to the atmosphere disrupt the natural equilibrium of carbon between its various reservoirs. There are two major sources of such emissions -- the clearing and conversion of forest and grassland and the excavation and combustion of fossil fuels. Deforestation is occurring on a large scale in developing countries, particularly in the rain forests of Brazil and Indonesia, where demands for wood and clear cutting for agriculture are the driving forces. In other parts of the world, particularly the Northern Hemisphere, reforestation is apparently a net sink for carbon. Globally, however, the net loss of carbon from forests to the atmosphere is estimated to be 1.6 ± 0.8 gigatons (10^9 tons) carbon per year. The IPCC reports that regenerated forests store less carbon than natural forests, even at maturity (Prentice et al., 2001). Thus, fully restoring the carbon lost during deforestation will be difficult to achieve.

Globally, fossil fuel combustion, estimated to release on the order of 5.8×10^9 metric

[3] Radiative forcing corresponds to the calculated additional radiation that human-added greenhouse gases radiate back to Earth's surface beyond that already radiated by the natural greenhouse effect.

tons of carbon per year, is responsible for three quarters of human influenced greenhouse gas emissions (Albritton et al., 2001). Nationally, CO_2 from fossil fuel combustion comprised 81 percent of gross greenhouse gas emissions with 1.6 x 10^9 metric tons carbon in 2000 (Environmental Protection Agency, 2002).

Methane (CH_4). Methane is the second most dominant greenhouse gas. By weight it possesses about 21 times the heat trapping capacity of carbon dioxide. Almost 20 percent of the increase (0.48 W/m^2) in radiative forcing by anthropogenic greenhouse gas emissions comes from methane (Ramaswamy, et al., 2001). Nationally, it accounted for 9 percent of greenhouse gas emissions in 2000 with 167 million MTCE (Environmental Protection Agency, 2002). Analysis of snow and ice cores has determined that the atmospheric concentration of this gas has increased two-and-one half times since preindustrial times, from about 700 parts per billion by volume (ppbv) to about 1750 ppbv, although the rate of increase has been declining in recent years (Environmental Protection Agency, 2001; Ehhalt et al., 2001). It is estimated that approximately 60 percent of this global increase originates from anthropogenic activities, and natural sources such as wetlands, termites, oceans and hydrates contribute the balance (Ehhalt et al., 2001).

Anaerobic decomposition of organic matter is the primary cause of human-derived methane emissions. The main sources are disposal of waste in landfills, enteric fermentation by domesticated animals, decomposition and treatment of organic wastes, and wetland rice cultivation. Other sources of methane release come from the energy sector and include emissions of unburned hydrocarbons from mobile and stationary combustion, coal mining, and fugitive emissions from drilling and transporting petroleum and natural gas. Another minor source comes from the burning of agricultural residues. In nature, methane is emitted from wetlands, termites, ocean water and sediment, and methane hydrate deposits on the ocean floor (Ehhalt et al, 2001; Environmental Protection Agency, 1999a).

The major removal mechanism of atmospheric methane is reaction with the hydroxyl radical (OH•) in the troposphere, producing water and carbon monoxide, which is rapidly oxidized to carbon dioxide (Environmental Protection Agency, 1999a).

Nitrous oxide (N_2O). Nitrous oxide accounts for about 6 percent (0.15 Wm^{-2}) of the increased global radiative forcing from well-mixed greenhouse gases. Although its concentration is about 1,000 times lower than carbon dioxide and 5.5 times lower than methane, it exerts a disproportional influence on radiative forcing because of its high GWP value of 310. Nationally, it is responsible for about 6 percent of gross greenhouse gas emissions at 117 million MTCE (Environmental Protection Agency, 2002).

Globally, the greatest source of rising emissions of N_2O is agricultural soils, caused by the ever increasing use of synthetic nitrogen fertilizers since the end of World War II and the increased production of legumes, which fix atmospheric nitrogen (i.e., convert N_2 to NH_3). Excess nitrogen amendments in these environments that are not taken up by crops undergo microbial conversion mostly to diatomic nitrogen (N_2), but also to nitrous oxide as a minor byproduct (Ehhalt et al, 2001).

Another major source of rising emissions is the combustion of fossil fuels by which high ignition temperatures convert atmospheric nitrogen (N_2) to nitric oxide (NO). The nitric oxide is subsequently converted to nitric acid (HNO_3) in the atmosphere and deposited on land. Some of the excess not taken up by plants is microbially transformed to N_2O, especially in phosphorus-limited ecosystems of the tropical southern hemisphere (Ehhalt et al, 2001).

Chlorofluorocarbons (CFCs), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexaflouride (SF_6). Since international bans against the production of ozone depleting CFCs began with the 1987 Montreal Protocol, chemical companies have been producing and marketing substitutes. This switch has led to a peaking and subsequent slow decline in atmospheric concentrations of CFCs. Although they were phased out because of concern for their ability to deplete stratospheric ozone, some of the CFCs are also long-lived, potent greenhouse gases. Currently among the well-mixed greenhouse gases CFCs as a group exert the third highest radiative forcing at 0.34 W/m^2, or 14 percent of the global total.

Although the substitute chemicals do not present a threat to stratospheric ozone, some of them, particularly the hydrofluorocarbons, are powerful greenhouse gases. One such species is HFC-134a, used as a refrigerant in car air conditioners. This gas has grown from an atmospheric concentration of near zero in 1990 to 7.5 parts per trillion in 2000 (Ramaswamy, et al., 2001). Although emissions of HFC-134a are still extremely low relative to other greenhouse gases, its high GWP value of 1,300 translates to a contribution in emissions of 41.6 million MTCE per year. None of the HCF molecules have significant natural sources, thus any accumulation in the atmosphere is due to human releases. Although their atmospheric abundance has grown nearly exponentially in the past decade, the gases still only represent a small part (0.003 W/m^2) of radiative forcing from well mixed gases. However, they are expected to have a greater influence in the future as a result of the ban on ozone depleting substances.

Because perfluorocarbons (including CF_4, C_2F_6, C_4F_{10}, C_6F_{14}) and sulfur hexaflouride (SF_6) have atmospheric lifetimes of more than 1,000 years and absorb a large range of infrared radiation, they are powerful greenhouse gases with GWPs ranging from 6,500 to 23,900 on a 100-year time horizon. They result mostly from industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Although their contribution to radiative forcing has been small in the past (0.006 W/m^2), it is expected to increase because of their extremely long lifetimes, strong ability to trap gases, and (except for SF_6) significant growth rates (Environmental Protection Agency, 2002).

Tropospheric ozone (O_3). From the time period extending from pre-industrial times to the present, tropospheric ozone is estimated to be the third most influential greenhouse gas[4] after carbon dioxide and methane (Ehhalt et al., 2001). Current estimates of atmospheric concentrations come only from direct monitoring and satellite data. This is because it is not directly emitted from any source, rather it is the product of photochemical reactions of CH_4, NO_x (i.e., NO and NO_2), CO and volatile organic compounds (VOCs) that are emitted during fossil fuel combustion, numerous industrial processes, and biomass burning (Environmental Protection Agency, 2002). Ozone has a very short lifetime relative to other greenhouse gases, ranging from days to months. With no agreed-upon value of GWP, and no method for estimating the load in the atmosphere originating from any one source, ozone is not included

[4] The class of CFC chemicals constitute the third most important greenhouse gas among well-mixed atmospheric gases. O_3 is the third most important overall, but it is not a well-mixed gas.

in greenhouse gas inventories.

Photochemically active and indirect greenhouse gases. Apart from possessing direct heat trapping ability, a gas may be a reagent in a chemical transformation leading to the production of a direct greenhouse gas species. Alternatively, it may interact with other gases to influence the radiative importance of direct greenhouse gases (Ehhalt et al., 2001). In these ways a gas can have an indirect forcing effect. For example as discussed above, the direct greenhouse gas ozone is formed by reactions of CH_4, NO_x, CO and VOCs. Because reactions leading to ozone production are largely dependent on environmental conditions (specifically sunlight), it is difficult to quantify the indirect GWP of these gases.

Chlorinated and brominated halocarbons have been found to exert a negative indirect climate forcing through reactions that destroy stratospheric ozone. Carbon monoxide is generated from incomplete combustion of fossil fuels and other organic materials. This gas has two indirect mechanisms that impact greenhouse forcing. By engaging the hydroxyl radical, the gas interferes with major pathways of removal of methane and tropospheric ozone from the atmosphere, thus prolonging their effective atmospheric lifetimes. Carbon monoxide is also involved in photochemical reactions that produce ozone, thus providing a second mechanism that increases ozone concentrations.

Methane exerts a similar feedback on its own atmospheric lifetime. Increased emissions of methane in past decades are thought to have reduced the availability of methane-destroying hydroxyl radicals, thereby reducing a major sink for removal of methane from the atmosphere (Ehhalt et al., 2001). The oxidation of methane by the hydroxyl radical also produces stratospheric water vapor and carbon dioxide, both of which are direct greenhouse gases. Besides the direct heat trapping capacity of methane, its indirect effect on ozone and water vapor has been incorporated in the GWP reported above.

For most indirect greenhouse gases, spatial variability, short lifetimes and complex interactions make it difficult to derive GWPs and include them in greenhouse gas inventories. Models using multidimensional analysis have attempted to quantify a GWP for carbon monoxide (CO). Although results are highly uncertain and not yet included in greenhouse gas inventories, they estimate a CO GWP value with a 100-year time horizon to be between 1 and 3 (Ramaswamy et al., 2001).

Units (MTCE)

The principal unit of measure in this inventory is “metric tons carbon equivalents” (MTCE). This is the standard reporting unit for state inventories as indicated in EIIP, volume VIII. The national inventory for 2000 as well as the 1990 Iowa inventory reported in a weight of “carbon dioxide equivalents” (Environmental Protection Agency, 2001). Both measures enable a weighted comparison between dissimilar greenhouse gases based on their global warming potential. To convert an amount of greenhouse gas to MTCE units, the following simple relationship holds:

MTCE = (weight of gas) x GWP x 12/44

where the fraction 12/44 is the ratio of the weight of atomic carbon (12) to molecular CO_2 (44). Because the GWP for CO_2 equals 1, when the gas is CO_2 it only needs to be multiplied by 12/44 to obtain the value of MTCE.

Quality Assurance and Control: Data Attribute Ranking System (DARS)

Accompanying the EIIP methodology is a quality assurance/quality control system that quantifies the level of reliability that one can expect from the emission estimation methods. This system is called the Data Attribute Rating System (DARS) and works by evaluating attributes of the two components of the estimation method, viz., emission factors and activity data. After qualitative analysis, a score between 1 and 10 is assigned to each of four attributes including *method of measurement, source specificity, spatial congruity*, and *temporal congruity*.

Evaluation of the measurement method is based on the quality and accuracy of the emission factor or the activity data, regardless of how appropriate it is for the estimation method. It is generally presumed that direct measurements of emissions and activity will yield more accurate data than indirect statistical models. Thus factors and activity data based on direct measurements will yield higher scores than estimations from models. Source specificity looks at the congruence of the component and the emission source. Emission factors developed directly for the source category will receive greater scores than those developed for surrogate sources.

Spatial congruity concerns the spatial scaling of components. Data measured at the state level loses accuracy as it is scaled up or down; the same can be said for the application of climate dependent emission factors as they are applied further away from the original location of development. Data that is measured at the desired level of application and use of geographically specific emission factors will receive relatively higher spatial congruity scores.

Temporal congruity evaluates how appropriately emission factors or activity data are applied regarding their temporal scale. For example, for the annual emission inventory the most appropriate data would be based on yearly activity rather than extrapolating monthly data to a year-long scale. This type of calculation would reduce a DARS score.

Each of the attribute scores is then divided by 10 and the scores for each of the two components are multiplied. Each of the sum attribute scores are averaged to arrive at a single composite score for the methodology. A composite score equal to one indicates greater reliability of the estimate than a lower score. *DARS scores are reported as fractions but do not indicate a percentage of accuracy. They serve as a measure of merit that can be used for comparison between estimates*. In this inventory, no source scored higher than 0.90, and the average score for all source categories was 0.58.

The DARS score for each emission source will be presented with the emission methodology for each source category in the electronic versions of this document. A more complete explanation of each score can be found at the end of each emission source chapter in the EIIP, volume VIII document found at http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html. For further explanation of the method of score assignment, see EIIP, volume VI (chapter 4 and appendix F).

Chapter 2: Summary of Findings

Net Greenhouse Gas Emissions in Iowa in Year 2000 and Comparison with Year 1990

Figure 1 provides an overview of the greenhouse gas emissions and sinks that will be discussed in detail in this inventory. It shows the relative magnitude of 21 greenhouse gas emission sources, and the five greenhouse gas sinks (far right of figure). It is apparent that on the basis of MTCE units carbon dioxide emitted from fossil fuel combustion was the largest source, followed by nitrous oxide emissions from agricultural soils. Methane from manure management, domesticated animals, and solid waste were also significant sources of greenhouse gases. Other sources exerted less impact on total emissions.

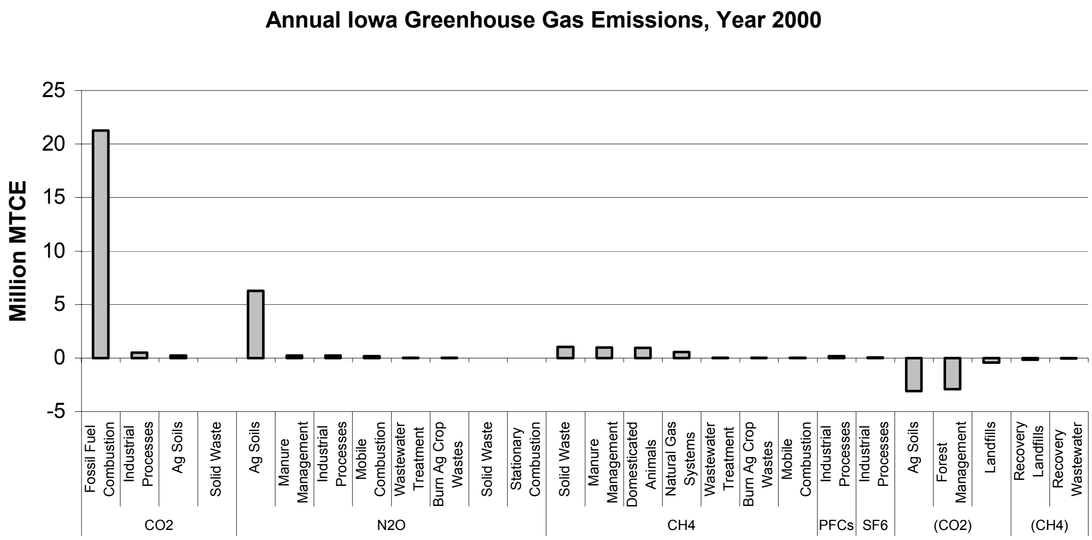


Figure 1. CO_2 from fossil fuel combustion and N_2O from agricultural soils make up 84 percent of all emissions. Agricultural soils and forests also sequestered large amounts of carbon (shown as negative emissions on far right).

Table 2 quantifies the amounts of the emissions for each of the sources depicted in Figure 1,[5] and compares them with the findings of the Iowa 1990 inventory by IDNR (Iowa Department of Natural Resources, 1996). The 1990 numbers are given as originally reported, and recalculated by the authors of the current report using the new calculation methods, where feasible, that were applied in the 2000 inventory. The total emissions are disaggregated into twelve sources for five greenhouse gases, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), and sulfur hexaflouride (SF_6).

[5] Table 2 also lists three sources not shown in Figure 1, viz.: CH_4 from coal mining, which gave no emissions in 2000 because there was no mining activity; CO_2 from crop burning, which yields no significant net CO_2 emissions; and CH_4 from stationary sources, for which no data were available.

Table 2. Summary of gross greenhouse emissions in Iowa in year 2000 and comparison with 1990 (MTCE).

Source	Gas	Reported 1990	Recalculated 1990 [a]	2000
Fossil fuel combustion	CO_2	19,924,586	16,964,059	21,268,523
Industrial processes	CO_2	3,272,252	1,142,768	489,194
	N_2O	0	0	229,071
	PFCs	NA[b]	2,740	163,916
	SF_6	NA	82,753	40,143
Natural gas systems	CH_4	124,105	124,105	553,278
Coal mining	CH_4	833	833	Not Applicable
Municipal solid waste disposal	CH_4	942,027	966,669	1,044,619
	CO_2	NA	2,507	2,505
	N_2O	NA	194	194
Domesticated animals	CH_4	2,069,418	1,221,943	941,024
Manure management	CH_4	641,949	854,941	989,376
	N_2O	0	220,845	235,916
Agricultural soils	CO_2	NA	NA	222,545
	N_2O	1,107,659	1,107,659 [c]	6,277,356 [c]
Burning of agricultural crop wastes	CO_2	1,929,437	0	0
	CH_4	46,305	21,375	26,558
	N_2O	43,890	13,245	17,431
Municipal wastewater treatment (treatment of human wastes)	CH_4	11,251	36,787	38,769
	N_2O	NA	23,138	26,064
Mobile combustion	CH_4	NA	NA	14,212
	N_2O	NA	NA	172,033
Stationary combustion	N_2O	NA	NA	61
	CH_4	NA	NA	NA
Total emissions per gas (all sources, excluding biomass fuels)	CO_2	25,126,275	18,109,334	21,982,767
	CH_4	3,835,888	3,226,653	3,607,836
	N_2O	1,151,549	1,365,081	6,958,126
	PFCs	0	2,740	163,916
	SF_6	NA	82,753	40,143
Total gross emissions		**30,113,712**	**22,786,561**	**32,752,788**

[a] Emissions were recalculated for 1990 where possible using best available new data and year 2000 methodology. If new data were unavailable, the data reported in the original 1990 inventory was retained. Total gross emissions are the sum of all sources, with emissions recalculated when possible, and as previously reported when no recalculation was performed.
[b] NA = not available.
[c] The large disparity between the 1990 and 2000 estimates is likely the result of an artifact in method of calculation.

It appears from the table that emissions have grown by about 10 million MTCE (30 percent) between 2000 and 1990, from 22.8 million MTCE (recalculated) per year to about 32.8 million MTCE per year. As will be discussed in more detail below, the biggest factor in this increase is the rise in fossil fuel combustion. The other large difference in emissions is nitrous oxide for agricultural soils, from about 1.1 million MTCE in 1990 to about 6.3 million MTCE in 2000. However, most of this disparity is undoubtedly an artifact in the calculations, caused by a change in methodology for the 2000 inventory, which accounted for more sources of emissions in the soil. The data for 1990 could not be recalculated using this revision for lack of adequate soil data. It is likely that the soil emissions of N_2O in the two years did not vary so significantly, and assuming that they were approximately the same, the overall rise in year 2000 emissions would only be15 percent relative to 1990.

Table 3 provides an overview in the sequestration and recovery of carbon in Iowa in years 1990 and 2000. The analysis shows that for cases where comparisons of values were feasible, carbon capture appears to have increased. In forestlands the increase was estimated to be about 1.7 million MTCE. The increase was due to the expansion of forestlands, although the difference in part may be explained by the use of a more sophisticated forest inventory in the year 2000. The amount of CH_4 recovered from landfills and wastewater in 1990 was unable to be recalculated, but it was undoubtedly low compared to the amount recovered in 2000 due to the great expansion of this activity in the 1990s. It is also likely that sequestration in agricultural soils grew to some extent owing to implementation of conservation tillage and inclusion of more land in the Conservation Reserve Program.

Table 3. Summary table reporting soil carbon sequestration and methane recovery in Iowa in years 1990 and 2000 (MTCE).

Source	Gas	Reported 1990	Recalculated 1990	2000
Agricultural Soils	(CO_2)	NA [a]	NA	-3,097,730
Forest Management and Land-Use Change	(CO_2)	-6,946,265	-1,200,000	-2,894,429
Carbon Sequestration in Landfills	(CO_2)	NA	-413,719	-413,377
Landfill CH_4 Recovery	(CH_4)	- 54,997	- 54,997 [b]	-148,619
Wastewater CH_4 Recovery	(CH_4)	-113	-113 [b]	-23,000
Total Sequestration	**C**	**-7,001,375** [c]	**-1,668,829** [c]	**-6,577,155**

[a] NA = not available
[b] Assumes same value (not recalculated) as originally reported in 1990.
[c] Does not include sequestration in agricultural soils, which may have been significant in 1990.

The net emissions of greenhouse gases are shown in Table 4. These numbers are the differences between the gross emissions given in Table 2 and the carbon captured as reported in Table 3. The difference in net emissions narrows to about 5 million MTCE per year, from about 21.1 million in 1990 to about 26.2 million in 2000 (corresponding to a 19 percent rise). If we assume that the nitrous oxide emissions from agricultural soils were comparable for the two years, gross emissions in 1990 would have been on the order of 5 million MTCE higher, making the apparent increase in net emissions in 2000 almost negligible. On the other hand, the recalculated 1990 carbon sequestration does not count carbon in agricultural soils, which would lower net emissions on the order of 3 million MTCE. These two discrepancies tend to cancel each other out to a large degree.

Table 4. Summary table for net greenhouse gas emissions in Iowa in year 2000 (MTCE).

	Recalculated 1990	**2000**
Total Gross Emissions	22,786,561	32,752,788
Carbon sequestration and methane recovery	-1,668,829 [a]	-6,577,155
Net Emissions	**21,117,732 [b]**	**26,175,633**

[a] Does not include sequestration in agricultural soils, which may have been significant in 1990.
[b] Includes original (not recalculated) value of N_2O emissions from agricultural soils, which may result in an large under-estimation of net emissions in 1990.

Emissions by Category: Overview

Figures 2 through 4 disaggregate CO_2, N_2O and CH_4 into their significant emission sources. Carbon dioxide emissions (Figure 2) were dominated by combustion of fossil fuels with much smaller contributions from industrial processes, agricultural soils and incineration of municipal solid waste. In total carbon dioxide contributed 67 percent of gross emissions or 22 million MTCE. Forests, agricultural soils and landfills are all sites of carbon sequestration (not shown in Figure 2) that offset the gross carbon emissions to a net 15.6 million MTCE. Carbon uptake in agricultural soils has increased recently owing to less intensive agricultural practices and greater yields. These trends enhance agricultural soils as a net sink for carbon dioxide.

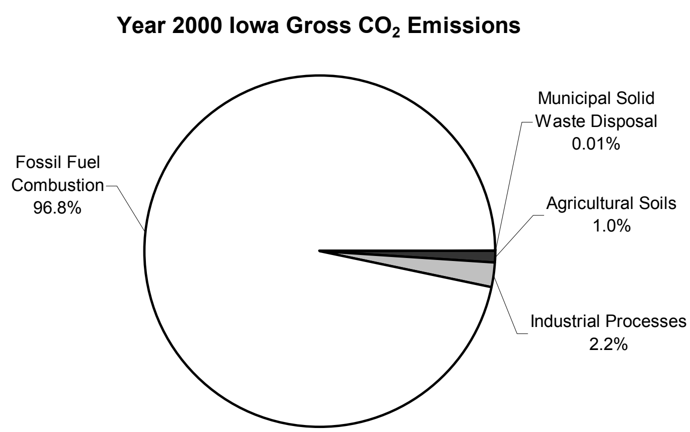


Figure 2. The 22 million MTCE of gross CO2 emissions were predominantly from fossil fuel combustion. Activities leading to these emissions include combustion of coal for electricity generation and industrial sources, gasoline for transportation, and natural gas for space heating. Cement manufacture (industrial processes) and limestone use (agricultural soils) were the largest sources of non-energy related industrial emissions.

Nitrous oxide emissions (Figure 3) contributed about 7.0 MTCE (21 percent) of Iowa's gross emissions in 2000. Like CO_2, they are dominated by a single source, in this case agricultural soils. Activities that add nitrogen to the soil result in emissions of this gas. In total they emitted about 6.3 million MTCE in 2000, 90 percent of the overall share. Many other sources of N_2O are present in the state, but their contributions are much smaller.

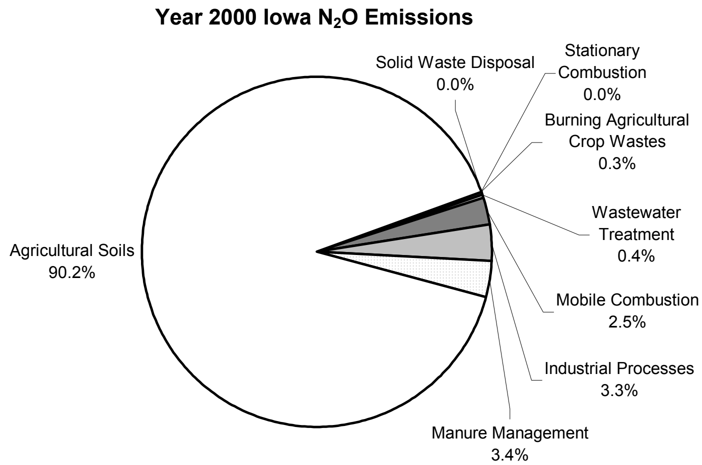


Figure 3. The major portion of Iowa's 7 million MTCE of N_2O emissions came from agricultural soils.

Methane emissions (Figure 4) were quite small in comparison with only 3.6 million MTCE or 9 percent of gross emissions. Unlike CO_2 and N_2O, methane emissions are spread more evenly among several sources. Unaccounted for in the figure is methane recovery from landfills and municipal wastewater treatment plants, which offset total gross emissions by about 1.2 million MTCE.

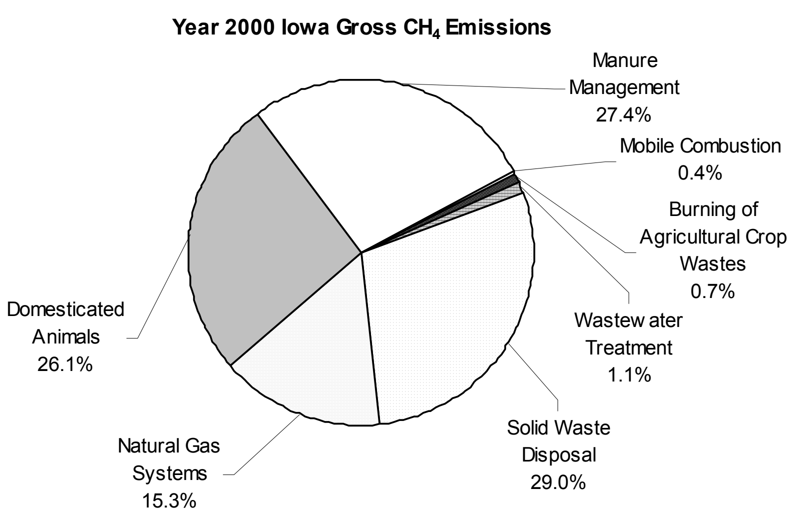


Figure 4. Most of the 3.6 million MTCE of CH_4 emissions came from landfilling of solid waste, manure management, and domesticated animals.

Chapter 3: Greenhouse Gases from Energy-Related Emissions

Combustion of fossil fuels is the primary source of greenhouse gas emissions in the United States, making carbon dioxide the principal contributor to total emissions. Nationally in the year 2000, carbon dioxide from burning of coal, natural gas and petroleum constituted 80 percent of all greenhouse gas emissions on a carbon equivalent basis (Environmental Protection Agency, 2002). In contrast, Iowa's fossil fuel combustion accounted for only 65 percent of the state total. The lower percentage for Iowa reflects the large contribution of N_2O from agricultural sources. As shown in Figure 5, there are smaller energy related sources of emissions. These include nitrous oxide produced at high temperatures from mobile and stationary fossil fuel combustion sources, and methane produced from incomplete combustion of fossil fuels in mobile and stationary sources. An additional source of methane is fugitive emissions from leaks during natural gas transmission and distribution. Previously coal mining in southern Iowa released fugitive methane emissions, which was accounted for in the 1990 inventory. By year 2000, however, all coal mining had ceased in Iowa, and thus this source is not included in the 2000 analysis.

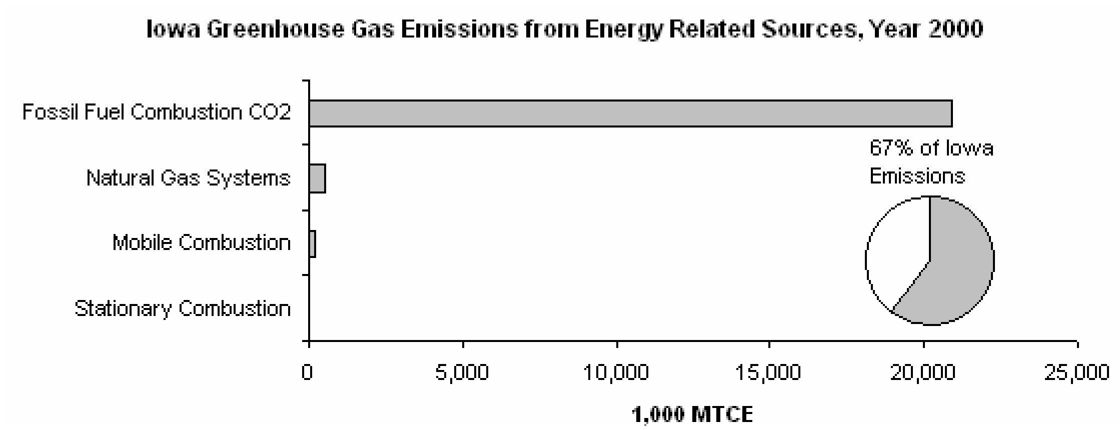


Figure 5. Most energy sector emissions came from CO_2 generated from fossil fuel combustion. N_2O and CH_4 were emitted in small amounts from mobile and stationary combustion, and CH_4 was emitted from leaks in natural gas systems.

Iowa's Energy Profile

The following section provides a detailed analysis of energy use activities in Iowa. Understanding energy use is important for targeting emission reduction strategies. The analysis summarizes changes in total energy use and electricity generation, carbon intensity, energy use by sector and per capita energy use. Also included is a comparison among states of carbon dioxide emissions from fossil fuel consumption. Subsequent sections summarize emission estimates from the energy related sources introduced above.

Trends from 1990 to 2000. As shown in Figure 6, total energy consumption of fossil fuels in Iowa grew by 26 percent (222.5 Trillion Btu) in the 1990s. Consumption of fossil fuels is the single greatest influence on the state's greenhouse gas emissions inventory. With the inexpensive price of coal, continuously decreasing since 1983, Iowa remains heavily dependent on this carbon-intense fuel source. It accounted for 39 percent of all energy Iowa produced in 2000. Most of that -- 84 percent -- was used for electricity generation by investor-owned, public and cooperative utilities. The remainder went to the industrial and commercial sectors, including chemical, metal and food manufacturers, government institutions, as well as non-utility power producers.

Petroleum consumption increased 37 percent (111.4 Trillion Btu) mostly due to increased use by the industrial sector, and, to a lesser degree, the transportation sector. Natural gas consumption increased a moderate 7 percent (15.0 Trillion Btu), most of which was in the industrial sector. The residential sector remains a small but important consumer of natural gas for space heating and cooking. Nuclear and renewable energy sources, including hydroelectric, wood and waste, geothermal, wind, photovoltaic, and solar thermal energies, make up about 7 percent of the state's total energy use.

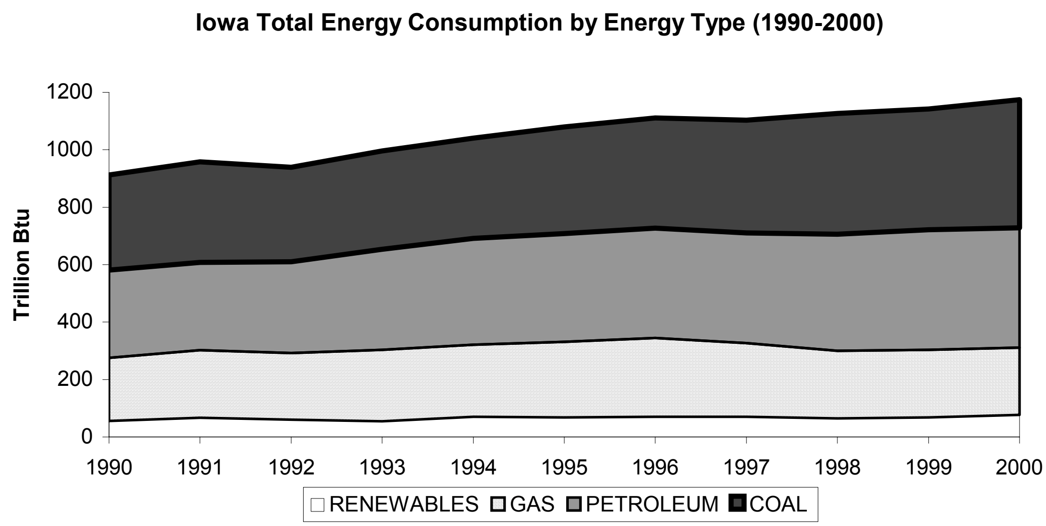


Figure 6. Total state fossil fuel energy consumption grew by 26 percent in the 1990s. Coal, petroleum, and natural gas continue to be the dominant fuel sources for the state, while renewable energy remains a very small part of total energy consumption.

Fuel mix and efficiency are important issues affecting emissions. Among the three major fossil fuels, coal is the most carbon intensive; it emits 56 pounds of carbon for every million Btu of energy produced, while petroleum and natural gas emit 43.5 and 31.9 pounds, respectively. Coal supplies 86 percent of energy inputs for electricity generated in Iowa. Thus, energy consumption for the production of electricity has the largest impact on greenhouse gas emissions. Nuclear, hydroelectric and wind energy sources produce no greenhouse gas emissions and make up 12.7 percent of total inputs to Iowa's electric utility generation.

Iowa electricity production: sources and trends. Figure 7 shows energy inputs and outputs in the year 2000 for all Iowa electric utilities, including commercial and non-commercial producers. The most notable feature is the 70 percent of the energy lost as waste heat. A large part of the loss is due to the Second Law of Thermodynamics, which governs the efficiency of a heat engine and dictates that all energy cannot be converted into work. The theoretical efficiency depends on the difference in temperature between the condenser and the boiler, and for a typical coal-fired power plant is about 65 percent. This means that 3 Btus of energy from coal combustion can produce no more than 2 Btus of electrical work. Owing to transmissions losses and other system inefficiencies, the actual efficiency for conventional coal plants is typically about half of the theoretical prediction, so in practice every 3 Btus of coal produces only about 1 Btu of electrical work. Measures that enhance the energy efficiency of these systems can have large, direct positive effects on Iowa's greenhouse gas burden.

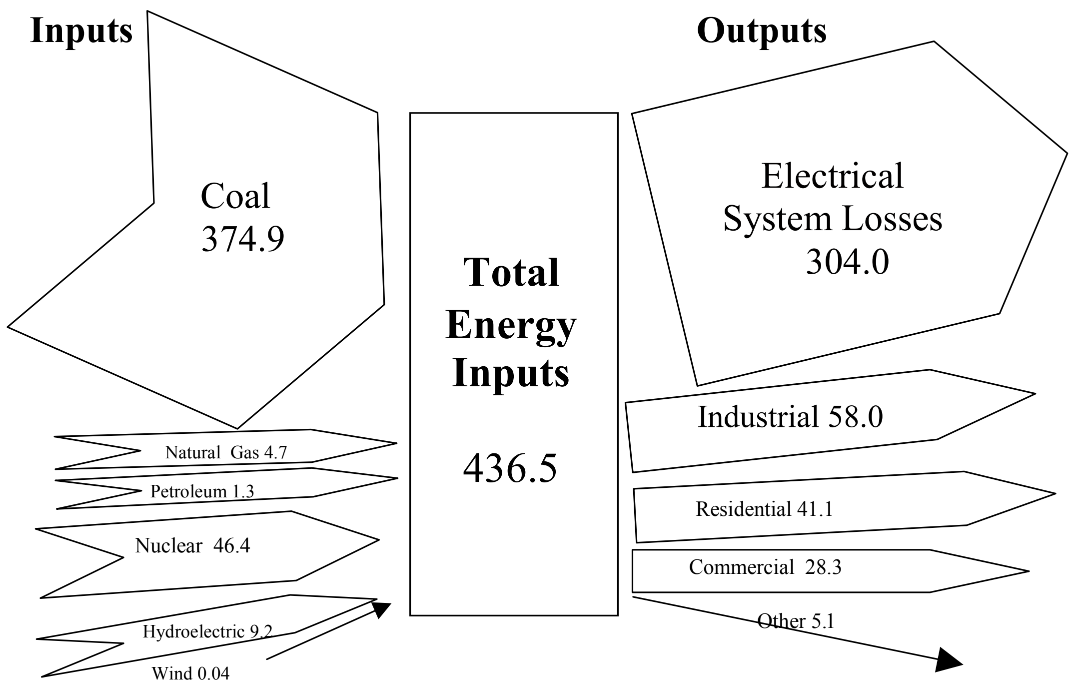


Figure 7. Inputs and outputs of energy in Iowa for electricity generation in year 2000 (Trillion Btu). Source: Energy Information Administration (2001b).

The industrial sector is the largest consumer of electricity, followed by the residential sector and finally the commercial sector. At the time of this report, the Energy Information Administration (EIA) reported electricity consumption for public street and highway lighting, interdepartmental and intradepartmental sales, and agricultural and electrified rails sales as "other" uses.

Like the rest of the country, Iowa has always relied heavily on coal for electricity generation. In the 1960s, it supplied almost half of the electric utility inputs, with natural gas providing slightly more. Even before the 1978 federal legislation banning the construction of new large gas-fired boilers Iowa, chose to shift away from use of natural gas, which was then thought to be in short supply. Since that time, the nation's abundant coal supply has been the number one source of fuel for Iowa's electricity generation. With changing priorities and concerns about air quality, however, some predict that in time electricity production will shift back toward cleaner burning fuels (Iowa Department of Natural Resources, 1996), which is already happening to a degree.

Table 5 shows the state's fuel sources for electricity generation in 2000 with comparison to 1990. In 2000, coal generated 84 percent (35.0 million MWh) of the state's total electricity output, increasing by more than a third (8.9 million MWh) since 1990. Installed nameplate coal capacity, however, decreased by 2 percent over this time. The drop marks a loss in the share of coal in total generation, resulting from development of other resources including the rapid increase in wind energy, which accounted for 2 percent of total generation capacity by 2000.

Table 5. Electric power industry capacity and generation by source for 2000 in comparison with 1990.

Fuel Source	Electricity Generation Year 2000 (1,000 MWh)	Percent of Generation Year 2000 (%)	Change in Generation 1990 – 2000 (%)	Nameplate Capacity Year 2000 (MW)	Percent of Nameplate Capacity Year 2000 (%)	Change in Nameplate Capacity 1990 - 2000 (%)
Coal	34,984	84	36	6,370	67	-2
Nuclear	4,453	11	48	597	6	0
Hydroelectric	906	2	4	131	1	0.6
Wind	572	1	NA	206	2	NA[a]
Natural Gas & Dual Fired	468	1	40	1,271	14	3
Petroleum	136	< 1	150	994	10	77
Total	**41,519**	**100**	**38**	**9,789**	**100**	**8**

[a] NA – not applicable because there was no nameplate capacity for wind in 1990.

Source: Data derived from Energy Information Administration (2001b, 2003b).

Nuclear power and renewable energy in the form of hydropower have long been sources of electricity in Iowa. Although hydropower has not grown much in the past ten years, it has been a very stable source and continues to provide a small share of electricity with carbon-free emissions. Nuclear energy generation has experienced substantial growth since the completion in 1974 of the Duane Arnold Energy Center in Palo, Iowa. Now generating more than three times as much electricity as it did at its opening, the state emitted 1.2 million MTCE less in 2000 than it would have if this electricity were generated by a coal-fired plant. This nuclear plant is now a significant part of Iowa's energy portfolio, accounting for more than one-tenth of total electricity generation.

While natural gas and petroleum comprise 24 percent of total installed nameplate capacity, they currently provide less than 2 percent of generated power. They typically serve as secondary sources, supplying additional power during times of peak generation or backup for security against power outages. However, in 2003, one new gas-fired combined-cycle plant came online as an intermediate generator providing electricity daily. These types of generators may be dispatched ahead of certain coal fired units as their high efficiency makes the cost of operation less expensive despite higher natural gas prices (Iowa Utilities Board, 2003). There are also two proposals for new natural gas fueled plants to be sited in Iowa for out-of-state export of electricity (Jack Clark, Iowa Utility Association, personal contact, March 17, 2004).

Wind generation has been the source experiencing the greatest rate of growth in Iowa since 1990. Capacity was nearly zero in 1990 and rose to 206 MW by 2000. The first significant leap came in 1999 when several large wind farms were installed across the state, bringing capacity up from 9 to 204 MW. Despite this dramatic expansion, wind power still accounts for only about 1 percent of total electricity generation.

Advances in the development of biomass fuels provide another exciting option for electricity generation from Iowa-grown renewable resources. The Chariton Valley Resource Conservation and Development Organization has partnered with Alliant Energy's Ottumwa power plant to test and develop a new market for switchgrass, an indigenous Iowa prairie grass, as a fuel to burn with coal in electricity generation. Their goal is to co-fire enough switchgrass to increase capacity by 35 MW. Other projects using biomass include a waste biomass gasification system in Cedar Rapids, and biogas recovery systems at livestock operations, landfills and wastewater treatment plants. However, biomass is currently an extremely small contributor to Iowa's electricity generation portfolio.

Most energy forecasts, including those from the U.S. Department of Energy, indicate that the country will continue to depend on fossil fuels for a long time even though the diversity of the fuel base is increasing to include renewables.

Carbon intensity. Carbon intensity is a measure of the carbon content of emissions per unit of energy generated. On a statewide basis, it is calculated by dividing total carbon in energy sources consumed by the total energy produced within the state. The lower this ratio, the less carbon dioxide is emitted per unit of energy generated. Figure 8 shows that carbon intensity has remained approximately flat over the decade of the 1990s, with a slight overall decrease of 2.8 percent. This trend is noteworthy because a large increase in coal consumption has occurred over the same time period, indicating that others factors have offset the coal increase. These include a slightly less carbon-intense coal mix combined with an increase in renewable energy production, and the use of less carbon-intense petroleum products in the industrial sector.

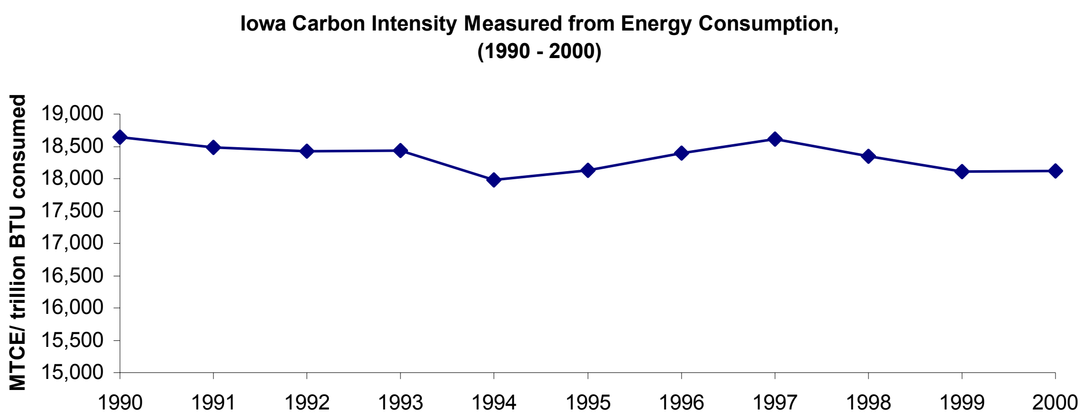


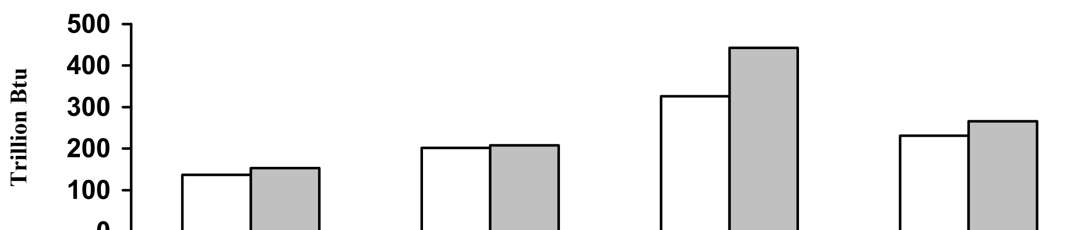
Figure 8. Despite increasing coal consumption, the slight decrease in carbon intensity is attributed to a less carbon-intense coal mix, more renewable energy use, and other factors.

Outlooks from the EIA (Energy Information Administration, 2004a) are optimistic that the proportion of coal-generated electricity capacity will decline continuously on a national scale. The major replacement fuel will be natural gas, which is expected to experience a two-thirds increase in demand for electricity generation by 2020. Any rise in use of a fuel with relatively low carbon emission potential such as natural gas would continue to hold the carbon intensity down.

Iowa end use sector energy analysis. Energy use in all economic sectors experienced growth in varying degrees. One manifestation of this growth was the large increase in electricity consumption, which reflected the growth in its demand among the individual sectors. Energy demands other than for electricity also grew, and in this section we analyze how the different forms of energy were distributed across the end use sectors.

As shown in Figure 9, a rapidly growing industrial sector saw the greatest rise in energy use among end users with a 36 percent increase. This sector includes activities related to manufacturing, agriculture, forestry, fisheries, mining and construction, and non-utility power producers. Growth in the petrochemical industry in the late 1990s brought a nearly 200 percent increase in feedstocks. Industrial liquid petroleum gas (LPG) consumption increased by 330 percent. As a highly versatile fuel, LPG is employed in numerous industrial applications, including drying of agricultural and chemical products, processing of metals, chemical and food products, and agricultural space heating. LPG is among the least carbon-intense fossil fuels used, second only to natural gas.

Total Energy Use by Sector 1990 vs 2000



	Commercial	Residential	Industrial	Transportation
1990	137	202	326	231
2000	153	208	443	266

Figure 9. All sectors saw growth in energy consumption in the past decade. Energy inputs at electric utilities were distributed across end use sectors in proportion to electricity consumed in that sector.

The transportation sector saw a 15 percent rise in energy use, mainly due to increased consumption of distillate fuels, lubricants, and motor gasoline. Motor vehicle gasoline consumption was 13 percent higher in 2000 than in 1990. This trend reflects in part the growing popularity of less efficient light duty vehicles. Since the late 1980s the market share of light duty trucks, including small pickups, vans and sport utility vehicles, has been growing nation-wide (Environmental Protection Agency, 2003). The increasing preference for these relatively inefficient vehicles over conventional passenger cars has played a critical role in increased fuel consumption and concomitant emissions.

The commercial sector includes businesses, federal, state, and local governments, private and public organizations, and institutional living facilities. Energy consumption among these enterprises rose by 12 percent compared to 1990. Electricity and natural gas are the energy sources in largest demand, satisfying the need for space and water heating, air conditioning, lighting, refrigeration, cooking and running a variety of office equipment.

Energy consumption in the residential sector had the slightest increase of all end use sectors, rising only 3 percent in 2000 relative to 1990. The EIA has monitored regional and national trends showing decreasing energy inputs for residential space and water heating, two needs drawing a large share of total home energy demand (Energy Information Administration, 2001c). This improvement is a credit to the effectiveness of energy efficiency programs, more stringent building energy codes, and technology advances that have targeted the residential sector. Other energy consuming needs include air conditioning, lighting, refrigeration, cooking and other appliances.

Per capita indices. Iowa's population growth was sluggish between 1990 and 2000, increasing at less than 0.5 percent per year. In the first half of the decade, much higher growth rates in energy use (3 percent per year) and energy-related carbon emissions (17 percent per year) drove up per capita energy consumption (Figure 10) and per capita carbon emissions (Figure 11). By 1996, the rise in emissions began to slow down to less than 1 percent per year, flattening out the trend while per capita energy use continued to rise after 1997. As we saw with the case of slightly decreasing carbon intensity, this trend was affected by a less carbon-intense coal mix, improved energy efficiency, and accelerated development of renewable fuels. Continuation of these positive measures will tend to lower per capita energy consumption and carbon emissions in the future.

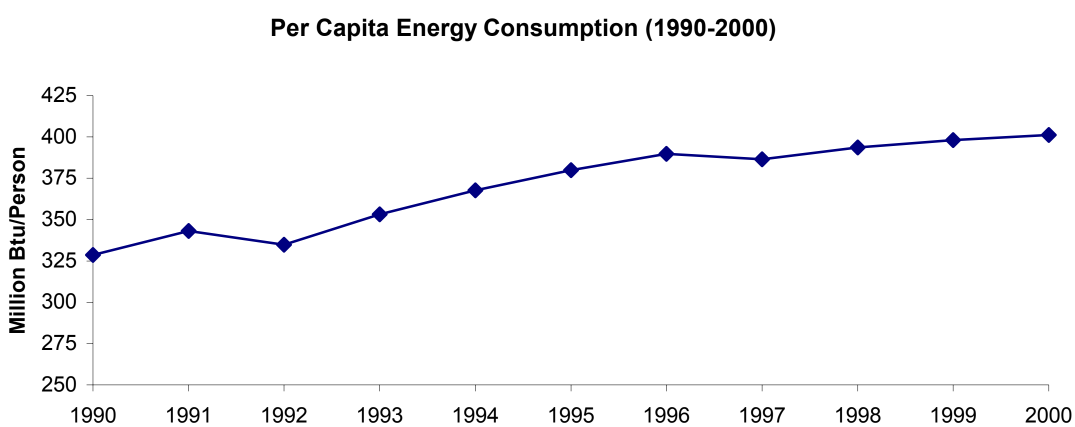


Figure 10. Per capita energy consumption rose almost continuously between 1990 and 2000.

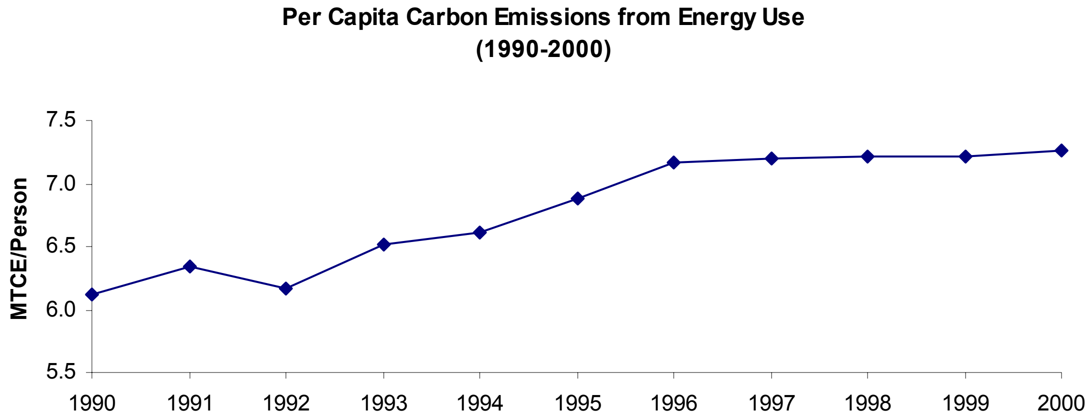


Figure 11. While per capita carbon emissions rose steadily in the first half of the decade, they began to flatten out after 1996 despite rising energy use.

State comparisons of per capita carbon emissions from fossil fuel use. In order to compare Iowa's energy-related emissions with the rest of the country, state comparisons of per capita carbon dioxide emissions from fossil fuel consumption have been estimated for each end use sector, and are summarized in Table 6 and Figures 12 through 16. Emissions were calculated from fossil fuel consumption data reported by the Energy Information Administration (EIA). Electric utility emissions have been distributed across end use sectors. Carbon stored in non-energy products (i.e., plastics, fertilizers, chemicals) were credited to each state's industrial and transportation sectors based on national estimates of "non-energy uses" of fossil fuels (Energy Information Administration, 2001a). Emissions from states that do not participate in activities that sequester fossil fuel carbon in non-energy products may be assigned too much carbon credit and, therefore, could be underestimated.

Table 6. Summary by end use sector of per capita carbon emissions from combustion of fossil fuels in Iowa, 2000

Sector	Iowa Per Capita CO_2 Emissions (MTCE/Person/Year)	Iowa State Ranking (out of 51[a])	U.S. Per Capita CO_2 Emissions (MTCE/Person/Year)
All Sectors	6.74	13	5.59
Commercial	1.00	18	0.83
Residential	1.33	10	0.98
Industrial	2.65	13	1.94
Transportation	1.75	32	1.84

[a] District of Columbia included in the ranking.

With the exception of transportation, Iowa emitted more carbon per capita than the U.S. average, indicating that overall the state uses more fuels with higher carbon intensity. This is not surprising given Iowa's decentralized population and robust agricultural economy, as well as a strong dependence on coal. Based on year 2000 data from the EIA (Energy Information Administration, 2003c) and U.S. Census Bureau (2001) , Iowa ranked 10th highest in per capita coal consumption, preceded by (from greatest to least) Wyoming, North Dakota, West Virginia, Indiana, Kentucky, Alabama, Montana, Utah, and New Mexico. All of these states also precede Iowa in total per capita carbon emissions except for Utah.

Iowa's per capita emissions for the transportation sector ranked relatively low among the states. Thirty-one states had higher values, thus placing Iowa below the U.S. average. Extensive use of ethanol blends has given Iowa an advantage over other states. Moreover, Iowa's transportation sector uses minimal amounts of some carbon-intense fuels used extensively in other states such as jet and residual fuels. For example, the state ranked 47th in its per capita use of jet fuel.

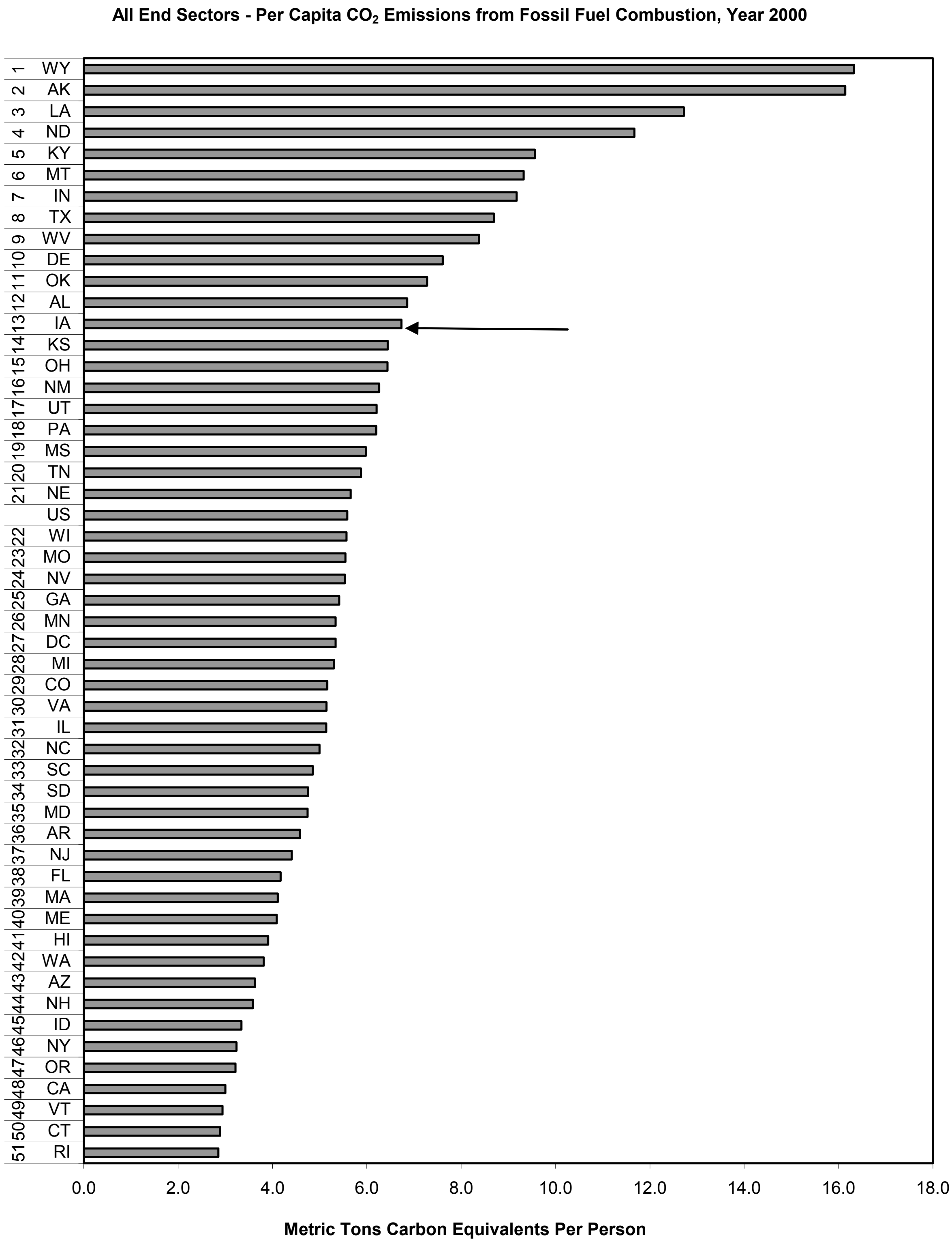


Figure 12. Iowa ranked as the 13th highest per capita carbon emitting state from fossil fuel combustion in all end use sectors, possessing annual emissions of 6.74 MTCE per person. The national average was 5.59 MTCE per person.

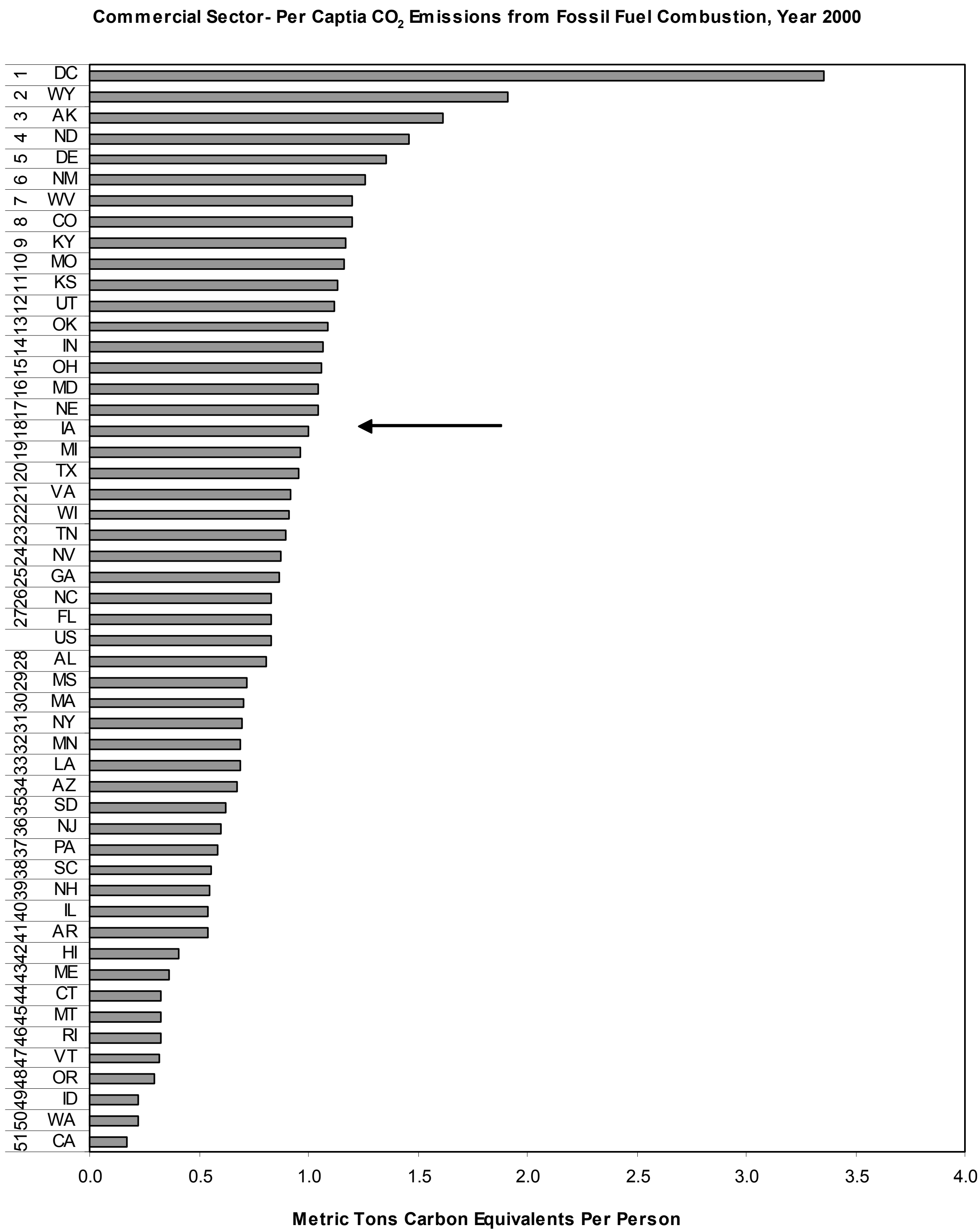


Figure 13. Iowa's commercial sector ranked 18th highest per capita carbon emitting state from fossil fuel combustion, possessing annual emissions of 1.00 MTCE per person. The national average was 0.83 MTCE per person.

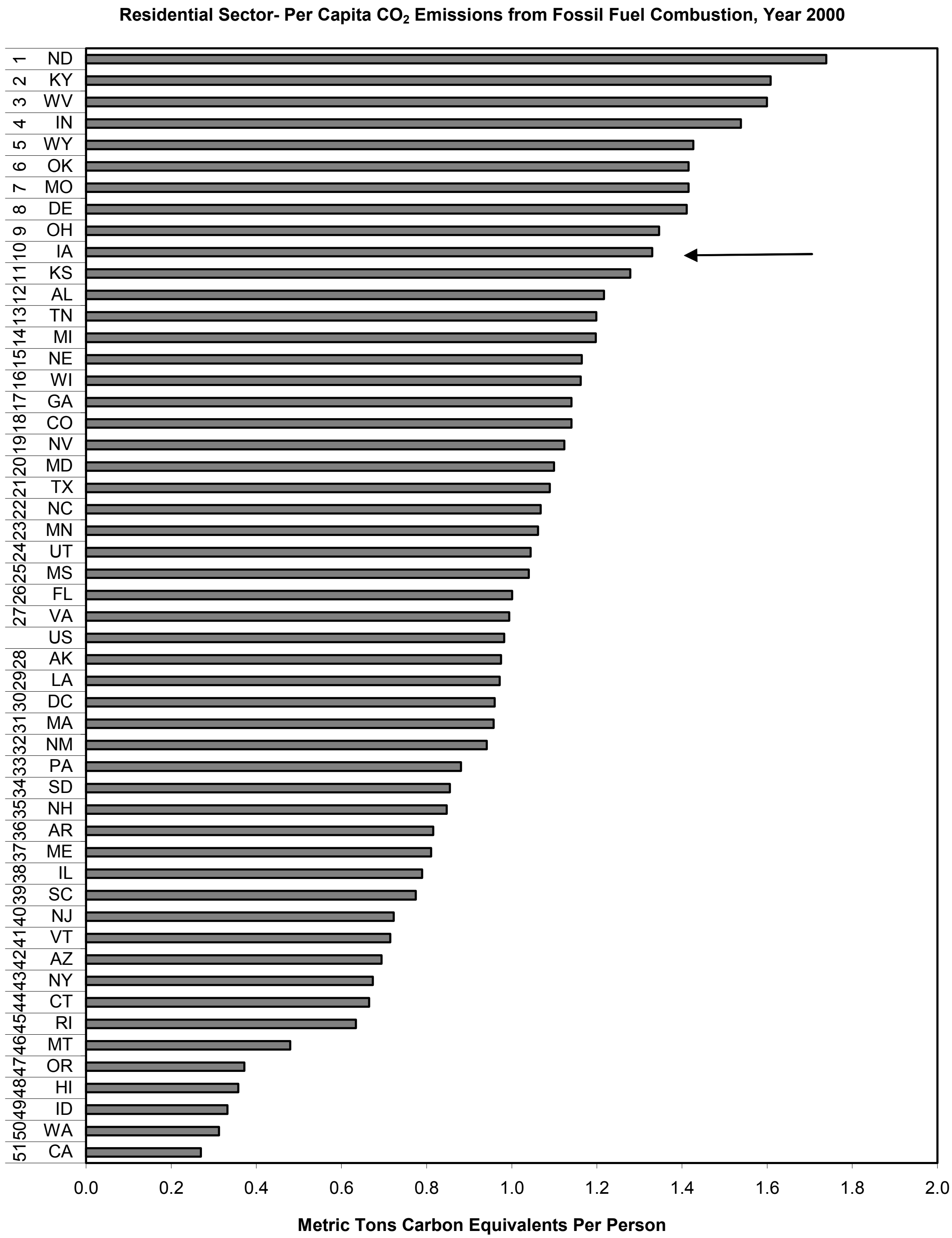


Figure 14. Iowa's residential sector ranked 10th highest per capita carbon emitting state from fossil fuel combustion, possessing annual emissions of 1.33 MTCE per person. The national average was 0.982 MTCE per person.

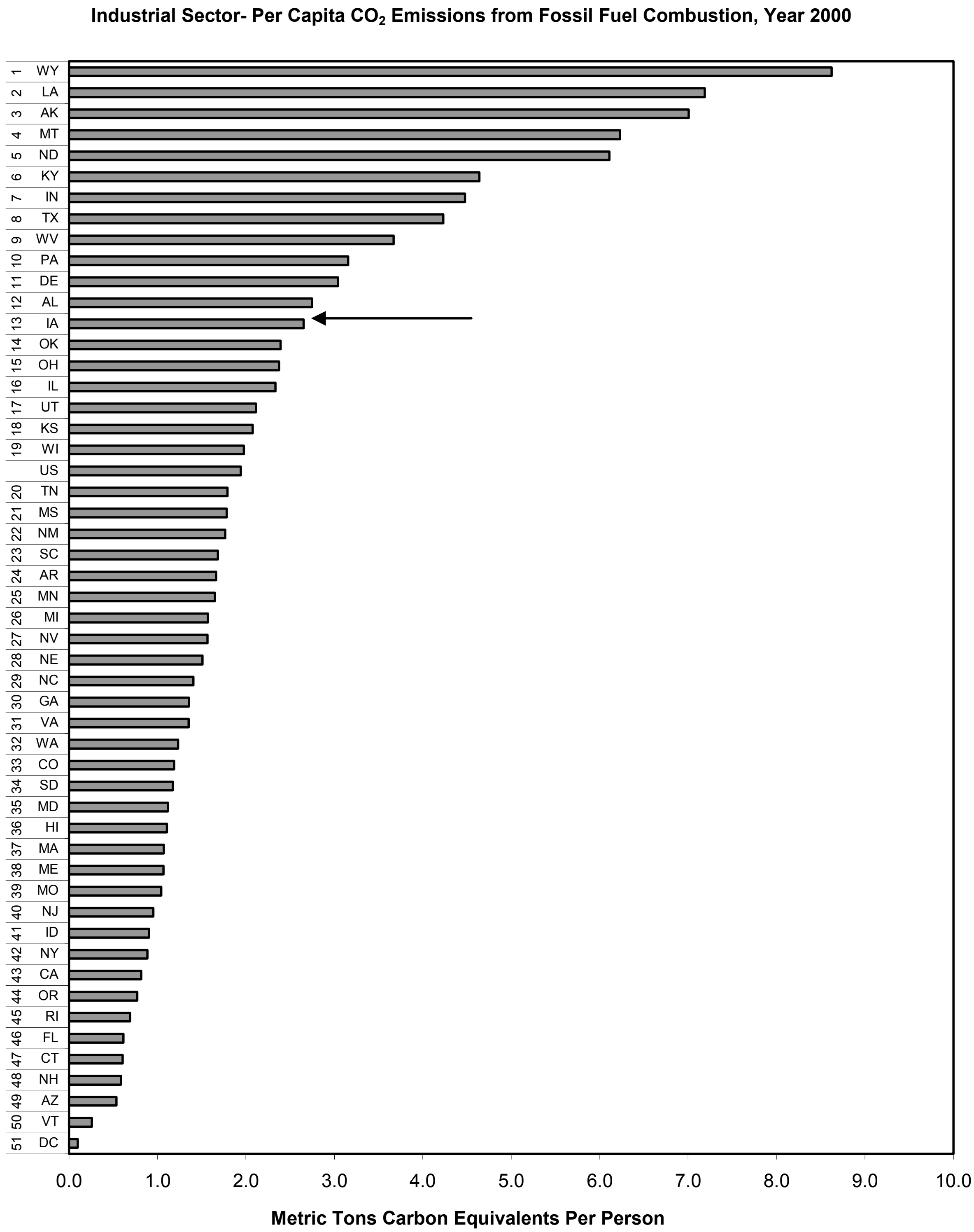


Figure 15. Iowa's industrial sector ranked 13th highest per capita carbon emitting state from fossil fuel combustion, possessing annual emissions of 2.65 MTCE per person. The national average was 1.94 MTCE per person.

Transportation Sector - Per Capita CO_2 Emissions from Fossil Fuel Combustion, Year 2000

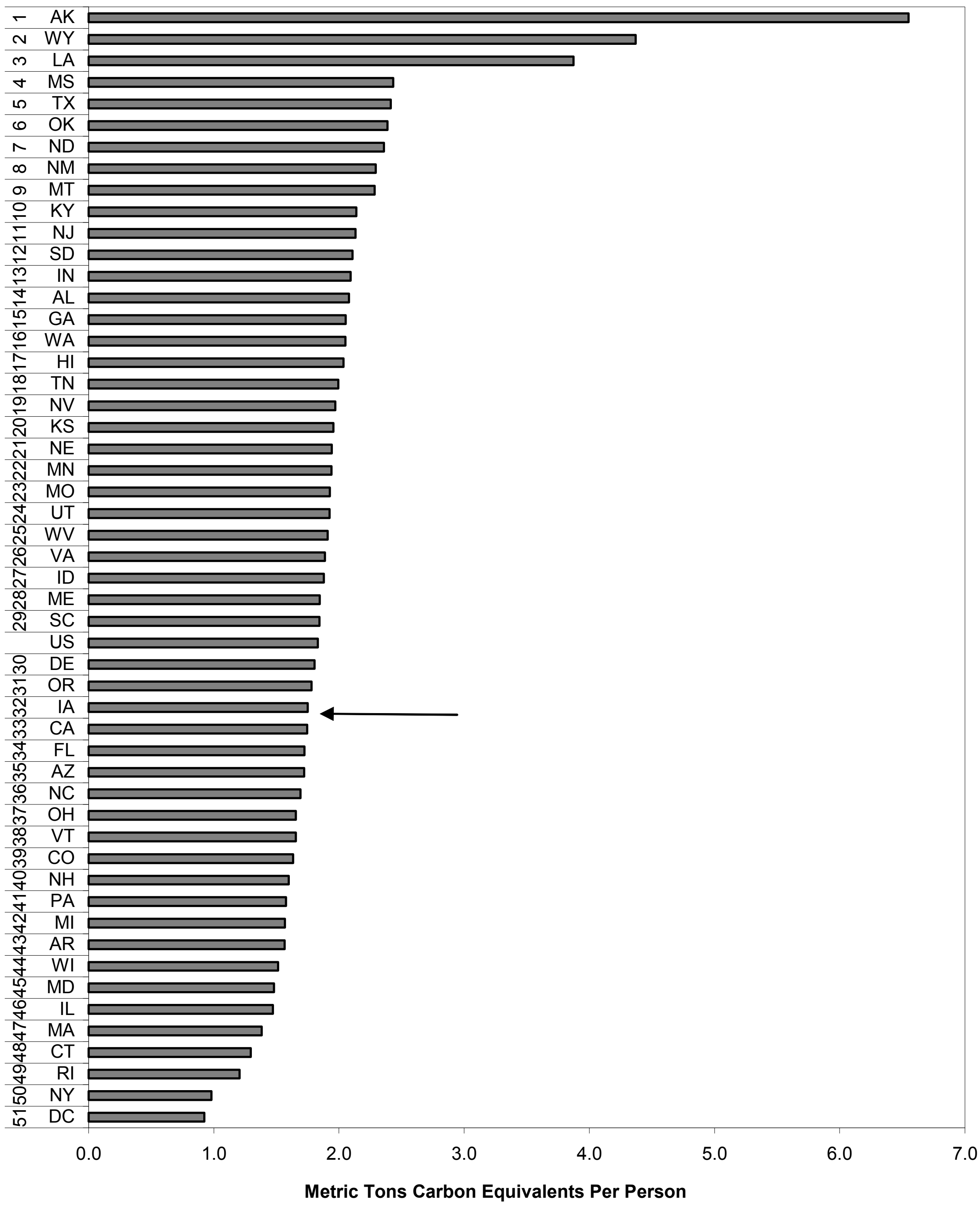


Figure 16. Iowa's transportation sector ranked 32nd highest per capita emitting state from fossil fuel combustion, possessing annual emissions of 1.75 MTCE per person. The national average was 1.84 MTCE per person.

CO_2 from the Combustion of Fossil Fuels

Carbon dioxide emissions increased concomitantly with energy use over the decade of the 1990s. Estimates based on total energy consumption show that for all end use sectors, Iowa emissions were 21.3 million MTCE in 2000 compared to 17.0 million MTCE recalculated for 1990. One major source of this increase was the rising emissions from electric power generation. Figure 17 shows the upward trend of carbon dioxide emissions from the electric utilities. In 2000 they released 9.5 million MTCE, comprising about 47 percent of all sources of emissions.

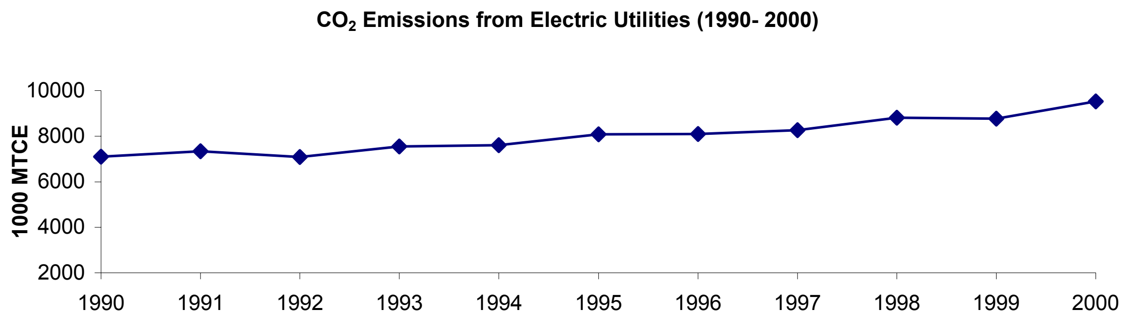
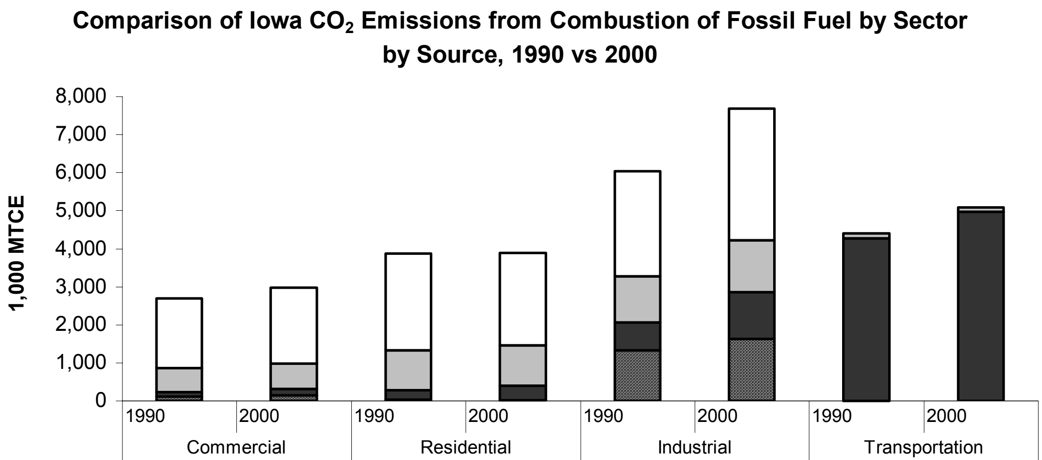


Figure 17. Emissions from electricity generation were on an upward trend in the 1990s.

Electricity generation is driven by the demand of end users, and is distributed according to demand across the commercial, residential, and industrial sectors. (Electricity demand in the transportation sector in Iowa is minimal.) Quantities for each sector's electricity consumption and associated energy losses were calculated (see details in appendices worksheets for fossil fuel combustion). Carbon emissions were estimated and an emission distribution factor was determined from the fraction of total utility emissions and all energy inputs including nuclear, hydroelectric and other types of generation. Electricity consumption and losses in the end use sectors were multiplied by the distribution factor. For 2000, the EIA reported that Iowa's net interstate flows of electricity and losses amounted to -74.6 trillion Btu. This number indicates that more electricity (including losses) went out of the state than entered it. Emissions from this interstate energy transfer make up the difference between electric utility inputs and consumption with losses in the in-state end use sectors. Figure 18 compares the emissions of carbon dioxide from fossil fuel combustion in 2000 with 1990 for all end use sectors by energy source. Clearly for the three electricity consuming sectors, most emissions came from this activity.

Figures 18 and 19 show total net emissions from industry increased 27 percent over the last decade, totaling 7.7 million MTCE in 2000. This figure does not include the almost 0.5 million MTCE that was estimated to be stored in non-energy products made from fossil fuels (e.g., fertilizer from natural gas, asphalt from road oil). With 36 percent of the total, the industrial sector was responsible for the largest share of emissions and experienced a 1 percent increase in share since 1990.



	Commercial 1990	Commercial 2000	Residential 1990	Residential 2000	Industrial 1990	Industrial 2000	Transportation 1990	Transportation 2000
Electricity	1,827	2,005	2,551	2,428	2,763	3,457	0	0
Natural Gas	638	659	1,035	1,068	1,200	1,374	132	119
Petroleum	109	167	261	383	746	1,229	4,272	4,967
Coal	120	153	28	18	1,323	1,628	0	0

Figure 18. Most energy-related emissions came from electricity consumption for the commercial, residential and industrial sectors.

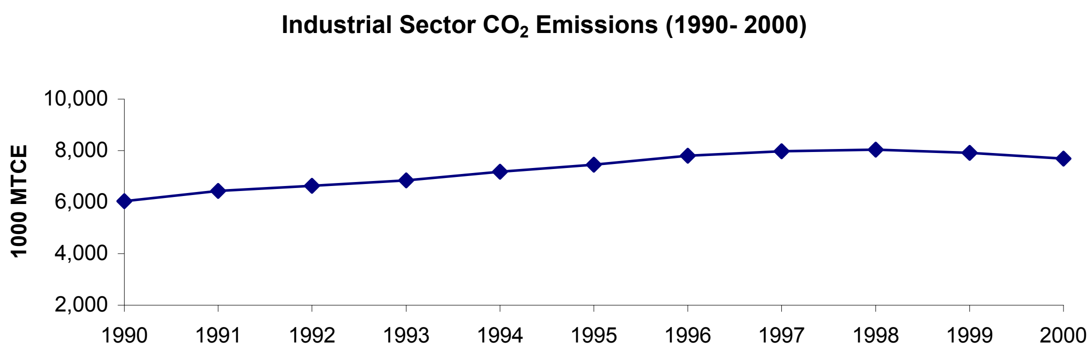


Figure 19. The industrial sector's emissions have increased 27 percent since 1990. Late in the decade emissions stabilized due to improved electricity transmission and reduced distribution losses, and an increase in use of less carbon-intense LPG.

Although not apparent from Figure 18, natural gas is the dominant fossil fuel consumed in the industrial sector, providing 22 percent of total energy. It is applied for cogeneration of industrial electric power and as an industrial feedstock. Coal provides only 15 percent of fuel, but it generates 3 percent more net carbon emissions than natural gas because, as noted above, it is a more carbon-intense fuel than natural gas. Industry fuel choices follow price variations more closely than other sectors owing to greater flexibility of fuel switching. With this ability to switch fuels, industry is an ideal sector for substitution by less carbon-intense fuels.

As shown in Figure 20, carbon dioxide emissions from the transportation sector rose to about 5 million MTCE over the decade and averaged about 17 percent higher in the last half. In 2000, motor gas consumption was up 13 percent relative to 1990, reflecting reduced energy efficiency owing to an increase in the number of light duty trucks including pick-ups, minivans and sport utility vehicles. The recent popularity of these relatively inefficient vehicles compared to passenger cars has played a critical role in increased fuel consumption and emissions.

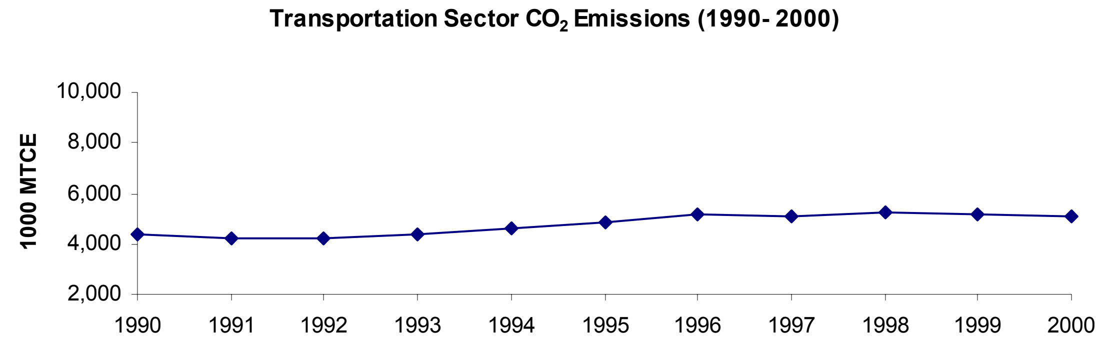


Figure 20. Emissions from the transportation sector were 17 percent higher by the end of the decade.

As a consequence of less stringent corporate average fuel economy (CAFE) standards for light duty trucks, total U.S. fleet fuel economy has been dropping since 1987 when it peaked at 26.2 miles per gallon (mpg). At that time light duty vehicles made up only 28.1 percent of the market. By 2001, these vehicles held a 46.7 percent market share, and fleet fuel economy had dropped to 24.4 mpg (U.S. Department of Commerce, 2004). Addressing this issue, the National Highway Traffic Safety Administration has raised the new light truck standard from the long maintained one of 20.7 mpg to 21.0 mpg for model year (MY) 2005, 21.6 mpg for MY 2006 and 22.2 mpg for MY 2007 (National Highway Traffic Safety Administration, 2004). Currently the conventional passenger car standard is remaining at 27.5 mpg where it has been set since 1990. The effect of the new standards will accumulate in time, hopefully bringing fleet fuel economy back up. Despite the increase in emissions, Iowa's transportation sector in 2000 held steady at 26 percent of the share of total emissions it had in 1990. With ethanol consumption more than doubling during the 1990s, transportation's carbon intensity was down 1 percent by the year 2000.

As shown in Figure 21, the commercial sector's emissions rose 11 percent but remained the smallest energy consuming and emitting sector, accounting for 3 million MTCE in 2000. Rises in coal use and electricity consumption drove this increase.

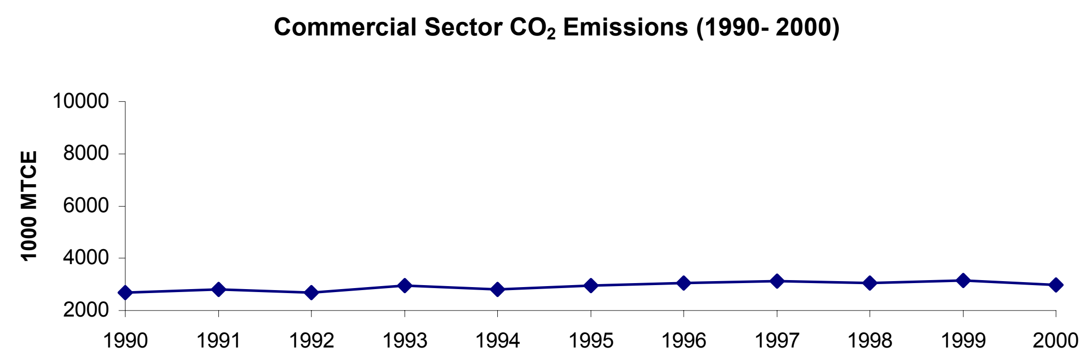


Figure 21. The commercial sector was the lowest emitter at 3 million MTCE in 2000.

Figure 22 indicates that in 2000 the residential sector emitted about 4 million MTCE with less than a 1 percent rise relative to 1990. A switch from carbon-intense fuel oil and coal to less intense natural gas and LPG gas allowed energy consumption to increase by 3 percent with almost no rise in carbon emissions. By 2000 the residential sector had lowered its share of total emissions by 3 percent, down to 20 percent of the total energy-derived emissions from the four sectors.

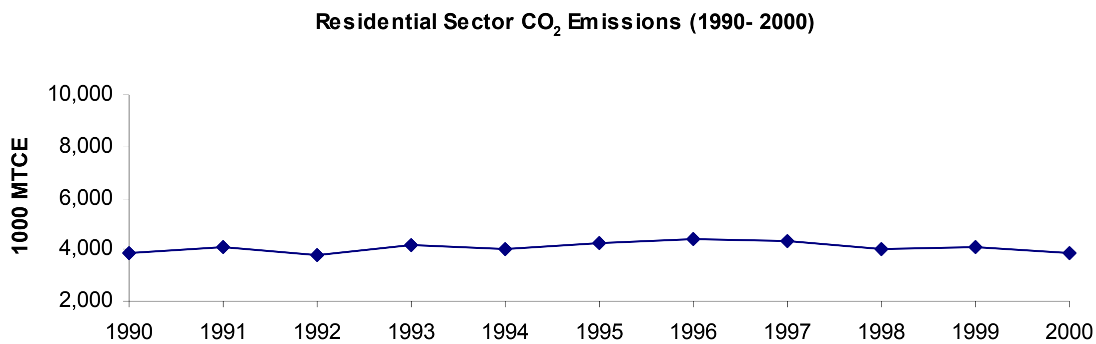
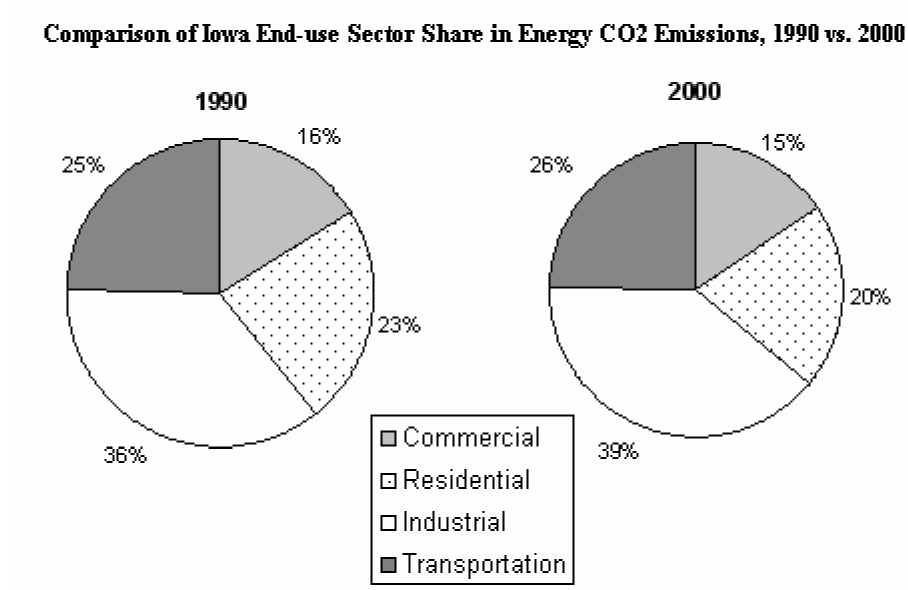


Figure 22. Emissions from the residential sector remained relatively steady with only a 1 percent rise since 1990 despite a 3 percent increase in energy consumption.

Figure 23 shows the percent shares of carbon dioxide emissions from the four end use sectors, and how those shares changed from 1990 to 2000. Total emissions increased by 15.6 percent, from 17.0 million MTCE to 19.7 million MTCE. The industrial sector had the highest increase at 27.5 percent while the residential sector had the lowest at 0.6 percent. This resulted in the industrial sector's increased share of emissions by 3 percent to 39 percent in 2000.



Sector	CO_2 Emissions (MTCE)		Percent Increase 1990 → 2000
	2000	1990	
Commercial	2,984,428	2,694,463	10.8 %
Residential	3,897,621	3,874,428	0.6 %
Industrial	7,687,837	6,031,709	27.5 %
Transportation	5,087,277	4,404,861	15.5 %
Total	19,657,163	17,005,461	15.6 %

Figure 23. End sector shares of CO_2 emissions from energy use.

CH_4 and N_2O Emissions

Emissions from stationary and mobile combustion sources. The above discussion focused on carbon dioxide as the primary greenhouse gas from fossil fuel combustion. In this section, emissions of methane and nitrous oxide from the same activities are reported. Methane is formed during incomplete combustion of fossil fuels; nitrous oxide forms when atmospheric nitrogen or nitrogen embedded in the fossil fuel reacts and combines with oxygen at high temperatures. Compared to carbon dioxide emissions, however, both gases are minor contributors to Iowa's total greenhouse gas emission inventory, accounting for a combined share of only 0.6 percent in 2000. The overall results are presented in Table 7. Nitrous oxide from mobile combustion contributed more than 90 percent of these emissions.

Different methodologies were devised for estimating emissions for stationary and mobile combustion sources. Stationary combustion includes the burning of fossil fuels in non-moving equipment (boilers, furnaces, kilns, ovens, etc.) in the utility, industrial, residential, and commercial sectors. Nitrous oxide emissions were estimated based on coal, natural gas and oil consumption data, and emission factors were provided by the EIIP, volume 8. Methane emissions were not estimated for stationary combustion due to the lack of availability of good quality data.

Table 7. Summary of CH_4 and N_2O emissions from mobile and stationary combustion (MTCE).				
Source	**CH_4**		**N_2O**	
	1990	**2000**	**1990**	**2000**
Mobile Combustion	NA [a]	14,212	NA	172,033
Stationary Combustion	NA	NA	44.1	61
Total	**NA**	**14,212**	**44.1**	**172,094**

[a] NA = not available

Sources of mobile combustion emissions are road vehicles, airplanes, boats, railroad and farm equipment. Again because of a lack of data, in this inventory only emissions from road vehicles were quantified. Estimates were based on unpublished vehicle registration data for 2001 provided upon request from the Iowa Department of Motor Vehicles, Federal Highway Administration state travel data, and EIIP emission factors for vehicle categories (defined by vehicle size, fuel type, and emission control technology). A more thorough discussion of the estimation methods is provided in the appendices for this section.

CH_4 emissions from natural gas and oil systems. Iowa neither extracts nor processes natural gas or oil. However, it is an active participant in the national natural gas system as both a direct consumer and as a conduit for transmission from western Canada to Chicago. Most gas consumed in Iowa has been transported from Oklahoma, Texas, Alberta, and Western Canada (Iowa Utilities Board, 2000). A cross-country network of high-pressure, large diameter pipelines transmits the gas. Stations are responsible for maintaining operations along these pipelines by metering, sustaining pressure, and scrubbing the gas. For local distribution and customer connections, the gas is transported via smaller diameter, low-pressure pipelines. Chronic leaks, venting and mechanical mishaps result in the release of natural gas from either the main transmission or local distribution pipeline systems. Iowa is served by four natural gas pipelines and more than 50 local distribution companies. Another pipeline, not catering to Iowa customers, runs across the eastern portion of the state.

In 2000, it was estimated that 553,000 MTCE of methane was released in Iowa during natural gas transmission and distribution activities. Two-thirds of this methane is attributed to gas transmission pipelines and storage leaks, the remaining third to distribution pipeline and customer connection leaks. These releases are Iowa’s sixth largest source of greenhouse gas emissions, comprising 2 percent of the total. They are also the fourth largest source of total methane emissions, with a share of 18.5 percent.

Comparison with past emissions as reported in the 1990 inventory is not appropriate due to the enhanced sophistication of the newer method of calculation. Previously, emissions were based solely on natural gas consumption in the state. That method does not account for emissions from non-stop interstate transmission, which is likely to be a large source given that the majority of methane emissions for 2000 came from natural gas transmission. It is likely, though, that emissions from transmission have increased since 1990 because of the expansion of pipelines in the late 1990s (Tobin, 1997).

Chapter 4: Greenhouse Gas Emissions from Agriculture

Agriculture is the second largest source category of greenhouse gas emissions after energy use. More than 8.7 million MTCE in emissions were derived from agricultural activities in 2000. Nitrogen and lime inputs to soils from agricultural practices contributed the largest share with 6.5 million MTCE from N_2O and CO_2 emissions, while manure management systems that handle waste from livestock contributed 1.2 million MTCE from N_2O and CH_4 emissions. Enteric fermentation in the digestive systems of domesticated livestock is another significant source of methane emissions, adding 941,000 MTCE to the annual total. Burning agricultural crop wastes contributed only a very small amount of methane and nitrous oxide emissions, estimated to be 44,000 MTCE. An overview of emissions and the agricultural sectors contributing to them is summarized in Figure 24.

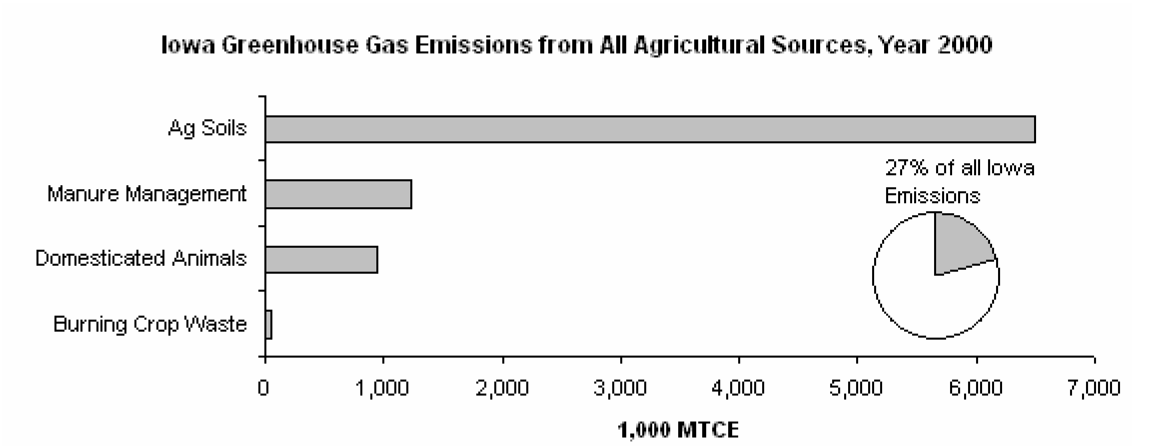


Figure 24 Emissions from the agricultural source categories were dominated by those from agricultural soils. Burning crop wastes was not a significant source of emissions.

N_2O and CO_2 from Agricultural Soils

Iowa's rich soils are its greatest natural resource. They also are one of the state's largest sources of greenhouse gas emissions. According to the methodology applied in the 2000 inventory, agricultural soil emissions are disaggregated into four types as indicated in the pie chart in Figure 25. Table 8 quantifies the emissions represented in the chart. Direct emissions from cropping practices contribute the largest share, accounting for 4.6 million MTCE from nitrous oxide, and 71 percent of all soil emissions. Contributing to N_2O emissions are soil nitrogen inputs via commercial fertilizer applications, production of nitrogen fixing crops, incorporation of crop residues into the soil, managed manure application and application of daily spread manure. Additional emissions occur from the cultivation of highly organic histosol soils. After the burning of fossil fuels, the application of commercial nitrogen fertilizer was the largest individual emitter of greenhouse gases in 2000, contributing about 4 percent of total state emissions from all sources.[6] When combined with other direct soil nitrogen sources such as manure, crop residues, nitrogen

[6] This percent probably underestimates the impact of commercial nitrogen fertilizer on nitrous oxide emissions since it does not count the fertilizer's nitrogen that ends up in crop residues, or in indirect emissions.

fixing crops, and the cultivation of histosols, nitrous oxide from soils comprised 14.1 percent of Iowa's total gross greenhouse gas emissions.

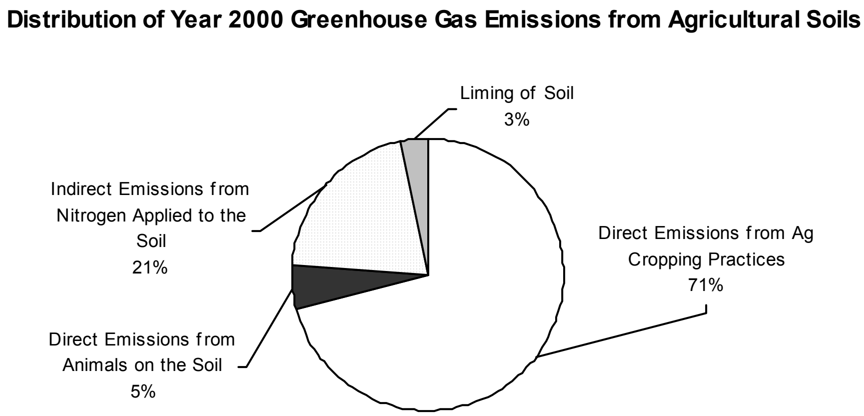


Figure 25. Emissions from agricultural soils were dominated by direct emissions from cropping practices that involve amending the soil with nitrogen and the cutivation of highly organic histosols.

Table 8. Summary of greenhouse gas emissions from agricultural soils in year 2000.

Type of Emission	Gas Emitted	Total Emissions (kg /yr)	Total Emissions (MTCE)
Direct emissions from cropping practices	N_2O	54,547,847	4,611,773
Direct emissions from animals on soil	N_2O	3,895,373	329,336
Indirect emissions from nitrogen applied to soil	N_2O	15,806,296	1,336,350
Total emissions from liming soil	CO_2	815,998,955	222,545
Total		**890,248,471**	**6,500,004**

Indirect emissions of nitrous oxide stem from volatilization and redeposition of nitrogen compounds from fertilizers and livestock manure. Such sources are considered to be indirect because nitrogen does not follow a direct pathway of denitrification from the nitrogen source to the atmosphere. In addition, excess nitrogen from fertilizer and manure is transported by leaching and runoff. Emissions of nitrous oxide occur during these processes, which are also classified as indirect. These sources add an additional 1.3 million MTCE (21 percent) of N_2O emitted from agricultural soils. Grazing animals are a significantly smaller source of direct emissions, comprising just 5 percent of the total. The direct, indirect, and grazing animal inputs combine to emit about 6.3 million MTCE in N_2O emissions, comprising about 19.2 percent of Iowa's total gross greenhouse gas emissions in 2000.

The only source of carbon dioxide emissions from agricultural soils comes from the application of lime for controlling soil pH. When this mineral is added to the soil and it reacts with acids, it dissolves and releases CO_2. Lime application contributed additional emissions, although rather minor at 0.2 million MTCE (3.4 percent).

One reviewer expressed concern about the potential for double emissions counting from nitrogen fixing crops. The methodology requires the inclusion of nitrogen inputs from aboveground residues of all crops (including soybeans), as well as estimates of additional inputs from cultivation of nitrogen fixing crops. At first glance, this may appear to duplicate the accounting of nitrogen soil inputs from nitrogen fixing crops. However, the methodology adjusted for this potential overestimation. Specifically for nitrogen fixing crops, the nitrogen contained in the aboveground plant material (including the crop product removed from the soil) was assumed only to be a reasonable proxy for the total amount of nitrogen (fixed plus residue) left in the soil by the crop (Intergovernmental Panel on Climate Change, 2000). In this way double counting of emissions from nitrogen fixing crops was avoided.

As shown in Table 2 (page 21), a cursory comparison between the 1990 and 2000 inventories would show a large apparent increase in emissions of N_2O from agricultural soils (from 1.1 million MTCE to 6.3 million MTCE). However, the increase is explained largely by the difference in complexity and exhaustiveness of the calculations. Since the 1990 inventory was completed, the method for estimating greenhouse gas emissions from agricultural soils has been expanded and refined. Previously, commercial fertilizer was the only nitrogen source considered, and from that only direct emissions were taken into account. The new method includes more nitrogen sources, direct and indirect nitrous oxide emissions, and different emission factors. Results of this newer and more refined method of calculation should be considered as a new baseline for comparison with future inventories.

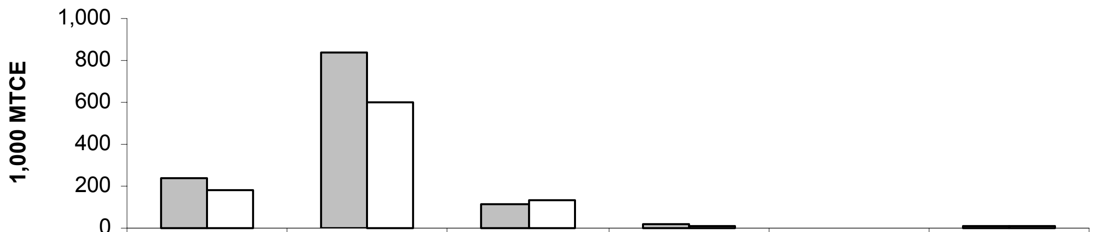
Recalculations applying the new method to the previously reported 1990 commercial fertilizer data indicate no significant difference in emissions from this one source. The new value for 1990 is 1.4 million MTCE compared to 1.5 million MTCE for 2000. This 7 percent increase may be due to statistical uncertainty of application data, or it may reflect a small shift toward application of more concentrated nitrogen inputs. Other components of the N_2O inventory could not be calculated for 1990 for lack of sufficient data.

CH_4 from Domesticated Animals

Methane is produced by animals as a by-product of digestion. Microbes aid in the breakdown of food material through the process of enteric fermentation, which produces methane. Ruminant animals, especially cattle, produce most of the methane attributed to domesticated animals because of their unique digestive systems. They possess a fore-stomach where coarse plant material and other food is rigorously attacked by an abundance of microbes. The methane that results is exhaled or eructated through the mouth. Other animals such as pigs and horses produce much less methane per head, because fermentation occurs to a much lesser extent in the large intestines. The relatively small amount of methane that is created is excreted.

Figure 26 shows the methane emissions disaggregated by animal type and compared for the years 2000 and 1990. In 2000, methane from domesticated animals accounted for 3 percent of Iowa's gross greenhouse gas emissions with a release of 941,000 MTCE. Because these emissions are primarily affected by herd population, Iowa's shift away from cattle production in the 1990s has significantly reduced emissions in recent years. Emissions reported for 1990 were not derived from average animal populations. For this reason, it was necessary to recalculate 1990 emissions for more accurate comparison. Total emissions from domesticated animals have dropped 23 percent since 1990, from 1.2 million MTCE to 0.9 million MTCE. As shown in Figure 27, this drop was largely due to the decline in Iowa cattle population. In the past decade, average populations of dairy and beef cattle decreased by 19.7 percent and 44.5 percent respectively. Because these animals are the largest source of methane among farm animals, their population change has greatly reduced total emissions. However, beef cattle still emit more as a single group than all other animal types combined.

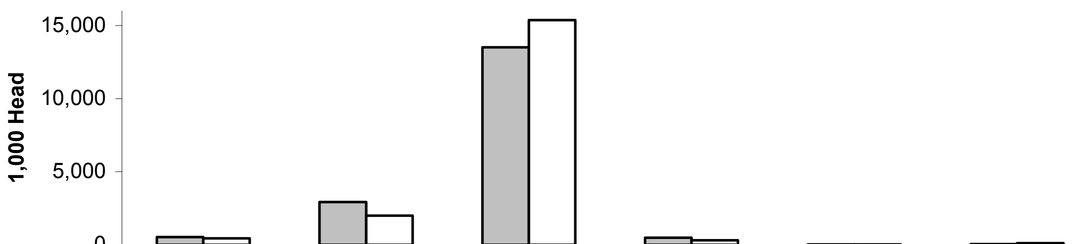
CH_4 Emissions from Domesticated Animals, 1990 vs 2000



	Dairy Cattle	Beef Cattle	Sw ine	Sheep	Goats	Equine
1990	236	842	116	22	0.3	5
2000	184	601	132	14	0.4	10

Figure 26. Emissions of methane from domesticated animals have declined 23 percent since 1990. The biggest influence was the shift away from cattle production.

Domesticated Animals Average Populations, 1990 vs 2000



	Dairy	Beef	Swine	Sheep	Goats	Equine
1990	533	2,934	13,501	490	12	49
2000	427	1,987	15,370	301	12	100

Figure 27. Iowa experienced a significant decline in cattle populations while the swine populations gained 1.6 million head.

Emissions from hogs have increased by 13.8 percent, concomitant with a 1.6 million head increase in the average population. The impact of this trend, however, is somewhat mitigated by the fact that hog methane production is the lowest per head of all the animal types considered in this analysis. Despite the relatively small amount of emissions that each hog produces, the immense population increase coupled with lower emissions from cattle has raised the hog contribution to a 14 percent share of total emissions from domestic animals. Sheep populations dropped by 39 percent in the 1990s. Their population remains low enough that the total contribution is only 1 to 3 percent in each inventory. Emissions from goats, mules/asses and horses continued to collectively represent less than 1 percent of the total emissions in the category.

CH_4 and N_2O from Manure Management Systems

Given Iowa's huge livestock population, manure management is a serious concern. Manure that is not applied by daily spread operations to croplands or deposited on pasture, range or paddock, is considered to be managed. Different management practices result in different quantities of methane and nitrous oxide emissions. Decomposition reactions that result in greenhouse gas emissions are very dependent upon environmental conditions including oxygen availability, heat, moisture, nutrient content, and pH, as well as duration of management. Because each management system and manure type has unique characteristics that determine these conditions, the result is a unique emission potential for each animal and system combination. Systems that result in largely anaerobic conditions, such as the anaerobic lagoons and liquid systems, release greater amounts of methane. Nitrous oxide emissions result from nitrification-denitrification reactions that require oxygen for initiation. Therefore, systems that are more aerated, such as solid storage and drylot storage, will result in greater nitrous oxide emissions. Table 9 provides estimates of emissions of these two gases in 1990 and 2000.

Table 9. Emissions from manure management systems; comparison between 1990 and 2000 (MTCE).

Greenhouse Gas	1990 (recalculated)	2000
CH_4	854,941	989,376
N_2O	220,845	235,916
Total	**1,075,786**	**1,225,292**

As the decade progressed emissions increased by 14 percent, from 1.1 million MTCE in 1990 to 1.2 million MTCE in 2000. The disaggregated data show a 16 percent increase in methane and a 7 percent increase in nitrous oxide emissions from manure management in the past decade. Methane from manure management alone represents the third leading emission source in Iowa, with 3 percent of the state's emissions coming from anaerobic lagoons, pit stores, drylots, liquid slurry systems and other methods of managing animal waste.

The changes observed reflect the interaction between changing animal population and emission potential. Figure 28 is a logarithmic representation of the annual CH_4 emission potential by animal type and management system. Bars that are below the axis represent emissions less than 1 kg of methane per head per year. Only three animal types, milk cows, breeding swine and market swine, represent the top 12 combinations emitting the highest amounts of CH_4. Paired with anaerobic lagoons, pit storage for more than one month, solid storage and other systems, 12 animals representing each of these configurations combine to emit 478 kg of methane per year. The remaining 19 animal and system combinations together produce only 16 kg of methane per year. Barring extraordinary changes in population, animals in the latter group cannot exert a significant effect on total methane emissions.

Milk cows combined with anaerobic lagoons produce far and away the most methane emissions per head, 211 kilograms per year, followed by milk cows with a liquid slurry system (79.5 kg/yr), breeding swine with an anaerobic lagoon system (42.6 kg/year), market swine with an anaerobic lagoon (40.5 kg/year), and milk cows in other systems not specified (30.3 kg/year). After these combinations, emissions are equal to or below 16 kg/year and drop off quickly to less than 1 kg/year for almost 40 percent of the categories.

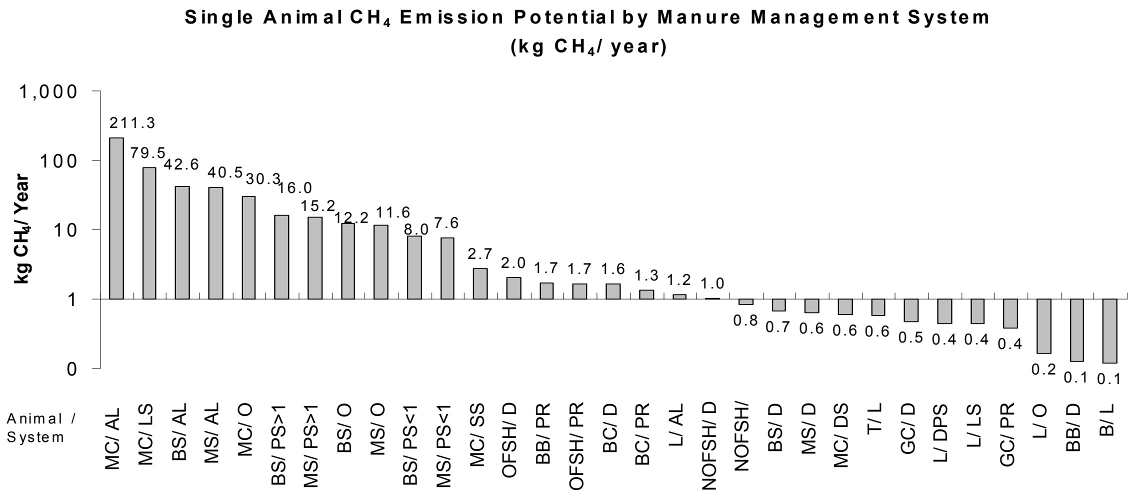
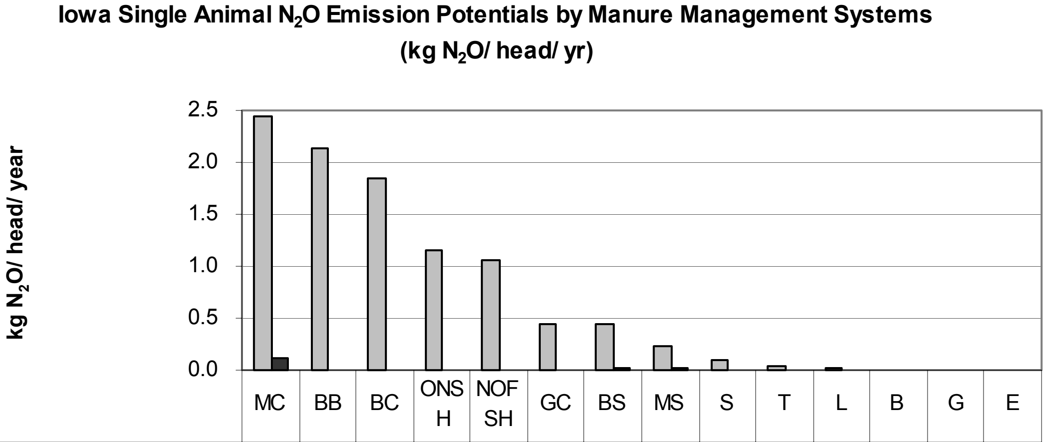


Figure 28. Milk cows, breeding swine and market swine have the highest CH_4 emission potentials when coupled with systems that lead to anaerobic conditions such as anaerobic lagoons (AL), liquid slurry (LS) and pit storage (PS). Most other animal and manure management system combinations have much smaller potentials. [Animal Types: MC (milk cow), BS (Breeding Swine), MS (Market Swine), H (Horse), BC (Beef Cow), BB (Breeding Bull), OFSH (Steers and Heifers On Feed), D (Donkey), L (Layers: Chickens), NOFSH (Steers and Heifers Not On Feed), GC (Growing Calves), S (Sheep), G (Goats), T (Turkeys), B (Broilers: Chickens); Management Systems: AL (Anaerobic Lagoon), LS (Liquid Slurry), O (Other), PS>1 (Pit Storage > 1 month), PS<1 (Pit Storage < 1 month), SS (Solid Storage), P (Paddock), PR (Pasture/Range), D (Drylot), DS (Daily Spread), LS (Liquid Slurry), L (Litter), DPS (Deep Pit Stacks).]

Figure 29 shows the emissions of nitrous oxide by animal type and management system. Comparing it with Figure 28, it is obvious that the nitrous oxide emission potentials per head are at least 2 orders of magnitude smaller than they are for methane on a per weight basis. Similar emission potentials among some systems permitted their aggregation into two groupings for calculation. The first group encompassed solid storage, drylot and other undefined systems. This group accounts for the vast majority of nitrous oxide emissions because of the availability of oxygen required for nitrification-denitrification reactions. Milk cows were the highest emitting animal type in these systems with 2.4 kg N_2O /head/year.

The second group included anaerobic lagoons and liquid slurry systems. Because of the lack of oxygen in these systems, they constitute a minimal source of N_2O emissions. A maximum emission from milk cow manure in these systems is 0.12 kg N_2O/yr.

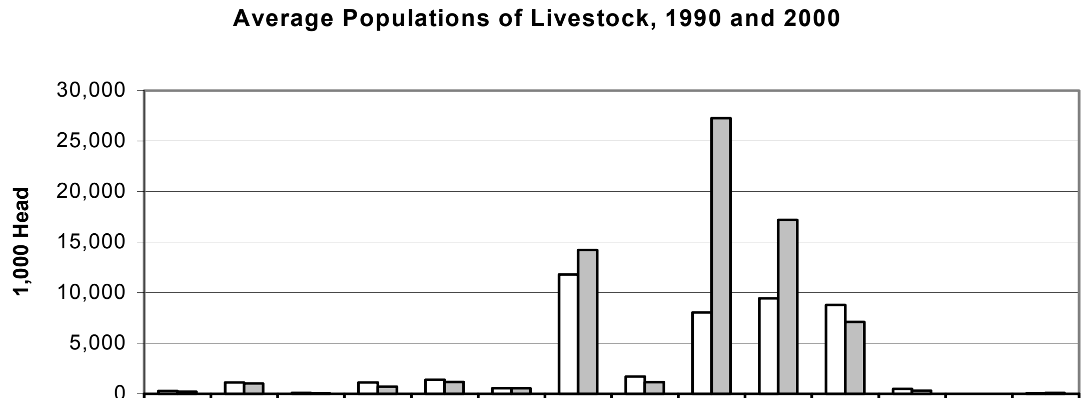


	MC	BB	BC	ONSH	NOFSH	GC	BS	MS	S	T	L	B	G	E
Solid Storage, Drylot, Other	2.44	2.13	1.84	1.16	1.05	0.44	0.44	0.23	0.10	0.05	0.01	0.01	0.00	0.00
Anerobic Lagoon, Liq Slurry	0.12	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Figure 29. Of the two groups of management systems, the "solid storage, drylot, other" group showed much greater N_2O emission potentials due to greater oxygen availability. [Animal Types: MC (milk cow), BB (Breeding Bull), BC (Beef Cow), ONSH (Steers and Heifers On Feed), NOFSH (Steers and Heifers Not On Feed), GC (Growing Calves), BS (Breeding Swine), MS (Market Swine), S (Sheep), T (Turkey), L (Layers: Chickens). B (Broilers: Chickens), G (Goat), E (Equine).]

The driving factor for the change in emissions of nitrous oxide has been the change in the makeup of livestock populations since 1990. In Iowa, all of the highest emitting animal populations have decreased except market swine. Figure 30 shows that populations of all cattle types have dropped, especially milk cows with a decrease of almost 25 percent. Also breeding swine dropped by more than 30 percent. In contrast, market swine increased by 21 percent between 1990 and 2000, leading to an increase in emissions by nearly 131,000 MTCE methane and 20,000 MTCE nitrous oxide.

Figure 31 shows the changing trends in methane emissions. In 2000, market swine accounted for 78 percent of total methane emissions from manure management, with most (61 percent) of that total coming from market swine manure managed in pit storage for more than one month. This combination has an emission potential of 15.2 kg CH_4/head/year and it is estimated that 39 percent of Iowa's market swine manure is channeled to this type of system.



	MC	BC	BB	GC	NOFSH	OFSH	MS	BS	L	B	T	S	G	H
1990	285	1,123	81	1,129	1,383	574	11,795	1,705	8,058	9,450	8,800	490	12	49
2000	216	1,031	67	713	1,174	563	14,227	1,163	27,282	17,200	7,100	301	12	100

Figure 30. Iowa's livestock populations underwent large shifts during the 1990s. There were drops in all cattle types and breeding swine, but market swine increased and the layer chicken population exploded, gaining more than 19 million head. [Animal Types: MC (milk cow), BC (Beef Cow), BB (Breeding Bull), GC (Growing Calves), NOFSH (Steers and Heifers Not On Feed), ONSH (Steers and Heifers On Feed), MS (Market Swine), BS (Breeding Swine), L (Layers: Chickens). B (Broilers: Chickens), T (Turkey), S (Sheep), G (Goat), H (Horses).]

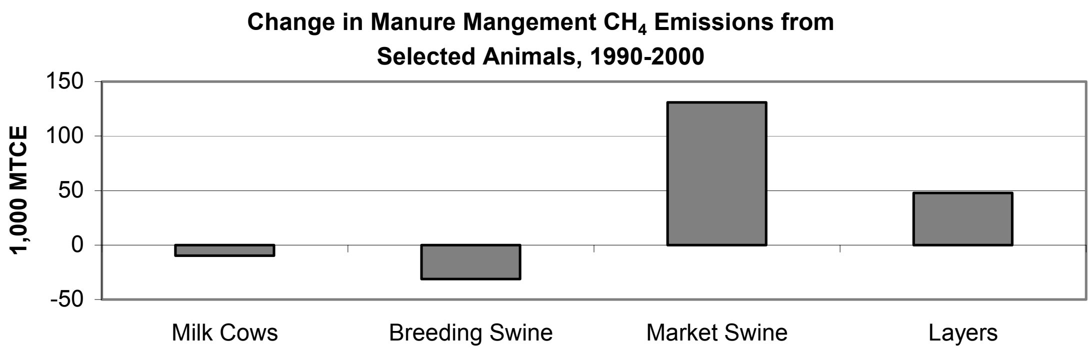


Figure 31. The largest change in CH_4 emissions in the 1990s was due to an increase of 131,000 MTCE from growth in the market swine population. Even larger growth in the layer chicken population caused a relatively large increase in emissions of 50,000 MTCE. These increases overshadowed the 41,000 MTCE drop in emissions from declining populations of milk cows and breeding swine.

There are other systems in use that yield fewer emissions. Pit storage for less than a month, which is thought to divert 11 percent of market swine manure, emits only 7.6 kg CH_4/head/year. Drylot storage, the system managing 30 percent of the market swine manure, generates the least emissions, about 6 kg CH_4/head/year. Even though these two systems handle more than 40 percent of market swine manure, they contribute only 6 percent of the methane emissions. They offer management alternatives that could be expanded further to produce less CH_4 emissions.

Anaerobic lagoons, with the potential to produce the highest methane emission rates, are used the least frequently in Iowa, accounting for only 3 percent of market swine manure management. Nevertheless, they generate 13 percent of CH_4 emissions from manure produced by market swine. For the sake of controlling methane emissions, use of lagoons should be discouraged, unless they can be coupled with CH_4 recovery systemss.

Even more noticeable was the change in chicken population, which increased by 239 percent in Iowa in the 1990s. Although their emission potential per head is among the lowest of all farm animals, their extreme population expansion was responsible for a 48,000 MTCE increase in methane emissions and a 15,700 MTCE increase in N_2O emissions.

Overall there was an increase in net emissions from manure management. The 24 percent drop in the milk cow population held down the increase somewhat because of their large per head emission potential. The increase of 2.4 million head of market swine, coupled with their relatively high emission potential, was the greatest factor in the net rise in emissions. An 8 million head increase in layer chicken population was the second greatest driver in elevating emissions.

CH_4 and N_2O from Burning of Agricultural Wastes

After crops are harvested fields still hold the residues of the harvest, which include substantial plant materials such as husks, stems, and leaves. This uncollected crop debris needs to be managed to mitigate entanglement and obstruction of farm equipment during successive plantings, or stifling the growth of emerging crops. There are different ways to manage residues, employing distribution, burial, removal, and burning (Korucu et al. 1999).

Combustion of residue releases large amounts of carbon dioxide and relatively smaller amounts of methane, nitrous oxide, carbon monoxide and nitric oxides. Because the emissions of carbon dioxide are from biological sources, however, they do not increase the burden of CO_2 in the atmosphere since the emissions are balanced by the original uptake of CO_2 during photosynthesis. Although the carbon in methane is also derived from atmospheric carbon dioxide during photosynthesis, methane emissions do represent a net increase in greenhouse gas forcing because the methane molecule has a global warming potential that is 21 times that of the original carbon dioxide molecule from which it was derived. Carbon monoxide and nitric oxide emissions have indirect effects on greenhouse forcing, although the GWPs for these gases have not been quantified.

Burning of residues is more common for some crops than others. According to national inventories, rice crop residues are the most frequently burned of all crop types, and they are considered in national emission assessments along with sugarcane, barley and peanuts (Environmental Protection Agency, 2002). For all crops other than rice, it is assumed that 3 percent of field crop residue is burned. For Iowa we only considered emissions for corn, soybean, and wheat residues assuming that 3 percent were burned, although it is believed that this activity occurs even less frequently in Iowa.

Emissions from this source are relatively minor compared to other agricultural sources. Crop residue burning comprises 0.13 percent of total Iowa greenhouse gas emissions at 44,000 MTCE. Sixty percent of this total is derived from methane and 40 percent from nitrous oxide. Table 10 disaggregates the emissions according to crop type. Greenhouse gas emissions from burning of agricultural residues were estimated to have increased by 27 percent between 1990 (recalculated) and 2000. Emissions were estimated based on crop production in the state, which can fluctuate from one year to another. The observed rise in the 2000 emissions is directly proportional to the rise in production relative to 1990.

Table 10. Methane and nitrous oxide emissions from residue burning by crop type, with comparison between 1990 (recalculated) and 2000 (MTCE).				
Crop Type	**1990 (recalculated)**		**2000**	
	CH_4	**N_2O**	**CH_4**	**N_2O**
Corn	14,346	4,526	16,808	5,303
Soybeans	6,994	8,707	9,739	12,125
Wheat	35	12	11	4
Total	**21,375**	**13,245**	**26,558**	**17,431**

It should be noted that the method used in the previous inventory assumed the fraction of residue burned was 10 percent. This is believed to be a gross overestimation, and has since been lowered to 3 percent. According to expert opinion, even this lower estimate is thought to be too large in Iowa because burning is mostly a maintenance tool for conservation plantings, which are not extensive (D. Christensen, Recycle Iowa, personal communication, August 8, 2003; R. Robinson, Iowa Farm Bureau, personal communication, August 11, 2003).

Chapter 5: Greenhouse Gas Emissions from Industrial Processes

In this industrial sector analysis, non-energy related greenhouse gas emissions from industrial activities are quantified. For practicality, only the largest emitting industries are considered in the inventory. Other industrial activities that are known to emit greenhouse gases, such as soda ash manufacture and consumption, primary aluminum production, adipic acid production, HFC-23 and HCFC-22 production, and magnesium production and processing, are not addressed here either because they do not exist in Iowa or data related to their activities were unavailable. Nevertheless, emissions from industries not analyzed are thought to be minimal in comparison to those investigated here. Figure 32 shows the industries covered and the relative strengths of their emissions. Overall, emissions from industrial processes are relatively small, generating about 922,000 MTCE (3 percent of Iowa's year 2000 gross greenhouse gas emissions), released as carbon dioxide, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons and perfluorocarbons.

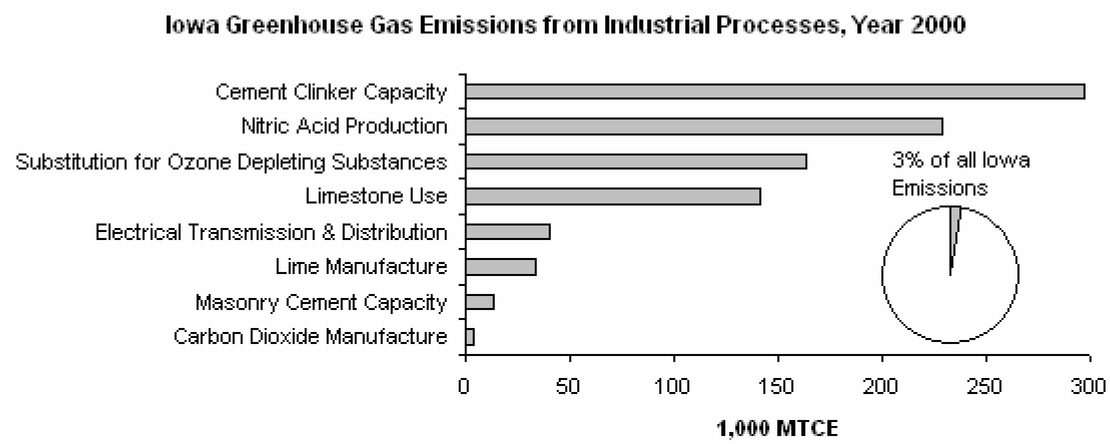


Figure 32. Industrial emissions were dominated by cement clinker production, and a few other processes.

Inventory of Greenhouse Gas Emitting Processes

CO_2 from cement clinker and masonry cement manufacture. Cement clinker manufacture in Iowa was the largest source of non-energy carbon dioxide emissions in the year 2000, yielding 296,770 MTCE. However, this source is a minor one overall as it only accounted for 0.9 percent of total greenhouse gas emissions. The gas is released when calcium carbonate is heated for the production of clinker, a cement precursor. Masonry cement requires additives including lime, an additional source of carbon dioxide emissions. Because detailed data were unavailable, production estimates were drawn from Iowa's clinker capacity as reported by the Portland Cement Association (H. Van Oss, U.S. Geological Survey, personal communication, September 24, 2002). A maximum emission scenario was assumed where all clinker went to masonry cement production leading to an additional 13,112 MTCE.

N_2O from nitric acid production. The EPA estimates that 70 percent of nitric acid (HNO_3) produced is consumed as an intermediate for the production of ammonium nitrate (NH_4NO_3), a major component of commercial fertilizer (Environmental Protection Agency, 1998a). Nitrous oxide is an unwanted by-product in the industrial process, formed from the oxidation of ammonia (NH_3). This source released an estimated 229,071 MTCE in 2000, and is the third highest emission source of N_2O in the state.

Substitutes for ozone depleting substances. HFCs and PFCs serve as substitutes for ozone depleting CFCs in a variety of applications including refrigeration and air conditioning, aerosols, solvent cleaning, fire extinguishing, foam blowing and sterilization. They were introduced after the 1987 Montreal Protocol, which began the process of banning the production and use of CFCs. Although these substitutes mitigate the degradation of Earth's protective ozone layer, they are powerful greenhouse gases with global warming potentials ranging from 140 to 11,700. Even with their extremely high GWPs, their releases were so low (163,916 MTCE) that they accounted for only an estimated 0.5 percent of Iowa's total greenhouse gas emissions.

CO_2 from limestone use. Limestone is composed of calcium carbonate ($CaCO_3$), which gives off CO_2 when heated. It has many chemical and industrial applications, including cement and lime (CaO) manufacture, and as a purifying flux in refining metals like iron. The construction industry is a large consumer of limestone for building roadways, although in this use it is not subjected to the same heat and chemical processes that cause emission of CO_2.

Lime and limestone are also applied to agricultural fields to neutralize acidic soils. This activity releases CO_2 and was accounted for in the analysis of emissions from agricultural soils. In this section, emissions are quantified only for limestone used in the chemical and metallurgical industries; their total contribution was estimated at 141,251 MTCE.

SF_6 electricity transmission and distribution. Sulfur hexaflouride is most commonly used as an insulator in electricity transmission and distribution equipment. Emission is a result of equipment leakage and to a lesser extent from the manufacture of this equipment. On a per weight basis, it is the most powerful greenhouse gas considered in this analysis with a GWP of 23,900. Nevertheless, emissions were too low (40,143 MTCE) to make it a major contributor to Iowa's inventory, accounting for only 0.1 percent of total Iowa greenhouse gas emissions.

CO_2 from lime manufacture. In 2000, only one facility manufactured lime in Iowa. For this reason, the US Geological Survey was unable to disclose proprietary production data needed to estimate emissions. Rather than calculating emissions based on production data, a U.S. government source, applying an undisclosed EPA methodology, estimated these emissions to be 34,091 MTCE.

This estimate illustrates the stark contrasts that can occur between different inventories. Our figure is a factor of five less than the emissions reported for the same activity in the 1990 inventory. Because neither the data nor the methodology were disclosed for the 2000 inventory, it is not possible to reliably compare the two emission figures or explain the discrepancy. This inconsistency, however, does not introduce a significant uncertainty in the overall inventory, as it only accounts for 0.1 percent of total emissions.

CO_2 emissions from CO_2 manufacture. Carbon dioxide is manufactured for applications in food processing, chemical production, carbonated beverages and enhanced oil recovery. This source was estimated to be very minor with an emission of only 3,970 MTCE.

Other industries. The production of adipic acid, primary aluminum, and HFC-23 from HCFC-22 are all processes that generate greenhouse gases as a part of their manufacturing processes. These industries are not found in Iowa. Soda ash manufacture and consumption are known to occur in the state, but data on these activities were not available, nor was a method of estimation. Thus, their emissions were not calculated.

Overall Industrial Emissions and Comparisons of the 1990 and 2000 Emission Inventories

Table 11 summarizes the emissions discussed above, and compares the 1990 and 2000 inventories. The original 1990 data were recalculated in two different ways to make a more valid comparison with the 2000 data.

Table 11. Emissions from industrial processes in Iowa in 2000, and compared with recalculated values for 1990 (MTCE).

Gas/Source	1990 (recalculated) [a]	1990 (alternative recalculated) [b]	2000
CO_2	**3,612,452**	**1,142,768**	**489,194**
Cement Clinker Manufacture	265,935	265,935	296,770
Masonry Cement Manufacture	83	83	13,112
Limestone Use	2,812,320	340,200	141,251
Lime Manufacture	534,114	534,114	34,091
CO_2 Manufacture	*2,436*	2,436	3,970
Soda Ash Manufacture and Use	UA	UA	UA
Primary Aluminum Production	NA	NA	NA
N_2O	**0**	**0**	**229,071**
Nitric Acid Production	UA	UA	229,071
Adipic Acid Production	NA	NA	NA
HFCs, PFCs and SF_6	**85,493**	**85,493**	**204,059**
Substitutes for Ozone Depleting Substances	*2,740*	2,740	163,916
Electrical Transmission and Distribution	*82,753*	82,753	40,143
HFC-23 Production	NA	NA	NA
Total for year	**3,700,381**	**1,228,261**	**922,324**
Difference from year 2000	**2,778,057**	**305,937**	

UA = activity data was unavailable
NA = not applicable; activity does not occur in Iowa
[a] Emissions were recalculated with the data from the 1990 inventory, and the methodology from the 2000 inventory. Numbers in italics were not included in the original 1990 inventory.
[b] The alternative recalculation uses what is believed to be more realistic data for "limestone use." Consumption of limestone in 1990 was previously reported as 25 million short tons (22.7 million metric tons). Instead, 3 million short tons (2.7 million metric tons) of limestone was used to recalculate emissions.

Although it appears from the “recalculated” 1990 estimates that emissions from production processes in 2000 decreased significantly, the apparent overall decrease is largely explained by questionable activity data, and the estimation methods for “limestone use” and “lime manufacture,” the two sources with the greatest inconsistency between inventories. Limestone use accounted for 76 percent of recalculated emissions from industrial processes in 1990, but in 2000 this share was only 15 percent. This radical change in emissions seems unlikely given the fairly stable number of producers in the state. Consumption data from the two periods shows a large discrepancy with 25 million short tons (22.7 million metric tons) reported in the 1990 inventory (Iowa Department of Natural Resources, 1996) and 1.3 million short tons reported for 1999 according to the Iowa Minerals Yearbook for 2000 (United States Geological Survey, 2000). Data for 2000 was withheld to protect proprietary information. No source was cited in the 1990 inventory, making comparison of data and emissions difficult. However, past Mineral Yearbooks show consumption by industry was on the order of 3 million short tons in the late 1980s and early 1990s (Harrison and McKay, 1991; Zelten and McKay, 1991). Data for 1990 was again unavailable.

Because activity data reported in the 1990 inventory is different by an order of magnitude, it seems more likely that it came from a dissimilar source and represents an inordinately large figure for limestone use. It is possible that the 1990 inventory overestimated industrial emissions by counting total crushed stone consumption, which includes use by agriculture and construction industries. Sources cite that figure to be in the range of 28 to 31 million short tons between 1989 and 1991 (Harrison asd McKay, 1993; Zelten and McKay, 1991). It thus seems most likely that emissions in actuality were much smaller in 1990 than reported in the 1990 inventory.

An alternative recalculation was conducted for 1990 limestone use based on the data from the Iowa Minerals Yearbooks. Consumption was set at 3 million short tons and emissions were calculated to be 340,200 MTCE for limestone use (see Table 11). This figure is 2.5 million MTCE lower than the first recalculated value. Using the alternative data brings total industrial emissions in 1990 closer to the 2000 estimate, but still higher by 25 percent. It may indeed reflect a true decrease in emissions from industrial limestone use in the 1990s.

The other large discrepancy in industrial emissions was from lime manufacture. For 1990, emissions were recalculated to be about 534,000 MTCE; emission estimates for year 2000 were 500,000 MTCE lower. As explained above, emissions from 2000 were provided by a government source with undisclosed documentation in order to protect proprietary information. Without the fundamental information about this source, a sound comparison cannot be made.

In the 1990 inventory, emissions of HFCs, PFCs, and SF_6 were unquantified. For these chemicals, recalculated 1990 emissions were based on recent calculations with the methods used in the 2000 inventory. Worksheets explaining the calculation methods can be found in the appendix under “Industrial Processes.” The differences in emissions of these gases are a consequence of the changing times and technologies. As noted above, the marked increase in use of HFCs and PFCs in the 1990s (subsumed in the table under “substitutes for ozone depleting substances”) is a result of the phase-out of CFCs that began after the 1987 Montreal Protocol, and was accelerated in subsequent follow-up agreements. The drop in SF_6 emissions from electrical transmission and distribution equipment by 42,600 MTCE reflects a worldwide trend of declining use owing to the increased price of the gas, and environmental awareness about its impact on the greenhouse effect.

Overall, applying the "alternative recalculated" emissions for the 1990 inventory given in Table 11 and comparing them to the emissions from the 2000 inventory, it is estimated that emissions from industrial sources decreased by 25 percent in the 1990s. The largest apparent reduction stemmed from a drop in lime manufacture emissions, although this assumption is not verifiable because of proprietary production data. Secondly, limestone use was apparently cut in half over the 1990s, thereby reducing emissions by nearly 200,000 MTCE. Somewhat offsetting the net downward trend in industrial emissions was the increased production in CFC substitute gases, which increased emissions by 160,000 MTCE.

Chapter 6: Greenhouse Gas Emissions from Wastes

Overview

The disposal and treatment of organic wastes generate continuous releases of greenhouse gases to the atmosphere. Practices can be employed to offset these emissions through carbon sequestration and recovery (collectively called "carbon capture"). Figure 33 summarizes the magnitudes of emissions and capture from waste management activities. As shown, landfills that collect municipal solid wastes (MSW) are the dominant source of methane emissions. Because minimization of space allocated for waste disposal is a common aim of landfill managers, decomposition of the organic fraction in the waste typically occurs in confined pockets, which are underexposed to oxygen. Inevitably, anaerobic microbial assemblages decompose the organic carbon to fulfill their needs for metabolic energy, and in the process release a mixture of carbon dioxide and methane. It is possible, however, to capture the methane and burn it, either as a fuel or simply to flare it to CO_2. The former option is of course preferable, but even in the latter case there is a benefit since there is conversion from CH_4 with a high GWP (21) to CO_2 which, because it is from biogenic organic wastes, has no net global warming impact. In addition to methane, nitrous oxide is released via denitrification under aerobic conditions by the action of microbes on the nitrogen contained in the wastes. Another option for treatment of MSW is incineration rather than landfill. In this case, small amounts of N_2O are generated during the combustion process.

Liquid wastes containing organic carbon, commonly known as sewage, are collected and treated at sewage treatment plants (STPs). Treatment of the wastewater involves several steps involving microbial decomposition under alternate anaerobic and aerobic conditions. In the process of reducing the organic burden in the wastewater, microbes emit CH_4, CO_2, and N_2O, just as they do in landfills.

MSW landfills, STPs, and to a very small degree incinerators together generate 1.0 million MTCE (3 percent) of the state's total greenhouse gas emissions. When factoring in carbon capture, the net emissions decline by about 600,000 MCTE. Despite efforts for methane recovery from landfills, they are still the dominant net source of greenhouse gases from wastes.

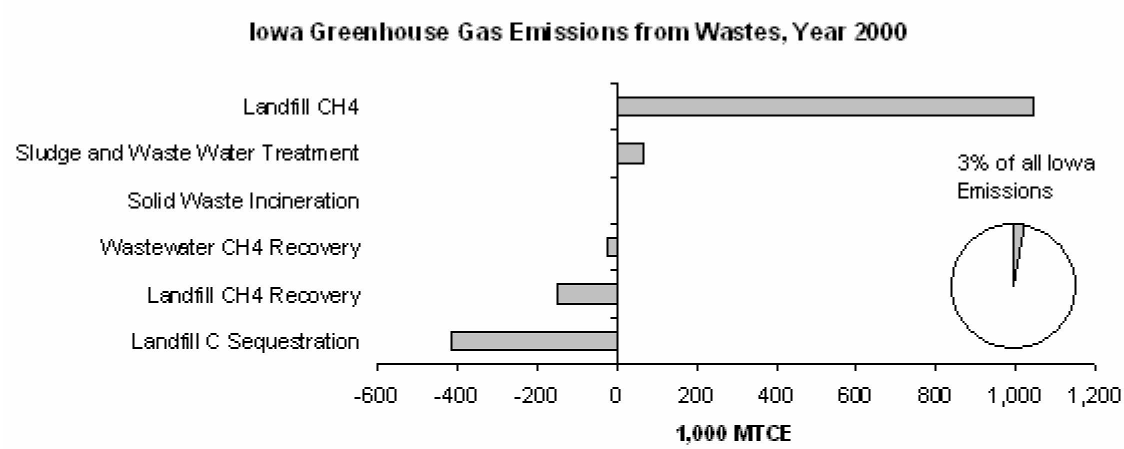


Figure 33. Landfills are both the largest source of emissions, and the largest sink for carbon capture among waste management practices.

Greenhouse Gas Emissions and Carbon Capture from Solid Waste Disposal

Landfill gas (biogas) generation is the product of microbial breakdown of organic wastes buried under the land surface. In the landfill, new wastes near the surface are initially exposed to atmospheric oxygen. Subsequently, as these recent wastes are covered by yet newer wastes and sink lower into the landfill, they enter the anaerobic zone where degradation switches from aerobic to anaerobic microbes. Ultimately, methanogenic bacteria break down the waste residues into water and biogas containing approximately 45 percent carbon dioxide and 55 percent methane. Only the methane portion of the biogas is counted in the greenhouse gas inventory; the carbon dioxide vented to the atmosphere merely replaces that which was taken from the air when the original organic material was biosysnthesized (thus, net emissions equal zero). The production of methane from degradation in the landfill is slow but steady. It may take up to 30 years for all the organic matter deposited at a given time to dissipate into biogas. Thus, accounting for emissions from landfills must incorporate a cumulative timescale factor that considers the ongoing, continued emissions from wastes that were deposited some decades in the past.

When municipal wastes are incinerated they emit carbon dioxide and nitrous oxide. Oxidation of carbon in synthetic wastes including plastics, rubber and other petroleum-based products constitutes a net emission of the greenhouse gas CO_2 because the source of the carbon is from petrochemicals rather than from biogenic photosynthesis of atmospheric CO_2.[7] Nitrous oxide is produced by processes analogous to those creating N_2O emissions from stationary combustion of fossil fuels (see page 43).

Large capacity landfills are now required by regulation to flare biogas. The practice oxidizes methane with a GWP of 21 to carbon dioxide and water with no net greenhouse gas emissions. However, much of the deposited carbon never gets degraded to biogas, and thus remains in the landfill rather than vents to the atmosphere. This remaining carbon is thus sequestered in the earth. Landfilled plastics and other petroleum-based products resistant to degradation do not count in the calculation of sequestered carbon, because they have been merely transferred from one long-term sink (fossil fuels in the ground before mining) to another (the landfill).

In 1989, an initiative by the Iowa Legislature, the Waste Reduction and Recycling Act, mandated that statewide landfill deposits decrease by 50 percent from 1988 to 2000. As a result of this initiative, the estimated rate of landfilling MSW has decreased significantly since 1990. Figure 34 shows the actual tonnage of wastes landfilled in Iowa between 1960 and 2000 (solid line) versus the estimated tonnage that would have pertained had there been no 1989 legislation (dotted line). The implementation of the regulation appears to have caused a zero-growth trend in quantities of waste landfilled during the 1990s despite a 5 percent increase in population.

[7] Carbon in synthetic polymers taken from a petrochemical and burned in an incinerator represents a net transfer of carbon from long-term storage (buried in the earth as petroleum, natural gas, or coal) to the atmosphere as CO_2.

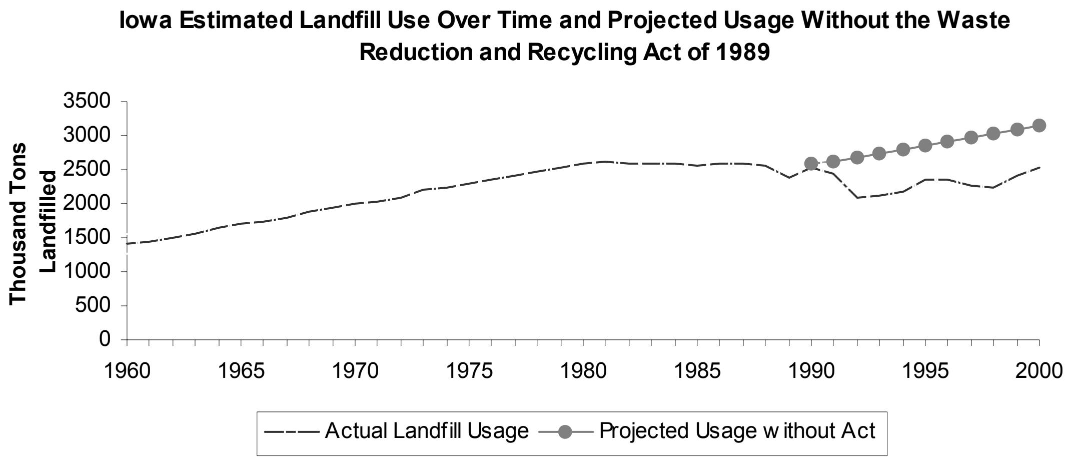


Figure 34. As a result of the Waste Reduction and Recycling Act of 1989, landfill use has remained relatively flat since 1990, even with a 5 percent rise in population.

Table 12 summarizes the data for greenhouse gas emissions and carbon capture from MSW waste disposal, and compares the years 1990 and 2000. MSW was the fourth highest source of Iowa's gross greenhouse gas emissions in 2000 and was responsible for 3 percent of total emissions. Landfill methane emissions made up the largest part of gross emissions from this source. Incineration makes up a very minimal part of total MSW treatment in the state and less than 0.01 percent of the gross greenhouse gas emissions.

Carbon sequestered in landfills and methane recovered from release of biogas equaled more than half of the estimated emissions, dropping the net emissions to 485,000 MTCE. In 2000, four Iowa landfills were known to be recovering or flaring methane. About 149,000 MTCE (29,000 tons methane) of methane were recovered for energy or flared by Des Moines Metro, Bluestem and Scott County landfills. The Johnson County landfill is known to have a flare, but no data were available for the site.

Table 12. Emissions and carbon capture from waste disposal (MTCE), years 2000 and 1990 (recalculated).

Source	Year 1990 Emissions (recalculated)	Year 2000 Emissions
Landfill CH_4 (before recovery)	966,669	1,044,619
Incineration CO_2	2,507	2,505
Incineration N_2O	194	194
Gross Total	969,370	1,047,318
Landfill Carbon Sequestration	- 413,719	-413,377
CH_4 Recovery	- 54,997	-148,619[a]
Net Total	**500,654**	**485,322**

[a] The actual amount of methane recovered in 2000 may exceed this value, as data were not available for all landfills recovering methane.

Emissions for 1990 were recalculated to ensure consistent comparison with the 2000 data. While landfill carbon sequestration remained stable, the recovery of methane increased 170 percent, from 55,000 MTCE (10,500 tons methane) to nearly 150,000 MTCE (28,600 tons methane). Overall, net emissions decreased 3 percent, from 500,654 MTCE in 1990 to 485,322 MTCE in 2000, while gross emissions increased by 8 percent.

In the future as landfills grow, the option of landfill gas recovery could prove to be low-hanging fruit in the effort to minimize Iowa's greenhouse gas emissions. The investment in these systems is already increasing. The combustion of gas for energy provides economic and environmental incentives and provides a double credit toward reducing greenhouse gas emissions by evading direct methane emissions from landfill gas, and circumventing CO_2 emissions from the conventional fossil fuels.

Greenhouse Gas Emissions and Carbon Capture from Municipal Wastewater at Sewage Treatment Plants

The function of a municipal sewage treatment plant is to remove the nutrient rich organic fraction from wastewater generated in the community and transported via sewage pipes to the central plant. This function is especially important to maintain the water quality of natural waterways into which the treated sewage effluent is released, and to protect the public from waterborne bacterial and viral diseases. Organic matter sent to the STP from households and commercial businesses include human excreta, food scraps, soaps, and dirt. If storm drains are connected to the sewage lines, during heavy storm events STPs may receive leaves and other plant debris, greases and oils contained in street dust, and runoff from lawns and other green space. Sometimes industries such as food processing plants send their nontoxic organic wastes to STPs. The treatment plant employs various aerobic and anaerobic processes to reduce the organic load in the water; methane production occurs under anaerobic conditions and nitrous oxide under aerobic conditions.

The potential methane and nitrous oxide production capacity of wastewater is determined by the degradable organic fraction, expressed as the biological oxygen demand (BOD). This variable quantifies the amount of oxygen required to degrade the organic matter under ideal aerobic conditions. A higher BOD indicates a greater amount of organic matter and greater CH_4 and N_2O production potential. The method used for this analysis is based on an estimation of per capita BOD generation rate and population.

Anaerobic biological treatment of wastewater results in biogas emissions containing approximately equal parts carbon dioxide and methane. Emissions of carbon dioxide from organic sources are considered to be in equilibrium with the atmosphere (with certain exceptions) producing no net global warming effect. Nitrous oxide also results from a complicated process of microbial cycling of nitrogen contained in the organic fraction. The content of nitrogen in human waste may be increasing since, according to the United Nations Food and Agriculture Organization (2004), the amount of protein, the chief source of nitrogen intake, has increased in the American diet in recent decades.

In the first treatment step at the STP, the mixture of water and organic matter sits under quiescent conditions, which allow solids to settle out. This concentrated buildup of organic matter, called sludge or biosolid, is skimmed from the settling tanks, stabilized and disposed of separately. Anaerobic digestion is one of the most widely used practices to stabilize the sludge, especially in larger treatment works because of its methane recovery potential (Environmental Protection Agency, 1999b). Ninety percent of all methane generated at the STP derives from sludge stabilization. The remainder is generated from wastewater treated in subsequent steps. In contrast to CH_4 emissions, most of the N_2O is generated in the treatment of wastewater after sludge removal, with only a small portion released from the sludge.

Table 13 provides estimates of the emissions of methane and nitrous oxide and recovery of methane at STPs in Iowa in 2000, with comparison to 1990. The total gross emissions only accounted for about 0.20 percent of Iowa's total greenhouse gas emissions in 2000, and net emissions through methane recovery reduced the share to 0.13 percent of total emissions. Although the quantity of methane released from STPs is relatively small compared to other sources such as landfills and manure management systems, its recovery as an energy source is among the most amenable of all methane emission categories. As can be observed from the table, about two-thirds of the methane generated from sludge treatment (35,000 MTCE) was recovered (23,000 MTCE). In recent years, treatment plants have begun to use biogas for process heat, and small scale space heating and electricity production. These activities serve to convert methane to biomass-derived carbon dioxide, which has no net global warming impact.

Table 13. Emissions and methane recovery from treatment of municipal wastewater at sewage treatment plants in Iowa (MTCE), years 2000 and 1990 (recalculated).

Source	Year 1990 Emissions (recalculated)	Year 2000 Emissions
CH_4 from Wastewater Treatment	3,679	3,877
CH_4 from Sludge Treatment	33,108	34,892
N_2O from Wastewater and Sludge Treatment	23,138	26,064
Gross Total	59,925	64,833
CH_4 Recovery	-113 [a]	- 23,000
Net Total	**59,812**	**41,833**

[a] Source: Iowa Department of Natural Resources (1996).

As noted above human biological wastes are but one of several sources of organic matter that is treated at the STP. The method employed in our analysis, however, only considers the human-derived source. This undoubtedly underestimates the emissions as it ignores other waste contributions from soaps, domestic food scraps, industrial food processing, and organics collected during storms. A full analysis of these omitted sources would result in higher emissions values than those quoted in Table 13. The extensiveness of recovery in Iowa was suggested by the IDNR, which estimated that more than 19 Iowa municipal STPs capture and use more than 1.2 million cubic feet of biogas per day (Iowa Department of Natural Resources, 1999).

The emissions estimation methods have changed between the 1990 and 2000 inventory years, including addition of a calculation estimating nitrous oxide emissions from wastewater and sludge treatment, and a near tripling of the methane emission factor. In addition, the national BOD generation rate increased by 5 percent, the fraction of waste treated anaerobically increased by 1.25 percent, and per capita American protein consumption has risen from 31.2 to 41.9 kg per year. A further factor affecting the emission rates is that the Iowa population increased by about 5 percent in the 1990s. All of these factors lead to an estimated increase in gross emissions of about 8 percent, from 59,925 MTCE to 64,833 MTCE. Despite these notable changes that have tended to increase emissions, this source was an even smaller net contributor to Iowa's total greenhouse gas releases in 2000. Efforts to recover methane expanded dramatically throughout the decade, reducing net emissions by 30 percent from 59,812 MTCE in 1990 to 41,833 MTCE in 2000.

Chapter 7: Carbon Sinks from Forest Management and Land Use Change

Soils and biomass can be thought of as large sinks or pools of stored organic carbon. These pools lose or gain carbon by exchange with the atmosphere. Carbon, in the form of carbon dioxide (CO_2), is taken out of the atmosphere during photosynthesis by plants (biomass), which produce a simple organic carbon (commonly characterized by the monomer unit CH_2O). Plants fashion these simple units into a myriad of complex carbohydrates that include sugars, starches, and cellulose, the building blocks of plant material. When plants die, microbes decompose the plant tissue back to simple units (CH_2O), which they react with oxygen or other oxidants when O_2 is unavailable. CH_2O is the "fuel" of the biosphere. Microbes oxidize it to generate the energy required to supply their metabolic needs, and CO_2 is released back to the atmosphere as a by-product, thus completing the cycling of carbon between the atmosphere and the plant biomass.

Not all of the organic carbon is rapidly returned to the atmosphere. Under anaerobic conditions microbes oxidize CH_2O using other oxidants (e.g., NO_3^-, Fe^{+3}, SO_4^{-2}), but these processes are typically slower than reaction with O_2, allowing organic carbon to accumulate. A good example of this occurrence is the large store of carbon found in the "muck" of anaerobic wetlands and swamps. Another reason for carbon retention in the biosphere is the inherent difficulty of decomposing some forms of biomass relative to others. This is particularly important with regard to cellulose, which is much more resistant to microbial decomposition in comparison to starch and sugars. Cellulose makes up the "woody" parts of plants and constitutes up to 50 percent of the mass of plants. Cellulose is not typically transformed completely into CO_2, but rather semi-decomposed into fragments named "humus," a major component of stored organic matter in soils.

The size of the organic carbon pool in soils and biomass depends on the balance of gains and losses (the flux) of carbon with the atmosphere. This balance is particularly sensitive to anthropogenic activities that alter the composition of the land, and to how the land is used and maintained. The two dominant land uses that affect carbon flux in Iowa are croplands and forests. Forestlands cover 2.6 million acres of the state, and croplands are ten times larger at 26 million acres (two-thirds of the state's total area). Our analysis employed a stock approach to account for carbon flux in the state's forestlands. Estimates of carbon flux from agricultural soils are reported from a study conducted by the US Department of Agriculture (USDA). As shown in Figure 35, despite the tenfold advantage in spatial coverage, Iowa's croplands were estimated to store only slightly more carbon annually than the forestlands.

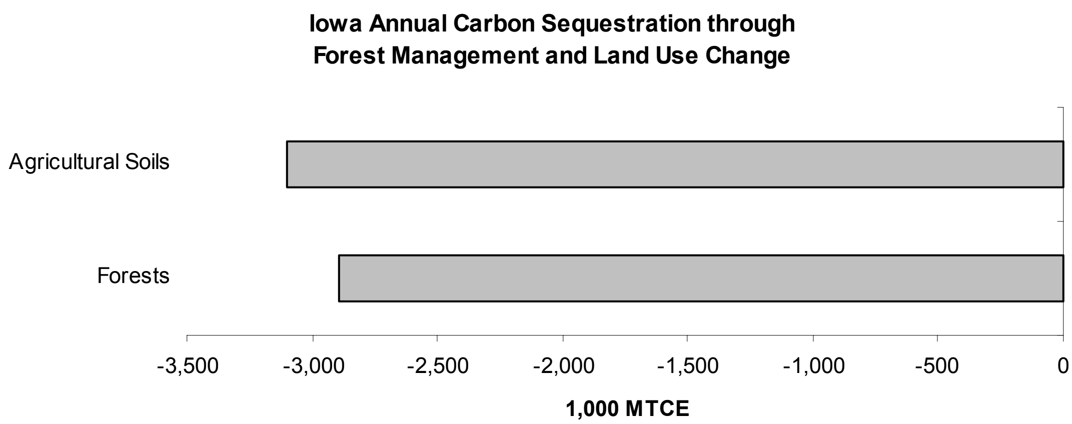


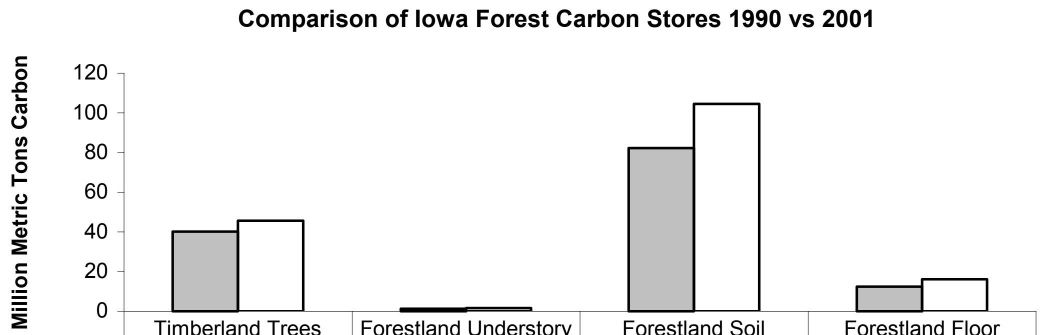
Figure 35. Forests in Iowa cover only a small part of the state but sequester almost as much carbon as agricultural soils.

Carbon Flux in Forests

Carbon in the forest environment is divisible into four pools: l*arge trees* store carbon in their trunk, branches, and roots; u*nderstory vegetation is* comprised of relatively short-lived species such as bushes, shrubs and small trees; the *forest floor* is the layer of fallen debris and litter that collects above the soil; and the *forest soil* contains the smallest broken down pieces of litter, debris, and humus. Understory vegetation is the smallest pool, and forest soils the largest. For our inventory, the stock approach was applied to the years 1990 and 2001[8] to estimate the change in carbon stores from Iowa forests during the interim between the two dates. Each carbon pool was analyzed from data in the Iowa forest inventories compiled by the USDA Forest Service, which are available at the online Forest Inventory Analysis Database (http://ncrs2.fs.fed.us/4801/fiadb/index.htm). For further explanation of the methods of calculation, see the appendices for this section.

Figure 36 compares carbon pool sizes in 1990 and 2001. Overall, the forests in 2001 held 168.0 million MTCE compared to 136.2 million MTCE in 1990, for an overall increase of 31.8 million MTCE (23 percent). This translates to an annual uptake of 2.9 million MTCE, which constitutes about 10 percent of Iowa's gross 2000 greenhouse gas emissions. The uptake rate has more than doubled since 1990 when annual forest sequestration was estimated to be 1.2 million MTCE (Ney et al. 2001). Soil, already the largest carbon pool, accumulated most of the additional carbon, accounting for 22.4 million MTCE or 70 percent of the total increase. This is a direct result of the estimated increase in the area of land reported as forestland.

[8] Year 2001 was adopted rather than 2000 because of the higher quality of its inventory data. It is assumed that the additional year of data will not greatly impact the outcome of the analysis.



	Timberland Trees	Forestland Understory	Forestland Soil	Forestland Floor
1990	40.2	1.3	82.2	12.4
2001	45.6	1.6	104.6	16.2

Figure 36. Carbon storage grew during the 1990s, with most storage occurring in forest soils.

There are several alternative explanations for the assumed increase in carbon storage. One is the unconfirmed trend observed by natural resource managers of increased forestland encroachment onto private lands. According to Vern Fish of the Black Hawk County Conservation Board this factor could have increased the forestland area captured in the 2001 forest inventory (personal communication, September 17, 2003). Ney et al. (2001) noted that increases in forestland between 1974 and 1990 were largely attributed to conversion of pasture areas that were no longer grazed. This pattern may have continued into the following decade, further expanding the forested areas. Another factor favoring forest expansion may have been the continued rise in enrollments in the Conservation Reserve Program (CRP), in which government subsidies are given to farmers to introduce measures such as planting trees for reducing erosion on marginal croplands. Finally, as discussed in the section on uncertainty, the apparent overall change in forestland area may be due in part to sampling and statistical errors stemming from the yet to be completed 2001 forest inventory.

Carbon Flux in Agricultural Soils

A study conducted by the US Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS) adopted the Century EcoSystem Soil Organic Matter Computer Model to estimate historical soil carbon dynamics of Iowa agricultural soils, and to predict county level changes that resulted from crop management and tillage practices (Brenner, 2001). The study was unique in that it collected data on historical land-use, dominant management practices (drainage, irrigation, crop rotations, tillage, fertilization) over time, and installation of conservation practices (e.g., CRP enrollment, grassed waterways, buffers). Providing the data were local experts from the conservation districts and local NRCS offices for every county in Iowa. The study concluded that Iowa agricultural soils are currently a net sink for carbon, and estimated annual carbon uptake to be 3.1 million MTCE. About 1.9 million MTCE of this amount is stored directly in cropland. The remaining storage was attributed to increased CRP enrollment, grassland and tree conversions, and wetland reversions. The increased adoption of moderate tillage and no tillage systems for row crop production as well as activities involved within the CRP had the greatest influence on storage trends. A smaller contributor was the impact of increased crop residue inputs from rising productivity, an ongoing development since the 1950s.

Uncertainty in Forest Carbon Flux

The 2001 Iowa Forest Inventory, the source of our estimation of carbon sequestered in Iowa's forestlands, marks the beginning of a new standardized five-year cycle inventorying system initiated in 1999. This is an alternative approach to the previous three periodic inventories taken in 1954, 1974 and 1990. Under the new system, a full and precise inventory will take 5 years to complete, as one fifth of the field plots in the state are measured each year. Thus, the most recent inventory will not be complete until after 2004 data are compiled. Preliminary data were available, but it was cautioned that the error would be minimized only when all the plots have been measured, which at the time of this analysis included 60 percent of the total. This introduces some level of uncertainty relative to the 1990 inventory. To minimize error, the most recent data at the time of the analysis, the 2001 cycle, was used rather than 2000 data. The North Central Research Station (2000) reported the sampling error for the 2000 update: 4.32 percent error for area of forestland; 4.72 percent for area of timberland; 8.35 percent for number of growing stock trees on timberland; 7.78 percent for volume of growing stock on timberland; and 9.20 percent for volume of saw timber on timberland. These errors are high in comparison to the 1990 inventory, which cited errors ranging from 1.9 percent for timberland area to 3.2 percent for growing stock volume. Error values for the 2001 cycle update were unavailable, but are expected to be somewhat lower than the 2000 data with the additional 20 percent of plot samples measured.

Differences in the methods of data collection and analysis further impede comparison between the 1990 and 2001 inventories. In 1990, manual interpretation of aerial photos was applied to classify land area. By 2001 this was replaced by remote sensing technology. Moreover, more field plots have been added and new field plot designs implemented to improve classifications and estimates. New nationally consistent algorithms were applied beginning with the 2000 inventory to assign forest type and stand-size class to each plot condition. Consequently, changes have been made to the list, grouping, and names of recognized forest types, the equations used to assign stocking values to individual trees, and the definition of non-stocked forests. Considering these modifications, the NRCS advises that comparisons between the early periodic and five-year cycle inventories should be made with caution.

Other areas of uncertainty involve the assignment of forest type specific carbon coefficients to incongruent forest types from survey data for calculating carbon in forest floors. When possible, the most appropriate coefficient was assigned to a forest type, but for five of the ten forest types examined in Iowa a state average, determined by Birdsey (1992), had to be used for want of better values. This average is smaller than any of the forest specific carbon coefficients, and likely introduces more uncertainty when comparing the two inventories.

Chapter 8: Potential to Offset Greenhouse Gas Emissions through Renewable Energy, Energy Efficiency, Recycling, and Carbon Sequestration

Progress to Date

As Iowa's greenhouse gas emissions increase, there is growing interest in the state in promoting technologies and policies that hold promise for reducing or offsetting the emissions. In fact, significant actions toward this end are already in progress. Table 14 summarizes the accomplishments in year 2000, showing reductions/offsets were in the range of 8.1 million MTCE for the most significant measures in place at that time. They include new energy technologies, biomass recovery, corn ethanol, energy efficiency and recycling/waste reduction initiatives, and carbon sequestration in different land forms.

Table 14. Measures in place in Iowa by year 2000, which reduced or offset greenhouse gas emissions.

Measure	**Reduction/Offset (MTCE)**
Wind Energy [a]	137,732
Biomass Energy	
Energy recovery from wood and waste [b]	411,506
CH_4 recovery from landfill [c]	181,641
CH_4 recovery from STPs [c, d]	34,126
CH_4 recovery from Livestock [c]	3,224
Total:	630,497
Ethanol	149,915
Energy Efficiency	279,656
Recycling/Waste Reduction [e]	575,589
Carbon Sequestration	
Agricultural land	3,097,730
Forest land	2,894,429
Municipal landfill	413,377
Total:	6,405,536
Grand Total:	8,178,925

[a] Assumes generated wind energy replaced electricity from coal-fired power plant.
[b] Based on Energy Information Administration (2003c) for data on energy from "wood and waste."
[c] Assumes all methane was burned for energy recovery, thus offsetting emissions from electricity consumption. Methane flared but not burned for energy recovery would constitute an overestimation of emission offsets: landfill sources may be overestimated by as much as 33,000 MTCE; STP sources by as much as 11,126 MTCE; livestock sources by up to 531 MTCE.
[d] STP = sewage treatment plant.
[e] Compared to baseline year of 1988.

The values in the table provide a baseline for assessing the state's larger potential for offsetting emissions by more intensive adoption of the cited measures as well as additional actions not yet initiated. Our analysis shows the potential for greatly expanding these technologies, as well as the development of new biomass resources such as corn stover residues, and expansion of solar energy and carbon sequestration. The following sections discuss options in Iowa's future for achieving reductions well beyond those quoted in the table.

Wind Energy

Since 1998, Iowa electricity generation from wind has enjoyed phenomenal growth. As noted earlier, nameplate capacity jumped from less than 0.5 MW in 1998 to 194 MW in 1999 to 318 MW in 2001, making wind the fastest growing renewable energy source in the state. Entering 2004, Iowa's nameplate wind capacity was estimated to be 471 MW (American Wind Energy Association, 2004). As shown in Table 15, however, the currently installed capacity doesn't begin to tap the full potential of Iowa's wind resource. By 2006, MidAmerican Energy plans to complete the world's largest land-based wind farm project to date, which will increase nameplate capacity by 310 MW, to 781 MW (Reuters News Service, 2003). At that time Iowa wind will deliver an estimated nearly 2 million MWh of electricity each year, avoiding 541,116 MTCE in carbon emissions annually.

Table 15. Past, planned and potential Iowa electricity generated from wind energy, and emissions from equivalent amount of coal-generated electricity in year 2000.

Timetable & Potential	Nameplate Capacity (MW)	Actual Capacity (MW)	Electricity Generated (MWh)	Electricity Delivered [a] (MWh)	Coal Replacement (metric tons)	Equivalent Emissions in Year 2000 (MTCE)
Past/Current						
2000	197	66	574,665	499,958	240,031	137,732
2001	318	106	927,737	807,131	387,505	222,355
2004	471	155	1,361,567	1,184,563	568,710	333,123
Planned						
2006	781	258	2,257,715	1,964,212	943,022	541,116
Potential						
PNNL [b]		18,420	161,357,521	140,381,043	67,399,969	38,674,843
AWEA [c]		62,900	551,004,000	479,373,480	230,148,002	132,061,454
1 percent		629	5,510,040	4,793,735	2,301,480	1,320,615
2 percent		1,258	11,020,080	9,587,470	4,602,960	2,641,229
10 percent		6,290	55,106,690	47,942,820	23,017,428	13,207,653

[a] Transmission and other losses are estimated at 13 percent based on assumptions for a 500 MW array (Factor and Wind, 2002).
[b] PNNL = Pacific Northwest National Laboratory
[c] AWEA = American Wind Energy Association

Estimates of Iowa's total wind potential vary, depending largely on the amount of land considered available for development. They range from almost four to more than 12 times Iowa's electricity demand for all end use sectors in 2000 (Elliott and Schwartz, 1993b; American Wind Energy Association, 2004). Land is typically considered feasible for wind energy development when it can deliver 400 – 500 W/m^2 at 50 meters above the ground. Land with this potential is classified in the "number 4 wind power class." In Iowa, class 4 land is found only in the northwest corner of the state. A report from the Pacific Northwest National Laboratory estimates Iowa's wind potential from this area alone can produce about 5 percent (approximately 140 million MWh per year) of the total 1990 electricity consumption of the contiguous United States (Elliot and Schwartz, 1993b). This is based on a moderate land exclusion scenario where no wind development occurs on urban or state- and federally owned lands (including parks, monuments, wilderness areas, wildlife refuge, and other protected areas). It also sets aside for non-development half of forestland, 30 percent of agricultural land and 10 percent of range land.

A much less restrictive scenario, reported from the American Wind Energy Association suggests that Iowa could deliver nearly 480 million MWh of clean electricity annually, supplying more than 12 times the amount consumed by Iowans in 2000. If an equivalent amount of electricity were generated with Iowa's current utilities, emissions would amount to more than 132 million MTCE. Of course, economic and technical feasibility are necessary considerations that will limit the extent of potential that will be tapped. Nevertheless, even if only 10 percent of the full potential is developed (about 50 million MWh delivered per year) it will exceed Iowa's electricity demand by all end use sectors in 2000.

Biomass

Biomass, including wood, agricultural residues, switchgrass, and other forms of vegetative material, offers another option as a major renewable energy resource in Iowa. As reported in the EIA State Energy Data 2000 Consumption tables (Energy Information Administration, 2003c), Iowa consumed 16,200 billion Btu of biomass energy from wood and waste. The residential and commercial sectors contributed slightly more than a third of this energy through wood burning for space heating. The industrial sector consumed the remaining two-thirds of the biomass for electricity generation and process steam. As shown in Table 14 (page 70), this total translates to a savings of as much as 411,506 MTCE in electricity production emissions.

Use of biomass in the electric utilities sector is still under development for the most part. The *Renewable Energy Annual for 2001* (Energy Information Administration, 2002) reports that Iowa power plants are currently generating electricity from biomass on small scales. In 2000 they generated almost 18,000 MWh in total, consuming more than 500 billion Btu of biomass.[9] The BFC Gas and Electric plant located in Cedar Rapids is fueled mainly by light paper mill waste, but also utilizes construction and demolition wood, unrecycled low-grade paper, tree trimmings, road brush, local sawmill wastes, agricultural by-products (including crop residues such as corn stalks, corn cobs, and waste seed corn), sweet sorghum, poplar trees and energy crops such as switchgrass (Iowa Energy Center,

[9] This consumption may underestimate actual biomass utilization by utilities as some projects known to exist in Iowa were not reported in the *Renewable Energy Annual for 2001*.

1999). Each day the plant consumes approximately 150 tons of material (BFC Gas and Electric, 2004). It gasifies the biomass into a low energy gas, which drives a 7.5 MW turbine. All of the electricity produced is sold to Alliant Energy in Cedar Rapids (Iowa Energy Center, 1999).

Another venture, under the auspices of Chariton Valley Resource Conservation and Development, is a demonstration project for marketing switchgrass as a renewable fuel. Tabbed the "Biomass Project" it focuses on generating the supply, demand and waste disposal infrastructure necessary for creating switchgrass markets. Partnering with Alliant Energy's Ottumwa generating station, the goal is to co-fire switchgrass with coal to generate 35 MW of biomass-derived electric power. If the goals of the project are met, 63,557 MTCE of carbon dioxide emissions could be avoided each year by replacing coal in the combustion mix (Ney et al., 2001).

A study from the Oak Ridge National Laboratory (ORNL) has estimated the national availability of five biomass feedstocks at the state level for different prices ranging from $20 to $50 per delivered dry ton (Walsh et al, 1999). The energy equivalent from the maximum available quantity in Iowa is shown in Table 16. Even after consideration of the quantity of agricultural litter that must remain on the fields to maintain soil quality, the availability of corn stover rivaled coal utility inputs, which were 375,000 billion Btu in 2000. Dedicated energy crops, such as switchgrass also showed promise for development as a clean fuel, with a delivery potential of 122,000 billion Btu.

Calculating only the carbon emissions avoided from combustion of biomass resources, however, offers an incomplete picture of the overall effect on net carbon emissions. In the case of dedicated energy crops such as switchgrass, emissions from production and delivery of the fuel must be counted and subtracted from the emissions avoided from burning the biomass. In contrast, for fuels such as corn stover that are by-products of other processes, the emissions associated with their production can be assumed to be minimal, as emissions are already accounted for in the life cycle of the original product generated. (For example, in the case of corn stover, emissions are already counted under the "energy generation" and "agriculture" categories for corn production.)

A study of switchgrass as a coal substitute estimated greenhouse gas emissions from production and delivery to be 177.42 lbs carbon dioxide equivalents per million Btu (2.19 MTCE/billion Btu) (Ney et al., 2001). These emissions constitute 81 percent of the carbon avoided from the coal substitution, thus significantly diminishing the net greenhouse gas reductions benefit from co-firing with switchgrass in place of coal. Full lifecycle analyses of the resources considered here are beyond the scope of this study. Nevertheless, such studies will be essential to assess the complete benefits in reducing greenhouse gas emissions by biomass fuel substitution.

Table 16. Potential electricity generation, coal replacement, and carbon dioxide and methane emissions avoided from biomass resources in Iowa.

Type of Biomass	Current Annual Generation (BBtu)	Potential Annual Generation (BBtu)	Potential Net Electricity Generation [a] (MWh/yr)	Equivalent Coal Energy (metric tons)	Potential Carbon Avoided (MTCE/yr)	Potential CH_4 Emissions Avoided (MTCE/yr)
ORNL Study [b]						
Forest Residue	NA	2,160	170,918	90,377	54,867	NA
Mill Residues	NA	2,530	200,038	105,774	64,266	NA
Corn Stover	NA	361,000	28,532,386	15,087,076	9,169,978	NA
Dedicated Energy Crops	NA	122,000	9,637,451	5,095,997	588,809 [c]	NA
Urban Wood Waste [d]	NA	4,580	362,521	191,690	116,339	NA
Other Sources						
MSW Waste-to-Energy [e]	NA	32,200	2,199,258	1,163,180	706,164	NA
Livestock CH_4 Recovery [f]	23 [g]	3,200 [h]	253,152	133,891	81,285	374,715
STP CH_4 Recovery [i]	438	3,000	237,330	125,523	76,205	351,295
Landfill CH_4 Recovery [e]	1,300	9,524	751,545	397,489	241,315	1,115,434
Total Potential	16,200 [j]	507,994 [k]	40,145,341 [k]	21,227,817 [k]	10,393,064 [k]	1,838,443

NA = Data not available. Numerous current activities recover energy from these sources in small quantities within the industrial sector, but disaggregated data for individual sources is unavailable.

[a] The systems of production and delivery are assumed to be 27 percent efficient.

[b] For each waste the maximum potential is not total waste produced, but maximum waste deliverable as fuel given economically feasible delivery price. Forest residues, mill residues and dedicated energy crops yield a maximum quantity at a delivered price of $50/ton/year. Corn stover's maximum amount sells at $40/ dry ton/year and urban wood waste is $30/dry ton/year.

[c] Owing to emissions from production and delivery of dedicated energy crops, net carbon emissions avoided are assumed to be only 19 percent of gross emissions saved from combustion of the energy crop (based on estimate of Ney and Shnoor, 2000).

[d] Urban wood waste is a subset of municipal solid waste.

[e] These scenarios represent mutually exclusive options. "MSW Waste-to-Energy" refers to combustion of municipal solid waste; combustion precludes MSW from being landfilled with subsequent recovery of CH_4. Conversely, MSW going to landfill for CH_4 recovery cannot be burned for energy.

[f] Source: Garrison and Richard (2001)

[g] Source: Iowa Department of Natural Resources (2003)

[h] Assumes only 10 percent of potential estimated by Garrison and Richard (2001) to take into account production losses and economic feasibility not considered in original estimate.

[i] Source: Iowa Department of Natural Resources (2002b).

[j] Total exceeds itemized entries in column. Source is Energy Information Administration (2003c), which provides total biomass energy consumed in Iowa in 2000 based on comprehensive list of sources including garbage, bagasse, sewage gas, and other industrial, agricultural and urban refuse, wood and wood products used as fuel including round wood (cord wood), limb wood, wood chips, bark, sawdust, forest residues, charcoal, pulp waste, and spent pulping liquor. The report, however, does not disaggregate overall total into individual components.

[k] Totals do not include values for "MSW Waste-to-Energy" because its application is mutually exclusive with "Landfill CH_4 Recovery," and the latter option is considered far more likely given minimal waste incineration in the state and concerns about dioxin emissions during MSW combustion.

Currently, there are no large-scale projects in Iowa that combust municipal solid waste for energy. However, there is considerable potential for energy recovery of this type. The more than 2.5 million tons of MSW landfilled in Iowa in the year 2000 contained an estimated 7.4 percent of the energy content of fossil fuel inputs to electric utilities. Because of concerns over the toxic air emissions from incineration, however, this source of fuel will likely remain largely untapped.

Biogas recovery systems are becoming more prevalent in Iowa. As shown in the lower part of the last two columns on the right in Table 16, recovery offers two opportunities for greenhouse gas emission reductions. First, whether the biogas is flared or recovered for energy production, burning it eliminates a large source of Iowa's methane emissions. Emissions from livestock, STP sludge, and landfills constituted 57 percent of all methane emissions in Iowa in 2000. Iowa's full potential emissions savings from eliminating these sources are shown in the far right column in the table, and amount to 1.8 million MTCE. The second opportunity is to replace conventional fuel with the methane obtained from recovery. Iowa's potential for this option is shown in the lower part of the second column to the right, with emissions avoided totalling nearly 400,000 MTCE.

Currently, there are three livestock operations, four landfills, and at least 19 municipal wastewater treatment plants using biogas generated from the anaerobic decomposition of organic wastes (Iowa Department of Natural Resources, 2002b). Composed of methane and carbon dioxide in almost equal parts, it is the methane portion of biogas that makes it a valuable and versatile energy resource that, like natural gas, can be burned for space heating or electricity generation. As with other biomass resources, combustion results in no net emissions of greenhouse gases because the carbon accounting is balanced by photosynthesis.

Livestock operations have a large potential for biogas recovery. Garrison and Richard (2001) estimated the expanded use of Iowa's massive manure resources, assuming no losses and no regard for economic feasibility, would provide 32 trillion Btus annually for energy production. However, the feasible amount of methane recovery is likely to be much lower, in the range of 1.7 to 2.6 trillion Btu, with emission reductions ranging from 43,000 to 66,000 MTCE (Garrison and Richard, 2001). Economic feasibility and market stimulation depend heavily on changes in electricity rates and interest rates.

As discussed earlier, methane from anaerobic treatment of wastewater and sludge is already being efficiently collected at STPs in the state. The IDNR (Iowa Department of Natural Resources, 1999) reported that more than 250,000 tons of municipal treated sludge could be available each year for anaerobic digestion in Iowa with the potential to produce three trillion Btus. This would replace 125,500 tons of coal and could avoid more than 76,000 MTCE in carbon dioxide emissions if utilized for electricity production. Also, more than 350,000 MTCE of methane would be removed from Iowa's emissions in this way.

Most of the methane recovery in Iowa occurs at landfills, where in 2000 they produced 1,300 billion Btus of biogas energy for heat and electricity production. As noted earlier, waste deposited in a landfill will produce biogas for 30 years. In its lifetime, a pound of organic waste is capable of generating two to six cubic feet of biogas (Iowa Department of Natural Resources, 1999). According to Iowa's statewide solid waste characterization study, organic matter accounts for about 63 percent of municipal solid waste entering landfills each year (R.W. Beck Inc, 1998). This suggests that waste put into the landfill in 2000 is capable of generating 323 billion Btus of energy from gas per year for 30 years, or 9,700 billion Btus over 30 years. The accumulated organic waste in place from the past 30 years is capable of producing 9,524 billion Btus in biogas energy per year. This generation may decrease in the future, however, as the amount of waste landfilled decreases from waste diversion. Nevertheless, utilizing this resource could abate more than 1 million MTCE in methane emissions and could offset 241,315 MTCE through replacement of conventional electricity generation.

Energy from biomass clearly represents a large potential for reduction in net greenhouse gas emissions. In Iowa, the most promising resources for further development are corn stover and dedicated energy crops. Expansion of methane recovery from landfills, wastewater and livestock also represent feasible options. Not all scenarios can be taken together because some represent exclusive use of the resource. For instance, waste cannot be placed in a landfill with subsequent CH_4 generated or carbon sequestered, and at the same time be available for energy recovery by incineration. Altogether, as shown in Table 16 the full development of biomass resources can offset greenhouse gas emissions in the range of 12 million MTCE with most of the resource derived from corn stover.

Solar Energy

Solar radiation is the most abundant form of renewable energy on earth. Enough sunlight falls yearly on each square meter of the U.S. to equal the energy content of 190 kilograms of coal, and the total solar resource is nearly 600 times more than total U.S. energy consumption in 2000. It is also versatile in its end uses, among which are passive solar space heating , daylighting and water heating, and direct and indirect conversions to electricity. Its use for electricity is particularly valuable since it is most efficient on hot sunny summer afternoons when the demand for electric power is at its peak. Also, the energy extracted is pollution free and generates zero emissions of greenhouse gases. Despite its numerous advantages, its implementation has been slow because of the expense of solar technologies relative to the fossil fuels and wind. Another factor has been public and private sector apathy with respect to promotion of building design that more fully exploits passive solar heating and natural daylighting. This does not detract, however, from the potential that exists for solar power to reduce the need to consume fossil fuels with their concomitant emissions of greenhouse gases. Solar power is one of Iowa's most promising underdeveloped energy resources.

Photovoltaic (PV) electricity generation is the primary solar technology in use in Iowa. Silicon-based semiconductor cells clustered into arrays and panels directly generate an electric current when illuminated with sunlight. Research and development are improving the efficiency with which PVs convert sunlight to electricity, extending cell lifetimes and streamlining manufacturing processes. All these advances continue to have significant impacts on the economics of PV electricity, bringing down costs 15- to 20-fold since its early development. Commercial modules are now available with conversion efficiencies in the range of 13 to 15 percent (National Renewable Energy Laboratory, 2003). Innovative new "thin film" semiconductor technology is a thriving area of research with promise to reduce costs even further in the future. Prototype multijunction silicon-based systems having 15 to 17 percent efficiencies are being tested in the desert areas of the U.S., while PV units with even greater efficiencies are on the drawing boards.

A great advantage to PV over other renewable energies is the ease with which systems can be sited. They can be installed just about anywhere with a sunny open surface.

Currently, major applications are in cell phone transmission towers, and in rural locations where grid connections to centralized power plants are either unavailable or too expensive to install. But the fastest growing market for PV technologies is in customer-sited, grid-connected, roof-mounted systems in the residential and commercial sectors (National Renewable Energy Laboratory, 2003). New architectural design is taking advantage of building-integrated photovoltaic systems, particularly in Europe. They are now available in façade coverings, shingles, roofing tiles, and awnings. Semi-transparent modules can also be mounted on windows, shading and skylights. When PV adaptations are included in the planning of new construction, their high installation costs are offset in part by savings on replacement costs of more conventional building materials.

Solar-powered applications have already proven their practicality in Iowa. The state Department of Transportation (DOT) has 34 solar-powered, portable, programmable message signs, 125 solar-powered automatic traffic recorders, and 14 solar-powered weight-in-motion detectors. An Iowa-based study found solar powered barricade warning lights to be an economically beneficial alternative to bulky battery-powered warning lights. The solar-powered light emitting diodes (LEDs) provided consistent illumination with minimal maintenance, driving down costs over the product's lifetime (Midwest States Smart Work Zone Deployment Initiative, 2000). With this endorsement, it can be expected that the Iowa DOT will further expand its use of solar-powered lights.

Another Iowa success story in solar power application is the PV mount on the rooftops of the Indian Creek Nature Center in Cedar Rapids. After a five-year onsite evaluation by Iowa State University demonstrated the technology's effectiveness, the Center invested in a 960-watt PV grid-connected system that supplies 10 percent of its power needs on weekdays, and sells power back to the grid on weekends (Shanks, 1999). Today in Iowa, more than 41 PV systems are in place with a generation capacity of 35 kW (Iowa Department of Natural Resources, 2002). These systems are estimated to avoid 15 MTCE of carbon dioxide emissions annually by replacing conventional electricity generation.

That Iowa's solar potential is underdeveloped is obvious by comparison with other states. The EIA State Energy Data 2000 Consumption tables (Energy Information Administration, 2003c) showed that Iowans generated 8.5 billion Btu in solar energy in year 2000. Neighboring Illinois generated 232 billion Btu, 27 times greater than Iowa's output, even though its annual solar irradiance is slightly less (National Renewable Energy Laboratory, 1994). New York state, at a higher latitude and possessing a smaller solar resource than Iowa, generated 562 billion Btus of solar energy (66 times as much) (National Renewable Energy Laboratory, 1994; EIA 2003c). Sunny California and Texas lead the country in solar electricity generation, but most locations in the U.S. and worldwide have sufficient sunlight to sustain a PV system. It is estimated that a PV generation station with an area 140 km by 140 km placed at a location with average solar irradiance in the U.S. could generate all the electricity needs of the country (2.5×10^6 GWh/yr) assuming a system efficiency of 10 percent and an area packing factor of 50 percent (to avoid self shading). This is an area equal to only 0.3 percent of the U.S. land area (National Renewable Energy Laboratory, 2003).

Iowa's solar resource appears ripe for development. A five-year study funded by the Iowa Energy Center (Shanks, 1999) found that solar PV modules are highly reliable, and durable enough to survive for extended periods in Iowa's environment. When solar irradiance data were compared to utility demand, it was found that peak solar output coincided closely with times of peak energy demands for air conditioning on hot, sweltering summer days.

Optimal siting for PV systems is important for gaining the most economic and efficiency benefits. South-facing panels angled to accommodate the latitude of the location (42 degrees in Iowa) receive the most sunlight and represent the best configuration. Panels that face east or west, while capturing less sunlight, may nevertheless be cost-effective. Devices that track the sun as it moves through the sky have been found to be impractical in the northern part of the U.S. (National Renewable Energy Laboratory, 2003).

The U.S. Department of Energy's (DOE) "Million Solar Roofs" program encourages the installment of rooftop solar-powered systems across the U.S. by creating partnerships that aid in their marketing, financing and construction. The goal is to install 1 million rooftop systems by 2010. The premise of the program is that PV rooftop systems are technologically feasible but currently stymied by economic barriers.

Table 17 shows the potential for rooftop solar electricity generation in Iowa. Housing data from the 2000 U.S. census indicates the state has more than 940,000 single family homes, and it is estimated that total rooftop area is 116.8 million square meters. If one-half this space were mounted with PV panels, the roofs could generate 13.6 million MWh of electricity annually, corresponding to 22 percent of electricity consumption in the year 2000. In this scenario, avoided emissions would amount to 3 million MTCE of carbon dioxide and offset 32 percent of emissions from electricity production. Even if 10 percent of homes took advantage of PV systems, 3 percent of power plant emissions could be offset, and 2 percent of electricity needs could be met. When one considers exploiting the additional pool of roofs in commercial and industrial buildings, and in multi-unit housing, potential for PV becomes even greater. Despite dedicated efforts like those of the U.S. DOE, Iowa's achievable potential for PV may continue to be modest when compared to renewable technologies such as wind and biomass that currently show a greater balance between costs, benefits, and economic interests.

Table 17. Electricity generation and emission savings from installation of PV on single family homes in Iowa.

Home Type	Single Family Homes (housing units) [a]	Half Roof Area per Home (square meters)	Electricity Generated per Unit Area (kWh/sq m/year)	Total Electricity Output (kWh/yr)
1 story	470,053	82.85	233.6	9,097,292,949
2 story	470,053	41.43	233.6	4,545,901,365
Total	940,106	124.28	233.6	13,643,194,314

Home Type	Total Energy Saved (billion Btu/yr) [b]	Carbon Emissions Avoided per Unit Energy Saved (tons C/ billion Btu)	Total Carbon Avoided (MTCE/yr)
1 story	92,795	21.8	2,024,758
2 story	46,369	21.8	1,011,768
Total	**139,164**	**21.8**	**3,036,526**

[a] Assumes half of all homes are one story and half are two story.
[b] Total energy saved is approximately 3 times the kWh generated because a coal-fired power plant releases approximately twice as much waste heat as the energy in the delivered electricity; 1 kWh = 3,413 Btu (delivered) + 6,826 Btu (loses) = 10,239 Btu (total energy expended).

Ethanol

With concerns over energy security and the environmental problems caused by consumption of fossil fuels, ethanol has become a more viable alternative transportation fuel. Because it is synthesized from domestic feedstocks, currently almost exclusively from corn kernel, its development is a positive step toward energy independence. Another important factor is the economic benefit to farmers. And because it is a form of biomass, combustion produces no net carbon dioxide emissions. The cultivation and processing of the corn feedstock, however, do consume fossil fuel energy, resulting in considerable greenhouse gas emissions.

Iowa has embraced the benefits of ethanol fuels; more than half of motor fuel purchases in 2000 were ethanol blends of either E10 (10 percent ethanol, 90 percent gasoline) or E85 (85 percent ethanol, 15 percent gasoline) (Iowa Department of Natural Resources, 2002a). Any vehicle that can run on gasoline can run on E10, which bodes well for ethanol's widespread applicability. Because of recent tax credits offered to ethanol retailers, nearly every gas station in the state offers E10 (Iowa Department of Natural Resources, 2002b). However, because it takes a specific flex fuel vehicle (FFV) to operate on E85, this blend is still sold in limited quantities. With only six stations in the state currently selling E85 to the general public, the vast amount of ethanol consumed is in the E10 formulation.

The Energy Information Administration (2003c) reported that in 2000 Iowa consumed 7.8 trillion Btus of energy contained in 93 million gallons of ethanol. As shown in Table 18, if gasoline had been burned instead of this quantity of ethanol, it would have produced 149,915 MTCE in CO_2 emissions. This represents the state's annual greenhouse gas emissions savings from ethanol replacement of gasoline in blended fuels. There is great potential in Iowa to expand gasoline replacement with ethanol. If 100 percent of transportation fuel sold were an E10 blend, 237,716 MTCE per year could be saved through offset of gasoline emissions. And if all transportation fuel sold were an E85 blend, savings would be 2,831,305 MTCE per year. These considerable savings, however, would be offset somewhat by emissions from increased agricultural and industrial activities for feedstock cultivation and ethanol production.

Table 18. Current and potential annual greenhouse gas emissions savings from combustion of ethanol blended fuels in place of 100 percent gasoline.

Scenario		MTCE/yr
Current use of ethanol blends		149,915
Potential	**All motor fuel sold as E10**	**237,716**
	All motor fuel sold as E85	**2,831,305**

An important question has been the extent to which emissions generated from corn production and ethanol processing diminish the emissions saved by replacing gasoline with ethanol in the gas tank. In seeking an answer, Argonne National Laboratory (ANL) prepared a full fuel cycle analysis for corn based ethanol blends produced in the Midwest (Wang, 1997). After thorough consideration of farming practices, transportation of corn feedstock, dry and wet milling, ethanol production processes and final vehicle combustion, it was concluded that in comparison to both conventional and reformulated gasoline each mile traveled on E10 fuel reduced greenhouse gas emissions by about 2.4 percent and fossil fuel energy inputs by 3.3 to 3.5 percent. Each mile traveled on E85 fuel reduced emissions by 31 percent and fossil fuel energy inputs by 42 to 44 percent.

Applying ethanol consumption information and findings from the ANL study, emission savings for the *entire fuel cycle* (feedstock production, fuel production, end-use combustion) were estimated from the replacement of 100 percent gasoline with E10. Table 19 shows the savings from Iowa's use of E10 fuel in year 2000. The left side of the table yields the result that total emissions using the E10 fuel were 2,658,716 MTCE, and the right side shows that if 100 percent gasoline had been used, emissions would have been 2,724,096 MTCE for a net emission savings of 65,380 MTCE. Further analysis shows that complete replacement of Iowa's gasoline consumption with E10 and E85 blends could produce full fuel cycle savings of about 100,000 and 1.2 million MTCE, respectively.

Table 19. Estimated full cycle greenhouse gas emissions savings from use of E10 fuel in Iowa in year 2000.[a]

	Passenger Cars with E10 Fuel [b]		Passenger Cars with 100 % Gasoline [c]	
Greenhouse Gas	**Unit Emission ($g\ CO_2$ eq/mi) [d]**	**Total Emission (MTCE/yr)**	**Unit Emission ($g\ CO_2$ eq/mi)**	**Total Emission (MTCE/yr)**
CO_2	358.6	1,930,408	370.9	1,996,621
CH_4	8.4	45,219	8.9	47,910
N_2O	6.5	34,991	2.9	15,611
Total	373.5	2,010,617	382.7	2,060,142
	Light Duty Trucks with E10 Fuel [e]		**Light Duty Trucks with 100 % Gasoline [f]**	
Greenhouse Gas	**Unit Emission ($g\ CO_2$ eq/mi)**	**Total Emission (MTCE/yr)**	**Unit Emission ($g\ CO_2$ eq/mi)**	**Total Emission (MTCE/yr)**
CO_2	483.9	623,737	500.4	645,006
CH_4	10.7	13,792	11.3	14,565
N_2O	8.2	10,570	3.4	4,383
Total	502.8	648,099	515.1	663,954
Total (cars + trucks)		**2,658,716**		**2,724,096**
Difference (Gas - E10)	**65,380**			

[a] Based on consumption of 930 million gallons of E10 fuel.
[b] Based on 19,738,320,000 passenger car miles traveled using E10 fuel.
[c] Compares emissions for 19.7 billion passenger miles traveled using 100 percent gasoline.
[d] Unit emissions account for emissions generated in production of corn and processing of ethanol.
[e] Based on 4,726,260,000 light duty truck miles traveled using E10 fuel.
[f] Compares emissions for 4.7 billion truck miles traveled using 100 percent gasoline.

The emissions savings and economics of ethanol production from corn could clearly benefit if stover produced as a by-product of the corn harvest were converted into ethanol as well as the kernel. We saw in the earlier section on biomass that the availability of stover in the state is immense. In fact, the embedded energy in the stover is larger than the energy consumed in gasoline in the state in 2000. The problem is that stover is composed of cellulose while the kernel is starch. It is economically more cost effective and technically far easier to convert starch to ethanol than to convert the tough, woody cellulose. If breakthroughs in research lower the costs and complexity of producing ethanol from cellulose, there could be perhaps a doubling in the net savings of greenhouse gas emissions from replacement of gasoline with ethanol. Thus, ethanol fuel could make a far greater positive impact on mitigating the state's greenhouse gas burden, but that potential depends on future research developments.

Energy Efficiency

The Iowa Utilities Board (IUB) is responsible for the review and approval of Iowa utility-sponsored energy efficiency (EE) programs conducted by investor-owned utilities (IOUs), and reviews and compiles data on the results of the programs. The IUB also compiles data on programs voluntarily implemented by municipal utilities and rural electric cooperatives, but does not verify the data.

Table 20 shows the annual energy and carbon emission savings in Iowa from implemented efficiency programs in the decade of the 1990s. Since 1990, these programs have offset 5 million MWh of electricity and about 1.5 million MTCE in emissions (Gordon Dunn, Iowa Utilities Board, personal communication, August 2003). To put these numbers in perspective, the EIA *Electric Power Annual 2002* (Energy Information Administration, 2003a) reported that over the same period total fossil fuel electricity production in Iowa was 329 million MWh and carbon dioxide emissions were 110 million MTCE.

EE programs have focused on demand-side management including residential tune-ups and weatherization, energy efficient equipment rebates and new construction. IOU programs provide rebates for purchase of energy efficient equipment for residential, commercial, industrial, and agricultural customers. The greatest potential for energy savings lies with industrial customers, as they consume the greatest amount of energy. Often programs are tailored to the needs of specific customers. In the residential sector, programs for low-income customers primarily focus on weatherization and education on wise energy use. They are delivered through community action agencies and combined with federal weatherization grants to Iowa. The utility programs fill in where community and federal funds cannot provide complete coverage of the homes.

EE programs and the savings they accrue will continue to grow in the future. Between 1990 and 2001, IOUs filed periodic modifications of their original programs. In 2002, all four IOUs filed new five-year energy efficiency program plans developed in collaboration with their customers and ratepayers. Following contested proceedings, the plans were approved by the IUB and implemented in 2003. All utilities increased the level of funding allocated for these programs. Additionally, the IUB ordered each of the utilities to double the level of spending allocated to their low-income programs. Utilities are developing expanded low-income programs in conjunction with the Iowa Department of Human Rights (which contracts with the community action agencies to deliver programs), the Iowa Finance Authority (which provides funding to multi-family low-income projects), and the Office of Consumer Advocate (which represents the rate payers). They are working together to carry out the request of the IUB to implement an accelerated 10-year program focused on low-income customers.

As these programs expand, savings tend to be ongoing and accumulate each year from past progress. On the other hand as the installed high efficiency equipment deteriorates, energy savings will diminish. Fortunately, such equipment has typical lifetimes on the order of 20 or more years, so any slowdown in savings accumulation will not be imminent. And when old equipment is replaced the new purchases are likely to be even more energy efficient, reflecting the ongoing trend toward greater focus on efficiency in new product development.

Table 20. Annual energy and emission savings through Iowa energy efficiency programs from the Electric Utilities Sector, 1990-2000.		
Year	**Electricity Savings (MWh)**	**Emission Savings (MTCE)**
1990	42,590	12,022
1991	92,820	25,398
1992	141,340	39,411
1993	233,285	66,475
1994	365,111	100,479
1995	513,859	144,636
1996	639,879	179,554
1997	743,041	207,777
1998	811,196	223,908
1999	894,149	247,968
2000	1,015,200	279,656
Cumulative	**5,492,470**	**1,527,284**
Emission savings calculated from data retrieved from Gordon Dunn, Iowa Utilities Board, personal contact, August 2003.		

Energy efficiency is a concern for all end use sectors statewide. Apart from efficiency efforts initiated by the utilities, the IDNR is an active partner in state and federal efficiency programs. It has been committed to improving Iowa's building energy use and expenditures since 1986. Three building energy management programs save Iowa taxpayers $22.7 million annually by implementing energy efficiency measures (Iowa Department of Natural Resources, 2002c). Since 1989, the Iowa Energy Bank, the State of Iowa Facilities Improvement Corporation, and Rebuild Iowa have implemented programs saving more than $173 million in energy costs (Iowa Department of Natural Resources, 2002c). Improvements have for the most part been related to mechanical issues, building envelope, lighting and controls. Additionally, installation of renewable energy generation equipment has been promoted by the IDNR. Each program provides energy audits, aids in identifying cost-effective energy use improvements, and establishes financing for the implementation of improvements. They have very successfully targeted projects for different entities that span the array from state run facilities, schools, hospitals, non-profit organizations, local governments, and private colleges to entire communities.

The IDNR also regularly encourages updates in the state energy building code, and sponsors educational programs for code compliance and enforcement. The Iowa Energy Center operates an EE initiative called the Energy Resource Center. Its mission is to research and demonstrate the feasibility of energy efficient building technologies, as well as heating ventilation and air conditioning, building control and daylighting systems.

The potential exists to achieve further large improvements in energy efficiency, and

Iowa is committed to driving its progress. An ongoing effort includes participation in the U.S. DOE Program, *Industries of the Future,* which seeks to improve industrial efficiency and productivity by lowering raw material inputs and energy use per unit of output, improve labor and capital productivity, and reduce the generation of wastes and pollutants. Through this program, the IDNR and Iowa State University received grants to pursue efficiency improvements in the agricultural and metal casting industries.

One study sponsored by the Iowa Energy Center and the U.S. DOE's Oakridge National Laboratory examined the potential for demand side management methods to improve energy efficiency and reduce energy consumption in Iowa by the year 2020 (Hadley, 2001). Specifically, the study examined the potential to replace less efficient equipment in the residential, commercial and industrial sectors. Using an economic simulation model, the *National Energy Modeling System*, with a moderate EE policy scenario (borrowed from the U.S. DOE *Scenarios for a Clean Energy Future*), and an industrial market assessment survey, the study found that Iowa sectors could reduce projected energy use by 5 percent by 2020.

The results of the study are provided in Table 21. In the residential sector, minimum equipment standards, and a lowered discount rate (a proxy representing market barriers, customer resistance, real or perceived risks associated with buying a new technology, transaction costs to customers, etc.) gave EE technologies greater market penetration. This scenario stimulated savings of 2.9 trillion Btus (TBtu) of electricity (5.3 percent of total projected sector use) and 2.1 TBtu of natural gas (2.4 percent of total projected sector use) through equipment replacement. The majority of the energy offset came from replacement of electric air conditioning and water heating equipment with more efficient models. These electricity and natural gas savings translate to avoidance of more than 269,000 MTCE per year carbon dioxide emissions, assuming coal-fired power plants generate the same share of electricity in the future as they do currently.

The commercial sector has an estimated potential of reducing annual energy use by 2.1 TBtu of electricity (2.3 percent of total sector use), and 5.1 TBtu of natural gas (3.7 percent of total sector use) through lowered discount rates. The greatest savings would be achieved in the areas of gas space heating and electric lighting. Total commercial sector energy savings would avoid 255,000 MTCE per year carbon dioxide emissions.

The greatest draw of electricity in the U.S. comes from industrial drive and motor systems, swallowing 23 percent of the nation's electricity consumption (Hadley, 2001). The analysis estimated 3.2 TBtu of electricity (6 percent of total projected sector use) could be saved in Iowa through installation of more efficient technologies. This would offset emissions of 263,000 MTCE per year.

Table 21. Potential savings in electricity and natural gas, and reductions in emissions through installment of energy efficient equipment. Source: Hadley (2001).				
Efficiency Savings in Electricity				
Sector	**Electricity Savings (TBtu/yr)**	**Energy Savings (TBtu/yr)** [a]	**Saved Carbon Emissions Unit Emission Factor (tons C/TBtu)**	**Total Emission Savings (MTCE/yr)**
Residential	2.9	10.7	22,064.4	236,089
Commercial	2.1	7.8	22,064.4	172,102
Industrial	3.2	11.9	22,064.4	262,566
Total	8.2	30.4	22,064.4	670,758
Efficiency Savings in Natural Gas				
Sector	**Natural Gas Savings (TBtu/yr)**	**Energy Savings (TBtu/yr)** [b]	**Saved Carbon Emissions Unit Emission Factor (tons C/TBtu)**	**Total Emission Savings (MTCE/yr)**
Residential	2.1	2.3	14,482.6	33,310
Commercial	5.1	5.7	14,482.6	82,551
Total	7.2	8.0	14,482.6	115,861
Total (electricity + natural gas)	**15.4**	**38.4**	**14,482.6**	**786,619**

[a] Includes avoided electricity delivered, losses of waste heat at the power plant, and transmission losses; power plant efficiency is assumed to be 27 percent.
[b] Included avoided natural gas use and losses during transmission; delivery efficiency is assumed to be 90 percent.

The total potential for energy savings through EE improvements is likely to be much greater than that calculated in Table 21. Because Hadley did not investigate building envelope improvements, lighting in the residential sector, efficiency standards in commercial equipment, or many of the other industrial sector energy issues, it only provides a glimpse of what may be achieved by improving the market for commercial and residential energy-consuming products and industrial motor and drive systems.

In 2001, the four Iowa IOUs commissioned a second, more in-depth analysis of Iowa's energy use and EE potential (Global Energy Partners, LLC, 2002). The goal of the study was to predict the *technical potential* for electricity and natural gas savings through the implementation of 258 demand-side EE measures specific to 26 segments of Iowa's residential, commercial and industrial/agricultural end users. These measures range from equipment replacement to duct repair and insulation to digital controls for cooling equipment to installation of window blinds that deflect sunlight in the summer. It is important to note that technical potential can only give insight into actual achievable potential, which will undoubtedly be lower owing to practical constraints (i.e., cost effectiveness, timing for equipment replacement, etc.). With an understanding of where the maximum energy reductions may be achieved, however, each utility will be better equipped to develop effective EE programs tailored to their particular circumstances. Table 22 summarizes some of the findings of the joint utility assessment, as well as independently derived greenhouse gas emission savings using the data of Global Energy Partners, LLC, and other sources.

While the utilities study gave only relative energy savings projections, this information was combined with additional data to estimate the potential for greenhouse gas emissions reductions. Year 2002 electricity sales and natural gas delivery data from EIA were applied with the corresponding emission factors from this inventory to estimate emission savings in the first year (Energy Information Administration, 2003a, Energy Information Administration, 2004b). They totaled 486,000 MTCE after implementation of the EE measures indicated in the study.

Interestingly, the residential sector has the greatest technical potential for EE improvements. Lighting, cooling and water heating are the areas where most electricity savings could be achieved with the greatest gas saving potential in furnaces and water heaters. In the past, utility EE programs have had a smaller impact on the residential sector than other sectors. This is likely because the latter experience greater turnover of equipment, and are more inclined to invest capital upfront to reduce long-term energy costs to stay competitive.

Ideally by year 10 of implementation, significant declines in projected electricity and natural gas consumption could be achieved. Using the projections of the IDNR (Iowa Department of Natural Resources, 2002a) for Iowa energy consumption in 2012 and sector energy use patterns consistent with year 2000, it was estimated that more than 5.3 million MTCE could be avoided, assuming the same electricity emission factors pertain in the future. This amounts to 16 percent of year 2000 gross greenhouse gas emissions. Once again, this estimate is only an indication of technical potential, and does not necessarily reflect feasible achievable reductions. Nevertheless, the analysis sets limits to achievement and may provide a roadmap to help target future EE projects with the biggest paybacks.

With a statewide collective effort, improvements in energy efficiency can make a large contribution to reducing greenhouse gas emissions. However, for maximum impact it is apparent that these improvements need to be coupled with other improvements in the energy sector, particularly through expanded development of renewable energies.

Table 22. Projected technical energy savings potential from 258 demand-side energy efficiency measures, and calculated carbon emission reductions. Sources: Global Energy Partners, LLC, 2002; Iowa Department of Natural Resources 2002a; Energy Information Administration 2003a and 2004b.

1st Year Technical Potential Energy Savings (2002)				
Sector	**Energy Consumption [a] (TBtu)**	**Energy Savings (TBtu)**	**Percent Energy Savings [b]**	**Emission Reductions (MTCE)**
Electricity				
Residential	44 (163)	9.8	6 %	215,976
Commercial	30 (111)	3.3	3 %	73,575
Industrial	56 (207)	4.1	2 %	92,201
Total	130 (481)	17.2	4 %	381,752
Natural Gas				
Residential	73 (81)	4.0	5 %	58,771
Commercial	48 (53)	1.1	2 %	15,248
Industrial	95 (106)	2.1	2 %	30,303
Total	216 (240)	7.2	4 %	104,322
Total (electricity + gas)	**346 (721)**	**24.4**	**3 %**	**486,074**

10th Year Technical Potential Energy Savings (2012)				
Sector	**Energy Consumption (TBtu)**	**Energy Savings[a] (TBtu)**	**Percent Energy Savings**	**Emission Reductions (MTCE)**
Electricity				
Residential	49.1 (182)	87.3	48 %	1,924,280
Commercial	40.6 (150)	42.1	28 %	928,174
Industrial	70.0 (259)	49.3	19 %	1,085,918
Total	159.7 (591)	178.7	30 %	3,938,373
Natural Gas				
Residential	100.8 (112)	50.4	45 %	729,280
Commercial	45.8 (51)	10.7	21 %	154,634
Industrial	137.0 (152)	35.0	23 %	506,605
Total	283.6 (315)	96.1	31 %	1,390,519
Total (electricity + gas)	**443.3 (906)**	**274.8**	**30 %**	**5,328,892**

[a] First number corresponds to electricity and natural gas delivered to customer; number in parentheses corresponds to actual total energy expended, which includes production and transmission losses. Efficiency for delivery of electricity and natural gas are assumed to be 27 and 90 percent, respectively.
[b] Obtained by dividing energy savings by total energy consumed (number in parentheses in first column).

Recycling

A report prepared by the Tellus Institute (1999) analyzed emission reductions in Iowa resulting from recycling and source reduction activities. The analysis used state landfill use reduction goals as the basis for the avoided emissions from resource extraction and manufacturing. The findings are shown in Table 23. In 1995, Iowa attained a 33 percent reduction in landfill waste generation relative to the 1988 baseline, reducing annual greenhouse gas emissions by an estimated at 576,000 MTCE. Projections for future scenarios show that if Iowa reaches a 50 percent waste diversion goal, it could avoid nearly 1 million MTCE annually. If diversions were to drop to 25 percent, avoided annual emissions would decline to 374,000 MTCE.

Table 23. Emission reductions from recycling and source reduction in Iowa for various waste diversion scenarios (Tellus Institute, 1999).

Scenario	Recycled (tons)	Source Reduction [a] (tons)	Diverted Waste (tons)	Avoided Emissions (MTCE)
25 percent diversion	447,227	527,142	974,369	374,023
33 percent diversion	600,000	707,221	1,307,221	575,589
50 percent diversion	**894,454**	**1,054,285**	**1,948,739**	**979,731**

[a] Source reduction is the best option in the "waste hierarchy," and refers to precluding production of materials that would otherwise generate wastes. Examples are reducing the amount of wrapping on consumer products, or the amount of plastic in a plastic bottle, thus lowering the amount of wrapping or plastic needing to be recycled or landfilled. It is the most energy saving of all options.

Carbon Sequestration

Another option to pursue in reducing Iowa's greenhouse gas burden is increasing carbon sequestration in biomass and soils. As biomass grows, carbon dioxide is pulled from the atmosphere and fixed into biological carbon that can be stored in living plant tissue and subsequently as organic matter in the soil. Long-term storage accrues from the accumulation of carbon in these pools.

As an agricultural state, Iowa is in an excellent position to sequester carbon through more aggressive adoption of conservation tillage. Conventional tillage disaggregates (breaks up) soil particles and the overturns the earth. Both actions serve to expose more of the organic soil fraction to air (O_2) leading to the reoxidation of soil carbon to atmospheric CO_2. Conservation tillage greatly reduces the disturbance of the soil, and in so doing inhibits oxidation, thus allowing soil organic matter to accumulate. The Iowa Carbon Storage Project, conducted through the USDA/NRCS, has created a county level database that provides modeled predictions of soil carbon storage resulting from changes in crop rotations, tillage regimes, and Conservation Reserve Program enrollment. This information allows estimation of the efficacy of different agricultural policies coupled to carbon sequestration planning projects (Brenner et al., 2001).

The study analyzed the impact of no-tillage farming on various soil types by simulating the interaction of key environmental factors including soil texture, drainage characteristics, and climate. It found the greatest potential for carbon storage was in the application of no tillage management in the lighter textured sandy soils in eastern Iowa. Under this scenario, the soil would store an estimated 0.65 metric tons carbon/ hectare/year (0.26 tonnes C/acre/yr). Most of the state's soils showed an intermediate response to the simulation under no till management, sequestering carbon in the range of 0.50-0.55 metric tons/ha/yr (0.20 – 0.23 tonne/acre/yr). The prospects are less promising in western Iowa where crop productivity is limited by lower precipitation; in this region the potential for carbon storage is estimated at < 0.5 metric tons/ha/yr. Overall, the model estimated that Iowa's agricultural soils are currently a net sink for carbon, absorbing 3.1 million MTCE per year. This figure includes land used to grow crops, land enrolled in the CRP, and agricultural land converted to grassland, tree cover or wetland in the past 10 years. Cropland accounts for 1.9 million MTCE of this total. With more than half of Iowa's 10.6 million hectares of cropland still managed by conventional tillage practices, conversion to no-tillage offers a large potential to increase carbon sequestration.[10] If three-quarters of Iowa's croplands were managed under a no-tillage regime assuming an intermediate level of carbon storage, an estimated 4.4 million MTCE could be sequestered annually.

With regard to sequestration in forests, a report from the University of Iowa's Center for Global and Regional Environmental Research (Ney, et al., 2001) updated the effectiveness of carbon sequestration measures proposed in the Iowa Greenhouse Gas Action Plan (Iowa Department of Natural Resources, 1996). The revised plan introduced two options; a priority option and a maximum feasible option for reforesting of 200,000 and 1 million acres of land, respectively. The report quantified the carbon sequestered for each option to be 224,000 and 1,120,000 MTCE per year. A third option explored planting 200,000 acres of riparian buffer strips with hybrid poplars. This action would sequester an estimated 817,000 MTCE per year, with 86 percent in above ground biomass and 14 percent stored in the soil.

Another option investigated was the potential for carbon sequestration from the development of switchgrass as a biofuel. Organic matter can accumulate in the soil from the grass' deep root system and litter that remain in the fields after harvest. Net sequestration was estimated to be 0.54 MTCE/acre. It was estimated that 62,500 acres of switchgrass would be required for a priority option of 35 MW of nameplate electricity capacity. In addition to generating power with no greenhouse gas combustion emissions, the grass would provide a net sequestration benefit of 33,750 MTCE per year. If one considers the offset from coal combustion, the net greenhouse gas reduction benefit is raised to 106,389 MTCE per year. A maximum feasible option of developing 100 MW of switchgrass-derived electricity capacity would require cultivation of 150,000 acres, which would sequester 81,400 MTCE with a net greenhouse gas reduction benefit of 123,709 MTCE per year.

Table 24 summarizes the options discussed above for carbon sequestration in Iowa. The information presented suggests the overall potential to sequester carbon as a means to offset emissions is significant. If all the options given in the table were undertaken, carbon storage would amount to between 5.4 million and 6.4 million MTCE per year. This would

[10] It should be mentioned that the prospect of increasing no-tillage agriculture has other pluses and minuses. Its implementation has played a large in role in reducing soil erosion in Iowa. On the negative side, it requires large inputs of herbicides such as atrizine, which have caused considerable ground and surface water pollution problems.

offset between 17 to 19 percent of gross greenhouse gas emissions in Iowa in 2000.

Table 24. Summary of options to increase carbon sequestration in Iowa.	
Management Action	**Annual Carbon Storage (MTCE)**
No-till management: 7.95 million acres of cropland with moderate potential for sequestration [a]	4,372,500
Reforestation [b]: Priority Option, addition of 200,000 acres of forestland Maximum Feasible Option, addition of 1,000,000 acres of forestland	 224,000 1,120,000
Hybrid poplar buffer strips [b]: Addition of 200,000 acres of buffer strips	 817,000
Bioenergy crops for electricity generation [b] 35 MW from switchgrass biomass 100 MW from switchgrass biomass	 33,750 [c] 81,400 [c]
Total: **high -** **low -**	 **6,390,900** **5,447,250**
[a] Based on data from Brenner et al. 2001. [b] Source: Ney et al 2001. [c] Represents net sequestration that accounts for the harvest of surface biomass.	

Summary

Figure 37 summarizes the results of the discussion presented in this chapter. It shows the potential of seven options for reducing net greenhouse gas emissions in Iowa by fuel substitution (wind, biomass, solar, ethanol), reduction in demand for energy (energy efficiency, recycling/reduction), and carbon sequestration. Wind and biomass energy, and carbon sequestration appear to have the greatest potential to reduce net emissions, but a combination of implementing all seven options would maximize the benefit.

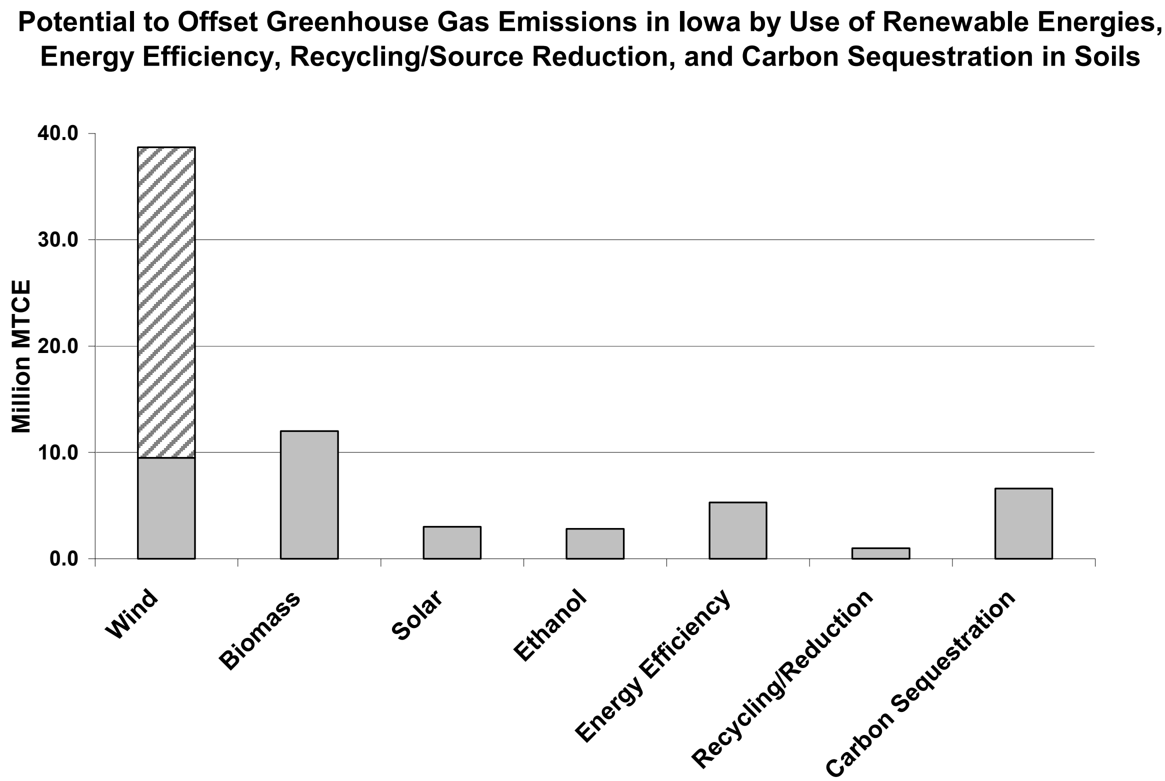


Figure 37. Potential to reduce net greenhouse gas emissions in Iowa for seven major options. Chart shows annual reduction potentials in million MTCE. Gray area under wind signifies emissions offset if wind-generated electricity were to equal state's total electricity consumption in 2000; combined gray/hatched area corresponds to emission offsets if wind-generated electricity were to produce four times the state's year 2000 consumption.

Chapter 9: Conclusions and Recommendations

Overall, it appears that total greenhouse gas emissions have increased from 22.8 million MTCE in 1990 to 32.8 million MTCE in 2000. A precise comparison, however, is difficult to make because of differences in methodology and data availability for the two years in question, particularly with respect to emissions from agricultural soils. Offsetting increases in emissions in the 1990s were increases in the amounts of carbon sequestered in forests, croplands, and landfills, and recovered in landfills and wastewater treatment plants. These increased carbon savings narrow the apparent increase in net emissions (emissions minus sequestration and recovery) from 21.1 million MTCE in 1990 and 26.2 million MTCE in 2000.

The energy-use category was by far Iowa's greatest source of greenhouse gases in 2000, contributing 22.0 million MTCE (67 percent) to total emissions. Growth in the consumption of fossil fuels, 26 percent between 1990 and 2000, was the major reason why emissions increased in the 1990s. Most of the rise in demand was for coal and petroleum, which grew by 28 and 37 percent, respectively.

The next largest emission source category in Iowa is agriculture, having contributed 27 percent to the total greenhouse gas inventory in year 2000. The major share of emissions stems from nitrogen amendments to the soils (6.3 million MTCE) followed by manure management. Emissions from the latter increased slightly from 1990 (1.1 million to 1.2 million MTCE), masking the large shifts that occurred in animal populations. The substantial rise in numbers of swine and layer chicken in the past decade pushed emissions upward, while the large drop in cattle populations served to hold down the overall increase. The lower ruminant cattle population decreased emissions from enteric fermentation in domesticated animals from 1.2 million to 0.9 million MTCE.

The contributions to greenhouse gas emissions from other source categories were far less significant, with releases from industry and waste treatment each amounting to 3 percent of total emissions.

Any comprehensive solution for mitigating greenhouse gas emissions in Iowa must place a large focus on reducing fossil-fuel derived emissions. One way to do this is by fuel substitution. Iowa is particularly rich in wind and biomass resources, and there appears to be an enormous potential for reducing emissions when these and other renewable resources are more fully exploited. The wind resource is so large that it can supply several times the state's electricity demand without generation of greenhouse gases. Someday Iowa could plausibly be a net exporter of emission-free wind-based electricity to other states. One of the most promising biomass fuels appears to be agricultural residues like corn stover, because in the energy/emissions balance they add significantly to the energy supply without a concomitant rise in emissions. Expanded methane recovery at landfills, wastewater treatment plants, and livestock farms will also reduce emissions and provide useful sources of renewable fuel.

Reducing greenhouse gas emissions can be achieved also by reducing energy demand. This has been accomplished thus far mainly through energy efficiency, and the expansion of existing programs will be well worth the effort. Recycling/source reduction is a less appreciated option for reducing energy demand and greenhouse gas emissions. Existing programs are small in scope but further initiatives, particularly in untapped opportunities for source reduction, could pay large dividends.

Another strategy for reducing net greenhouse gas emissions is to offset them by sequestering carbon in soils. Currently carbon sequestration in forest and agricultural lands offsets more than 20 percent of total greenhouse gas emissions in the state. The percentage can be even higher if the options recommended in the *Iowa Greenhouse Gas Action Plan* (Iowa Department of Natural Resources, 1996) and Ney et al. (2001) are enacted that couple reforestation and agroforestry to biofuel development. Extension of agricultural practices that build up organic carbon in cropland soils will complement carbon gains in forest soils.

After fossil fuel combustion, the largest single contributing activity to greenhouse gas emissions in Iowa is the addition of nitrogen amendments to agricultural soils. This results in emissions of N_2O (GWP = 296), which contributed 19 percent of total emissions in year 2000. Thus, any actions to reduce nitrogen inputs to the soil will have important benefits in reducing Iowa's greenhouse gas burden. According to Ney et al. (2001) it has been demonstrated that field nitrogen amendments can be cut substantially without loss of crop yield. Reduced nitrogen applications also have the additional environmental benefit of improving water quality, an issue that has the specific attention of the Governor in his plan *The New Face of Iowa* for 2010. Thus, there seems to be compelling reasons for enacting programs to reduce nitrogen inputs.

Combining the potential for renewable energies, energy efficiency, recycling/source reduction, carbon sequestration, and more efficient agricultural nitrogen management, it is conceivable that Iowa could one day become a net negative greenhouse gas emissions state.

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APPENDIX A
ENERGY RELATED ACTIVITES

I. CO_2 from Combustion of Fossil Fuels

Energy use emissions were calculated based on energy consumption figures from the Energy Information Administration (EIA) published as the State Energy Data 2000 Consumption Tables formerly the State Energy Data Report (SEDR) (EIA, 2003c). Consumption estimates are reported for 5 economic sectors including the commercial, residential, industrial, transportation and electric utilities. For each sector, emissions are estimated by multiplying the fuel use by the established carbon content coefficient and the assumed fraction of oxidization. Carbon stored in non-energy products namely from the petrochemical industry, was credited to the state. National estimates of fossil fuel consumption for non-fuel use are published in the EIA 2000 Annual Energy Review (2001a). Estimates of the quantity of carbon stored in Iowa industrial products were made based on the national fraction of non-fuel use to total U.S. industrial consumption. Seven fuels, including asphalt and road oil, liquid petroleum gas, lubricants, natural gas, coal, petrochemical feedstocks and other oils, were considered to store carbon in non-energy products. Carbon stored in lubricants used by the transportation sector was also credited to the state.

Emissions contributed from the electric utilities sector were distributed to each end use sector based on its consumption and associated losses. A distribution factor was calculated as the fraction of total emissions from electric utilities divided by the total energy input at all electric utilities. Energy inputs into forms of generation that do not emit greenhouse gases were also included in this total (i.e. nuclear, hydroelectric, wood, etc.). As more generation comes from nuclear, hydroelectric, wind and other renewables, it will be reflected in a smaller fraction of emissions per unit of electricity. It was assumed that electricity consumption and losses equaled energy consumption by the electric utilities. The difference between the two represents electricity that is exported from the state and is accounted for as net interstate flow of electricity. The difference may also be the result of statistical error from different methods of data collection. The emission distribution factor served as any emission factor does. For each end use sector, the electricity consumption and associated losses from transmission and distribution were multiplied by the electric generation emission distribution factor. Therefore, emissions from electric utilities are accounted for within the four end use sectors and as net interstate flows of electricity.

Summary of Iowa CO_2 Emissions from Combustion of Fossil Fuels, 2000

	Input A Consumption (10^6 Btu)	Input B Carbon Content Coefficient (lbs C/ 10^6 Btu)	A x B / 2000 C Total Carbon (tons C)	Input D Stored Carbon (tons C)	C- D E Net Carbon Potential (tons C)	Input F Fraction Oxidized	E x F x 0.9072 G Net Carbon Emissions (metric tons C)
Electric Utilities							
Natural Gas	4,700,000	31.9	74,965	0	74,965	0.995	67,668
Coal	374,900,000	56.0	10,495,496	0	10,495,496	0.99	9,426,299
Light Oil	1,300,000	43.5	28,275	0	28,275	0.99	25,395
	380,900,000					**Total**	**NA**
Net Interstate Flow of Electricity [a]							
	-74,600,000	48.1	1,794,130	0	1,794,130	0.99	1,611,358
	-74,600,000						**1,611,358**
Transportation							
Aviation Gasoline	400,000	41.6	8,320	0	8,320	0.99	7,472
Distillate Fuel Oil	73,000,000	44.0	1,606,000	0	1,606,000	0.99	1,442,394
Jet Fuel	4,400,000	43.5	95,700	0	95,700	0.99	85,951
Liquefied Petroleum Ga	0	37.8	0	0	0	0.99	0
Lubricants	3,300,000	44.6	73,590	35,870.97	37,719	0.99	33,877
Motor Gasoline	176,800,000	42.8	3,783,520	0	3,783,520	0.99	3,398,085
Natural Gas	8,300,000	31.9	132,385	0	132,385	0.995	119,499
	266,200,000					**Total**	**5,087,278**
Industrial							
Asphalt & Road Oil	16,400,000	45.5	373,100	373,100	0	0.99	0
Distillate Fuel Oil	34,600,000	44.0	761,200	0	761,200	0.99	683,655
Kerosene	0	43.5	0	0	0	0.99	0
Liquefied Petroleum Ga	48,200,000	37.8	910,980	584,128	326,852	0.99	293,555
Lubricants	1,200,000	44.6	26,760	13,044	13,716	0.99	12,319
Motor Gasoline	4,100,000	42.8	87,740	0	87,740	0.99	78,802
Residual Fuel Oil	1,100,000	44.0	24,200	0	24,200	0.99	21,735
Other Oil 2/	4,900,000	47.4	116,130	5,899	110,231	0.99	99,002
Natural Gas	100,900,000	31.9	1,609,355	87,631	1,521,724	0.995	1,373,605
Coal	64,200,000	56.6	1,818,319	5,518	1,812,801	0.99	1,628,127
Petrochemical Feedstoc	8,300,000	42.7	177,205	132,904	44,301	0.99	39,788
Electricity	58,400,000	48.1	1,403,257	0	1,403,257	NA	1,273,035
Electricial Losses	100,200,000	48.1	2,407,643	0	2,407,643	NA	2,184,214
	442,500,000					**Total**	**7,687,837**
Residential							
Distillate Fuel Oil	2,800,000	44.0	61,600	0	61,600	0.99	55,325
Kerosene	200,000	43.5	4,350	0	4,350	0.99	3,907
Liquefied Petroleum Ga	19,100,000	37.8	360,990	0	360,990	0.99	324,215
Natural Gas	74,200,000	31.9	1,183,490	0	1,183,490	0.995	1,068,294
Coal	700,000	55.7	19,511	0	19,511	0.99	17,523
Electricity	41,000,000	48.1	985,163	0	985,163	NA	893,740
Electricial Losses	70,400,000	48.1	1,691,598	0	1,691,598	NA	1,534,617
	208,400,000					**Total**	**3,897,622**
Commercial							
Natural Gas	45,800,000	31.9	730,510	0	730,510	0.995	659,405
Coal	6,100,000	55.7	170,024	0	170,024	0.99	152,703
Distillate Fuel	2,800,000	44.0	61,600	0	61,600	0.99	55,325
Kerosene	0	43.5	0	0	0	0.99	0
Liquefied Petroleum Ga	3,400,000	37.8	64,260	0	64,260	0.99	57,714
Motor Gasoline	2,800,000	42.8	59,920	0	59,920	0.99	53,816
Residual Fuel Oil	0	47.4	0	0	0	0.99	0
Electricity	33,900,000	48.1	814,562	0	814,562	NA	738,971
Electricial Losses	58,100,000	48.1	1,396,049	0	1,396,049	NA	1,266,495
	152,900,000					**Total**	**2,984,428**
All Sectors	1,070,000,000					**Total**	**21,268,523**

[a] Net interstate flow of electricity is the difference between the amount of energy in the electricity sold within a state (including associated losses) and the energy input at the electric utilities within the State. A positive number indicates that more electricity (and associated losses) came into the state than went out of the State during the year, conversely, a negative number indicates the more electricity (including associated losses) went out of the State than came into the State.

Summary of Iowa CO_2 Emissions from Combustion of Fossil Fuels, recalculated 1990

	Input A Consumption (10^6 Btu)	Input B Carbon Content Coefficient (lbs C/ 10^6 Btu)	A x B / 2000 C Total Carbon (tons C)	Input D Stored Carbon (tons C)	C- D E Net Carbon Potential (tons C)	Input F Fraction Oxidized	E x F x 0.9072 G Net Carbon Emissions (metric tons C)
Electric Utilities							
Natural Gas	3,500,000	31.9	55,825	0	55,825	0.995	50,391
Coal	272,600,000	57.5	7,837,250	0	7,837,250	0.99	7,038,854
Light Oil	700,000	43.5	15,225	0	15,225	0.99	13,674
	276,800,000					**Total**	**NA**
Net Interstate Flows of Electricity [a]							
	1,700,000	49.2	-41,820	0	-41,820	0.99	-41,402
	1,700,000						**-41,402**
Transportation							
Aviation Gasoline	500,000	41.6	10,400	0	10,400	0.99	9,341
Distillate Fuel Oil	56,300,000	44.0	1,238,600	0	1,238,600	0.99	1,112,421
Jet Fuel	5,000,000	43.5	108,750	0	108,750	0.99	97,671
Liquefied Petroleum G	200,000	37.8	3,780	0	3,780	0.99	3,395
Lubricants	3,200,000	44.6	71,360	35,680	35,680	0.99	32,045
Motor Gasoline	157,000,000	42.8	3,359,800	0	3,359,800	0.99	3,017,530
Natural Gas	9,200,000	31.9	146,740	0	146,740	0.995	132,457
	231,400,000						**4,404,861**
Industrial							
Asphalt & Road Oil	10,200,000	45.5	232,050	232,050	0	0.99	0
Distillate Fuel Oil	24,100,000	44.0	530,200	0	530,200	0.99	476,187
Kerosene	100,000	43.5	2,175	0	2,175	0.99	1,953
Liquefied Petroleum G	11,200,000	37.8	211,680	126,388	85,292	0.99	76,603
Lubricants	1,200,000	44.6	26,760	13,380	13,380	0.99	12,017
Motor Gasoline	5,600,000	42.8	119,840	0	119,840	0.99	107,632
Residual Fuel Oil	600,000	44.0	13,200	0	13,200	0.99	11,855
Other Oil	2,300,000	47.4	54,510	2,728	51,782	0.99	46,507
Natural Gas	90,900,000	31.9	1,449,855	120,826	1,329,029	0.995	1,199,667
Coal	53,100,000	55.9	1,484,386	11,490	1,472,897	0.99	1,322,850
Petrochemical Feedsto	2,800,000	42.7	59,780	44,835	14,945	0.99	13,423
Electricity	38,900,000	49.2	957,768	0	957,768	NA	868,887
Electrical Losses	84,800,000	49.2	2,087,884	0	2,087,884	NA	1,894,128
	325,800,000			551,696			**6,031,709**
Residential							
Distillate Fuel Oil	4,600,000	44.0	101,200	0	101,200	0.99	90,891
Kerosene	100,000	43.5	2,175	0	2,175	0.99	1,953
Liquefied Petroleum G	9,900,000	37.8	187,110	0	187,110	0.99	168,049
Natural Gas	71,900,000	31.9	1,146,805	0	1,146,805	0.995	1,035,180
Coal	1,100,000	55.7	30,660	0	30,660	0.99	27,537
Electricity	35,900,000	49.2	883,904	0	883,904	NA	801,877
Electrical Losses	78,300,000	49.2	1,927,846	0	1,927,846	NA	1,748,942
	201,800,000					**Total**	**3,874,428**
Commercial							
Natural Gas	44,300,000	31.9	706,585	0	706,585	0.995	637,809
Coal	4,800,000	55.7	133,680	0	133,680	0.99	120,062
Distillate Fuel	2,900,000	44.0	63,800	0	63,800	0.99	57,301
Kerosene	200,000	43.5	4,350	0	4,350	0.99	3,907
Liquefied Petroleum G	1,800,000	37.8	34,020	0	34,020	0.99	30,554
Motor Gasoline	700,000	42.8	14,980	0	14,980	0.99	13,454
Residual Fuel Oil	200,000	47.4	4,740	0	4,740	0.99	4,257
Electricity	25,700,000	49.2	632,767	0	632,767	NA	574,046
Electrical Losses	56,100,000	49.2	1,381,253	0	1,381,253	NA	1,253,073
	136,700,000					**Total**	**2,694,463**
All Sectors	895,700,000					**Total**	**16,964,059**

[a] Net interstate flow of electricity is the difference between the amount of energy in the electricity sold within a state (including associated losses) and the energy input at the electric utilities within the State. A positive number indicates that more electricity (and associated losses) came into the state than went out of the State during the year, conversely, a negative number indicates the more electricity (including associated losses) went out of the State than came into the State.

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Commercial Sector

	Input	Input	A x B / 2000	Input	C x D x .9072
	A	B	C	D	E
	Consumption	**Carbon Content Coefficient 1/**	**Total Carbon**	**Fraction Oxidized**	**Net Carbon Emissions**
	(10^6 Btu)	**(lbs C/ 10^6 Btu)**	**(tons C)**		**(metric tons C)**
2000					
Natural Gas	45,800,000	31.9	730,510.00	0.995	659,405.08
Coal	6,100,000	55.7	170,023.64	0.99	152,702.99
Distillate Fuel	2,800,000	44.0	61,600.00	0.99	55,324.68
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	3,400,000	37.8	64,260.00	0.99	57,713.71
Motor Gasoline	2,800,000	42.8	59,920.00	0.99	53,815.83
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	33,900,000	48.1	814,561.98	NA	738,970.63
Electrical System Losses 2/	58,100,000	48.1	1,396,048.70	NA	1,266,495.38
Total	152,900,000				**2,984,428.29**
1999					
Natural Gas	45,800,000	31.9	730,510.00	0.995	659,405.08
Coal	8,200,000	55.7	228,556.36	0.99	205,272.87
Distillate Fuel	2,600,000	44.0	57,200.00	0.99	51,372.92
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	3,300,000	37.8	62,370.00	0.99	56,016.24
Motor Gasoline	2,300,000	42.8	49,220.00	0.99	44,205.86
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	33,000,000	48.4	798,272.29	NA	724,192.62
Electrical System Losses 2/	64,100,000	48.4	1,550,583.45	NA	1,406,689.31
Total	159,300,000				**3,147,154.90**
1998					
Natural Gas	43,500,000	31.9	693,825.00	0.995	626,290.85
Coal	5,900,000	55.9	164,770.91	0.99	147,985.37
Distillate Fuel	2,700,000	44.0	59,400.00	0.99	53,348.80
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	2,700,000	37.8	51,030.00	0.99	45,831.47
Motor Gasoline	2,400,000	42.8	51,360.00	0.99	46,127.85
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	32,000,000	48.2	770,451.97	NA	698,954.03
Electrical System Losses 2/	65,700,000	48.2	1,581,834.20	NA	1,435,039.99
Total	154,900,000				**3,053,578.36**
1997					
Natural Gas	50,600,000	31.9	807,070.00	0.995	728,513.03
Coal	7,800,000	55.6	216,875.45	0.99	194,781.92
Distillate Fuel	2,000,000	44.0	44,000.00	0.99	39,517.63
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	3,100,000	37.8	58,590.00	0.99	52,621.32
Motor Gasoline	2,300,000	42.8	49,220.00	0.99	44,205.86
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	30,500,000	48.8	743,936.62	NA	674,899.30
Electrical System Losses 2/	63,100,000	48.8	1,539,095.11	NA	1,396,267.08
Total	159,400,000				**3,130,806.15**
1996					
Natural Gas	54,900,000	31.9	875,655.00	0.995	790,422.24
Coal	4,800,000	55.7	133,745.45	0.99	120,120.54
Distillate Fuel	2,100,000	44.0	46,200.00	0.99	41,493.51
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	3,400,000	37.8	64,260.00	0.99	57,713.71

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Commercial Sector

	Input	Input	A x B / 2000	Input	C x D x .9072
	A	B	C	D	E
	Consumption	Carbon Content Coefficient 1/	Total Carbon	Fraction Oxidized	Net Carbon Emissions
	(10^6 Btu)	(lbs C/ 10^6 Btu)	(tons C)		(metric tons C)
Motor Gasoline	1,300,000	42.8	27,820.00	0.99	24,985.92
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	29,600,000	49.0	724,504.17	NA	657,270.19
Electrical System Losses 2/	61,400,000	49.0	1,502,856.63	NA	1,363,391.53
Total	157,500,000				**3,055,397.64**
1995					
Natural Gas	50,600,000	31.9	807,070.00	0.995	728,513.03
Coal	1,900,000	55.9	53,061.82	0.99	47,656.30
Distillate Fuel	2,600,000	44.0	57,200.00	0.99	51,372.92
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	2,500,000	37.8	47,250.00	0.99	42,436.55
Motor Gasoline	200,000	42.8	4,280.00	0.99	3,843.99
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	30,300,000	49.1	743,919.88	NA	674,884.12
Electrical System Losses 2/	62,900,000	49.1	1,544,308.93	NA	1,400,997.06
Total	151,000,000				**2,949,703.97**
1994					
Natural Gas	48,300,000	31.9	770,385.00	0.995	695,398.81
Coal	800,000	55.8	22,320.00	0.99	20,046.22
Distillate Fuel	2,300,000	44.0	50,600.00	0.99	45,445.28
Kerosene	100,000	43.5	2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	2,500,000	37.8	47,250.00	0.99	42,436.55
Motor Gasoline	200,000	42.8	4,280.00	0.99	3,843.99
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	29,900,000	48.0	717,751.50	NA	651,144.16
Electrical System Losses 2/	61,900,000	48.0	1,485,913.65	NA	1,348,020.86
Total	146,000,000				**2,808,289.29**
1993					
Natural Gas	50,500,000	31.9	805,475.00	0.995	727,073.29
Coal	1,400,000	55.8	39,040.91	0.99	35,063.73
Distillate Fuel	2,100,000	44.0	46,200.00	0.99	41,493.51
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	2,500,000	37.8	47,250.00	0.99	42,436.55
Motor Gasoline	3,300,000	42.8	70,620.00	0.99	63,425.80
Residual Fuel Oil	0	47.4	0.00	0.99	0.00
Electricity 2/	29,100,000	49.7	723,298.95	NA	656,176.81
Electrical System Losses 2/	61,200,000	49.7	1,521,164.81	NA	1,380,000.72
Total	150,100,000				**2,945,670.41**
1992					
Natural Gas	46,300,000	31.9	738,485.00	0.995	666,603.82
Coal	1,300,000	55.7	36,199.09	0.99	32,511.42
Distillate Fuel	2,800,000	44.0	61,600.00	0.99	55,324.68
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	2,200,000	37.8	41,580.00	0.99	37,344.16
Motor Gasoline	3,400,000	42.8	72,760.00	0.99	65,347.79
Residual Fuel Oil	200,000	47.4	4,740.00	0.99	4,257.13
Electricity 2/	26,600,000	48.6	646,973.37	NA	586,934.24
Electrical System Losses 2/	56,300,000	48.6	1,369,345.89	NA	1,242,270.59
Total	139,100,000				**2,690,593.84**
1991					

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Commercial Sector

	Input	Input	A x B / 2000	Input	C x D x .9072
	A	B	C	D	E
	Consumption	**Carbon Content Coefficient 1/**	**Total Carbon**	**Fraction Oxidized**	**Net Carbon Emissions**
	(10^6 Btu)	**(lbs C/ 10^6 Btu)**	**(tons C)**		**(metric tons C)**
Natural Gas	47,000,000	31.9	749,650.00	0.995	676,682.07
Coal	4,500,000	55.6	124,997.73	0.99	112,263.96
Distillate Fuel	3,300,000	44.0	72,600.00	0.99	65,204.09
Kerosene	0	43.5	0.00	0.99	0.00
Liquefied Petroleum Gas	2,100,000	37.8	39,690.00	0.99	35,646.70
Motor Gasoline	3,800,000	42.8	81,320.00	0.99	73,035.77
Residual Fuel Oil	100,000	47.4	2,370.00	0.99	2,128.56
Electricity 2/	27,100,000	47.7	646,815.20	NA	586,790.75
Electrical System Losses 2/	58,400,000	47.7	1,393,874.82	NA	1,264,523.23
Total	146,300,000				**2,816,275.13**
1990					
Natural Gas	44,300,000	31.9	706,585.00	0.995	637,808.84
Coal	4,800,000	55.7	133,592.73	0.99	119,983.37
Distillate Fuel	2,900,000	44.0	63,800.00	0.99	57,300.57
Kerosene	200,000	43.5	4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	1,800,000	37.8	34,020.00	0.99	30,554.31
Motor Gasoline	700,000	42.8	14,980.00	0.99	13,453.96
Residual Fuel Oil	200,000	47.4	4,740.00	0.99	4,257.13
Electricity 2/	25,700,000	49.2	632,766.72	NA	574,045.97
Electrical System Losses 2/	56,100,000	49.2	1,381,253.43	NA	1,253,073.11
Total	136,700,000				**2,694,384.12**

1/ Coal Carbon Content is determined from EIA State Energy Data Report 2000 Appendix E Table E1.
For 1996 figure is an average of those from 1990 to 1999

2/ Carbon Content Coefficient was determined from ratio of electric utilities carbon emissions to electric utilities energy inputs

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990-2000

Residential Sector

	Input	Input	A x B / 2000	Input	C x D x 0.9072
	A	B	C	D	E
	Consumption	Carbon Content Coefficient 1/	Total Carbon	Fraction Oxidized	Net Carbon Emissions
	(10^6 Btu)	(lbs C/ 10^6 Btu)	(tons C)		(metric tons C)
2000					
Distillate Fuel Oil	2,800,000	44.0	61,600.00	0.99	55,324.68
Kerosene	200,000	43.5	4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	19,100,000	37.8	360,990.00	0.99	324,215.23
Natural Gas	74,200,000	31.9	1,183,490.00	0.995	1,068,293.82
Coal	700,000	55.7	19,510.91	0.99	17,523.29
Electricity 2/	41,000,000	48.1	985,163.45	NA	893,740.29
Electrical System Losses 2/	70,400,000	48.1	1,691,597.74	NA	1,534,617.47
Total	208,400,000				**3,897,621.63**
1999					
Distillate Fuel Oil	2,800,000	44.0	61,600.00	0.99	55,324.68
Kerosene	100,000	43.5	2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	18,900,000	37.8	357,210.00	0.99	320,820.30
Natural Gas	72,800,000	31.9	1,161,160.00	0.995	1,048,137.33
Coal	1,100,000	55.7	30,660.00	0.99	27,536.60
Electricity 2/	40,500,000	48.4	979,697.81	NA	888,781.86
Electrical System Losses 2/	78,700,000	48.4	1,903,758.46	NA	1,727,089.68
Total	214,900,000				**4,069,643.88**
1998					
Distillate Fuel Oil	3,200,000	44.0	70,400.00	0.99	63,228.21
Kerosene	100,000	43.5	2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	15,100,000	37.8	285,390.00	0.99	256,316.75
Natural Gas	69,700,000	31.9	1,111,715.00	0.995	1,003,505.11
Coal	700,000	55.9	19,549.09	0.99	17,557.59
Electricity 2/	40,500,000	48.2	975,103.28	NA	884,613.69
Electrical System Losses 2/	83,100,000	48.2	2,000,767.46	NA	1,815,096.24
Total	212,400,000				**4,042,271.02**
1997					
Distillate Fuel Oil	4,500,000	44.0	99,000.00	0.99	88,914.67
Kerosene	200,000	43.5	4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	17,800,000	37.8	336,420.00	0.99	302,148.22
Natural Gas	82,400,000	31.9	1,314,280.00	0.995	1,186,353.24
Coal	1,000,000	55.6	27,804.55	0.99	24,972.04
Electricity 2/	39,800,000	48.8	970,776.31	NA	880,688.27
Electrical System Losses 2/	82,300,000	48.8	2,007,409.31	NA	1,821,121.73
Total	228,000,000				**4,308,105.03**
1996					
Distillate Fuel Oil	4,600,000	44.0	101,200.00	0.99	90,890.55
Kerosene	200,000	43.5	4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	19,200,000	37.8	362,880.00	0.99	325,912.69
Natural Gas	88,600,000	31.9	1,413,170.00	0.995	1,275,617.68
Coal 1/	700,000	55.7	19,504.55	0.99	17,517.58
Electricity 2/	39,400,000	49.0	964,373.80	NA	874,879.91
Electrical System Losses 2/	81,700,000	49.0	1,999,729.42	NA	1,814,154.53
Total	234,400,000				**4,402,879.81**
1995					
Distillate Fuel Oil	4,900,000	44.0	107,800.00	0.99	96,818.20
Kerosene	100,000	43.5	2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	14,400,000	37.8	272,160.00	0.99	244,434.52
Natural Gas	82,600,000	31.9	1,317,470.00	0.995	1,189,232.74
Coal	300,000	55.9	8,378.18	0.99	7,524.68
Electricity 2/	39,700,000	49.1	974,706.91	NA	884,254.11
Electrical System Losses 2/	82,400,000	49.1	2,023,069.25	NA	1,835,328.42
Total	224,400,000				**4,259,546.09**
1994					
Distillate Fuel Oil	5,700,000	44.0	125,400.00	0.99	112,625.25
Kerosene	100,000	43.5	2,175.00	0.99	1,953.43

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990-2000

Residential Sector

	Input A	Input B	A x B / 2000 C	Input D	C x D x 0.9072 E
	Consumption	**Carbon Content Coefficient 1/**	**Total Carbon**	**Fraction Oxidized**	**Net Carbon Emissions**
	(10^6 Btu)	**(lbs C/ 10^6 Btu)**	**(tons C)**		**(metric tons C)**
Liquefied Petroleum Gas	14,300,000	37.8	270,270.00	0.99	242,737.05
Natural Gas	78,900,000	31.9	1,258,455.00	0.995	1,135,962.02
Coal	100,000	55.8	2,790.00	0.99	2,505.78
Electricity 2/	37,700,000	48.0	904,991.02	NA	821,007.86
Electrical System Losses 2/	78,200,000	48.0	1,877,196.24	NA	1,702,992.43
Total	215,000,000				**4,019,783.82**
1993					
Distillate Fuel Oil	4,800,000	44.0	105,600.00	0.99	94,842.32
Kerosene	200,000	43.5	4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	14,300,000	37.8	270,270.00	0.99	242,737.05
Natural Gas	83,700,000	31.9	1,335,015.00	0.995	1,205,069.98
Coal	300,000	55.8	8,365.91	0.99	7,513.66
Electricity 2/	37,900,000	49.7	942,028.53	NA	854,608.29
Electrical System Losses 2/	79,600,000	49.7	1,978,508.48	NA	1,794,902.89
Total	220,800,000				**4,203,581.04**
1992					
Distillate Fuel Oil	4,500,000	44.0	99,000.00	0.99	88,914.67
Kerosene	100,000	43.5	2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	12,300,000	37.8	232,470.00	0.99	208,787.82
Natural Gas	75,200,000	31.9	1,199,440.00	0.995	1,082,691.31
Coal	300,000	55.7	8,353.64	0.99	7,502.63
Electricity 2/	35,100,000	48.6	853,712.98	NA	774,488.42
Electrical System Losses 2/	74,400,000	48.6	1,809,579.65	NA	1,641,650.66
Total	201,900,000				**3,805,988.93**
1991					
Distillate Fuel Oil	5,200,000	44.0	114,400.00	0.99	102,745.84
Kerosene	200,000	43.5	4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	12,100,000	37.8	228,690.00	0.99	205,392.89
Natural Gas	79,400,000	31.9	1,266,430.00	0.995	1,143,160.77
Coal	900,000	55.6	24,999.55	0.99	22,452.79
Electricity 2/	38,100,000	47.7	909,360.11	NA	824,971.49
Electrical System Losses 2/	82,100,000	47.7	1,959,539.77	NA	1,777,694.48
Total	218,000,000				**4,080,325.13**
1990					
Distillate Fuel Oil	4,600,000	44.0	101,200.00	0.99	90,890.55
Kerosene	100,000	43.5	2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	9,900,000	37.8	187,110.00	0.99	168,048.73
Natural Gas	71,900,000	31.9	1,146,805.00	0.995	1,035,179.59
Coal	1,100,000	55.7	30,615.00	0.99	27,496.19
Electricity 2/	35,900,000	49.2	883,903.71	NA	801,877.45
Electrical System Losses 2/	78,300,000	49.2	1,927,845.70	NA	1,748,941.62
Total	201,800,000				**3,874,387.55**

1/ Coal Carbon Content is determined from EIA State Energy Data Report 2000 Appendix E Table E1.
For 1996 figure is an average of those from 1990 to 1999

2/ Carbon Content Coefficient was determined from ratio of electric utilities carbon emissions to electric utilities energy inputs

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Industrial Sector

	A	B	C	D	E	G	H
	Input	Input	A x B / 2000	Input	[C - D]	Input	E x G x .9072
	Consumption (10^6 Btu)	Carbon Content Coefficient 1/ (lbs C/10^6)	Total Carbon (tons C)	Stored Carbon (tons C)	Net Potential Carbon Emissions (tons C)	Fraction Oxidized	Net Carbon Emissions (metric tons C)
2000							
Asphalt & Road Oil	16,400,000	45.5	373,100.00	373,100.00	0.00	0.99	0.00
Distillate Fuel Oil	34,600,000	44.0	761,200.00		761,200.00	0.99	683,655.03
Kerosene	0	43.5	0.00		0.00	0.99	0.00
Liquefied Petroleum Gas	48,200,000	37.8	910,980.00	584,127.66	326,852.34	0.99	293,555.23
Lubricants	1,200,000	44.6	26,760.00	13,043.99	13,716.01	0.99	12,318.73
Motor Gasoline	4,100,000	42.8	87,740.00		87,740.00	0.99	78,801.75
Residual Fuel Oil	1,100,000	44.0	24,200.00		24,200.00	0.99	21,734.70
Other Oil 2/	4,900,000	47.4	116,130.00	5,898.90	110,231.10	0.99	99,001.63
Natural Gas	100,900,000	31.9	1,609,355.00	87,630.99	1,521,724.01	0.995	1,373,605.48
Coal	64,200,000	56.6	1,818,319.09	5,518.10	1,812,800.99	0.99	1,628,127.33
Petrochemical Feedstock 3/	8,300,000	42.7	177,205.00	132,903.75	44,301.25	0.99	39,788.19
Electricty 4/	58,400,000	48.1	1,403,257.21		NA	NA	1,273,034.94
Electrical System Losses 4/	100,200,000	48.1	2,407,643.37		NA	NA	2,184,214.06
Total	442,500,000						**7,687,837.10**
1999							
Asphalt & Road Oil	19,500,000	45.5	443,625.00	443,625.00	0.00	0.99	0.00
Distillate Fuel Oil	31,400,000	44.0	690,800.00		690,800.00	0.99	620,426.82
Kerosene	200,000	43.5	4,350.00		4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	45,500,000	37.8	859,950.00	552,037.40	307,912.60	0.99	276,544.93
Lubricants	1,200,000	44.6	26,760.00	11,420.77	15,339.23	0.99	13,776.59
Motor Gasoline	4,600,000	42.8	98,440.00		98,440.00	0.99	88,411.72
Residual Fuel Oil	800,000	44.0	17,600.00		17,600.00	0.99	15,807.05
Other Oil	6,000,000	47.4	142,200.00	7,595.03	134,604.97	0.99	120,892.50
Natural Gas	103,900,000	31.9	1,657,205.00	94,111.86	1,563,093.14	0.995	1,410,947.91
Coal	66,600,000	56.6	1,886,293.64	8,869.55	1,877,424.09	0.99	1,686,167.14
Petrochemical Feedstock	8,100,000	42.7	172,935.00	129,701.25	43,233.75	0.99	38,829.44
Electricty 4/	56,300,000	48.4	1,361,900.91		NA	NA	1,235,516.50
Electrical System Losses 4/	109,500,000	48.4	2,648,812.60		NA	NA	2,403,002.79
Total	453,600,000						**7,914,230.26**
1998							
Asphalt & Road Oil	14,300,000	45.5	325,325.00	325,325.00	0.00	0.99	0.00
Distillate Fuel Oil	37,700,000	44.0	829,400.00		829,400.00	0.99	744,907.36
Kerosene	200,000	43.5	4,350.00		4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	35,900,000	37.8	678,510.00	424,010.13	254,499.87	0.99	228,573.46
Lubricants	1,200,000	44.6	26,760.00	11,900.89	14,859.11	0.99	13,345.38
Motor Gasoline	4,700,000	42.8	100,580.00		100,580.00	0.99	90,333.71
Residual Fuel Oil	600,000	44.0	13,200.00		13,200.00	0.99	11,855.29
Other Oil	4,900,000	47.4	116,130.00	4,897.51	111,232.49	0.99	99,901.01
Natural Gas	107,100,000	31.9	1,708,245.00	101,616.15	1,606,628.85	1.00	1,450,246.02
Coal	67,400,000	56.6	1,908,951.82	20,672.33	1,888,279.49	0.99	1,695,916.68
Petrochemical Feedstock	8,700,000	42.7	185,745.00	139,308.75	46,436.25	0.99	41,705.70
Electricty 4/	54,900,000	48.2	1,321,806.66		NA	NA	1,199,143.00
Electrical System Losses 4/	112,600,000	48.2	2,711,027.87		NA	NA	2,459,444.48
Total	450,200,000						**8,039,278.96**
1997							
Asphalt & Road Oil	17,400,000	45.5	395,850.00	395,850.00	0.00	0.99	0.00
Distillate Fuel Oil	40,000,000	44.0	880,000.00		880,000.00	0.99	790,352.64
Kerosene	200,000	43.5	4,350.00		4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	15,900,000	37.8	300,510.00	188,124.07	112,385.93	0.99	100,936.95
Lubricants	1,200,000	44.6	26,760.00	12,836.04	13,923.96	0.99	12,505.50
Motor Gasoline	5,700,000	42.8	121,980.00		121,980.00	0.99	109,553.65
Residual Fuel Oil	500,000	44.0	11,000.00		11,000.00	0.99	9,879.41
Other Oil	4,400,000	47.4	104,280.00	4,329.85	99,950.15	0.99	89,768.03
Natural Gas	108,400,000	31.9	1,728,980.00	101,041.09	1,627,938.91	1.00	1,469,481.85
Coal	68,900,000	56.8	1,957,073.18	15,849.00	1,941,224.19	0.99	1,743,467.80
Petrochemical Feedstock	8,700,000	42.7	185,745.00	139,308.75	46,436.25	0.99	41,705.70
Electricty 4/	53,000,000	48.8	1,292,742.33		NA	NA	1,172,775.84
Electrical System Losses 4/	109,600,000	48.8	2,673,293.57		NA	NA	2,425,211.93
Total	433,900,000						**7,969,546.14**
1996							

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Industrial Secto

	A	B	C	D	E	G	H
	Input	Input	A x B / 2000	Input	[C - D]	Input	E x G x .9072
	Consumption	**Carbon Content Coefficient 1/**	**Total Carbon**	**Stored Carbon**	**Net Potential Carbon Emissions**	**Fraction Oxidized**	**Net Carbon Emissions**
	(10^6 Btu)	**(lbs C/10^6)**	**(tons C)**	**(tons C)**	**(tons C)**		**(metric tons C)**
Asphalt & Road Oil	13,600,000	45.5	309,400.00	309,400.00	0.00	0.99	0.00
Distillate Fuel Oil	36,900,000	44.0	811,800.00		811,800.00	0.99	729,100.31
Kerosene	100,000	43.5	2,175.00		2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	18,000,000	37.8	340,200.00	214,974.83	125,225.17	0.99	112,468.23
Lubricants	1,100,000	44.6	24,530.00	12,265.00	12,265.00	0.99	11,015.54
Motor Gasoline	5,800,000	42.8	124,120.00		124,120.00	0.99	111,475.65
Residual Fuel Oil	600,000	44.0	13,200.00		13,200.00	0.99	11,855.29
Other Oil	4,600,000	47.4	109,020.00	4,696.78	104,323.22	0.99	93,695.60
Natural Gas	114,700,000	31.9	1,829,465.00	120,845.48	1,708,619.52	1.00	1,542,309.33
Coal	68,700,000	55.7	1,914,856.36	15,048.51	1,899,807.85	0.99	1,706,270.62
Petrochemical Feedstock	7,500,000	42.7	160,125.00	120,093.75	40,031.25	0.99	35,953.19
Electricty 4/	50,500,000	49.0	1,236,062.86		NA	NA	1,121,356.23
Electrical System Losses 4/	104,800,000	49.0	2,565,136.40		NA	NA	2,327,091.74
Total	426,900,000						**7,804,545.16**
1995							
Asphalt & Road Oil	10,900,000	45.5	247,975.00	247,975.00	0.00	0.99	0.00
Distillate Fuel Oil	35,500,000	44.0	781,000.00		781,000.00	0.99	701,437.97
Kerosene	200,000	43.5	4,350.00		4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	44,400,000	37.8	839,160.00	528,576.14	310,583.86	0.99	278,944.06
Lubricants	1,100,000	44.6	24,530.00	12,265.00	12,265.00	0.99	11,015.54
Motor Gasoline	5,400,000	42.8	115,560.00		115,560.00	0.99	103,787.67
Residual Fuel Oil	600,000	44.0	13,200.00		13,200.00	0.99	11,855.29
Other Oil	2,200,000	47.4	52,140.00	2,445.90	49,694.10	0.99	44,631.67
Natural Gas	115,700,000	31.9	1,845,415.00	120,488.68	1,724,926.32	1.00	1,557,028.89
Coal	60,000,000	56.7	1,700,181.82	13,119.16	1,687,062.66	0.99	1,515,198.21
Petrochemical Feedstock	1,200,000	42.7	25,620.00	19,215.00	6,405.00	0.99	5,752.51
Electricty 4/	47,000,000	49.1	1,153,935.13		NA	NA	1,046,849.95
Electrical System Losses 4/	97,500,000	49.1	2,393,801.60		NA	NA	2,171,656.81
Total	421,700,000						**7,452,065.43**
1994							
Asphalt & Road Oil	13,000,000	45.5	295,750.00	295,750.00	0.00	0.99	0.00
Distillate Fuel Oil	38,900,000	44.0	855,800.00		855,800.00	0.99	768,617.94
Kerosene	200,000	43.5	4,350.00		4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	39,600,000	37.8	748,440.00	464,845.91	283,594.09	0.99	254,703.80
Lubricants	1,200,000	44.6	26,760.00	12,933.65	13,826.35	0.99	12,417.83
Motor Gasoline	5,800,000	42.8	124,120.00		124,120.00	0.99	111,475.65
Residual Fuel Oil	1,100,000	44.0	24,200.00		24,200.00	0.99	21,734.70
Other Oil	2,500,000	47.4	59,250.00	2,542.75	56,707.25	0.99	50,930.37
Natural Gas	109,600,000	31.9	1,748,120.00	122,128.70	1,625,991.30	0.995	1,467,723.81
Coal	57,600,000	56.9	1,638,458.18	12,705.77	1,625,752.42	0.99	1,460,133.77
Petrochemical Feedstock	1,200,000	42.7	25,620.00	19,215.00	6,405.00	0.99	5,752.51
Electricty 4/	45,100,000	48.0	1,082,628.52		NA	NA	982,160.59
Electrical System Losses 4/	93,500,000	48.0	2,244,473.76		NA	NA	2,036,186.60
Total	409,300,000						**7,175,744.41**
1993							
Asphalt & Road Oil	9,000,000	45.5	204,750.00	204,750.00	0.00	0.99	0.00
Distillate Fuel Oil	35,800,000	44.0	787,600.00		787,600.00	0.99	707,365.61
Kerosene	200,000	43.5	4,350.00		4,350.00	0.99	3,906.86
Liquefied Petroleum Gas	39,500,000	37.8	746,550.00	449,339.49	297,210.51	0.99	266,933.08
Lubricants	1,100,000	44.6	24,530.00	12,265.00	12,265.00	0.99	11,015.54
Motor Gasoline	4,200,000	42.8	89,880.00		89,880.00	0.99	80,723.74
Residual Fuel Oil	1,000,000	44.0	22,000.00		22,000.00	0.99	19,758.82
Other Oil	2,800,000	47.4	66,360.00	3,136.15	63,223.85	0.99	56,783.11
Natural Gas	102,900,000	31.9	1,641,255.00	120,224.28	1,521,030.72	0.995	1,372,979.67
Coal	53,100,000	56.8	1,507,557.27	11,976.36	1,495,580.91	0.99	1,343,223.10
Petrochemical Feedstock	1,200,000	42.7	25,620.00	19,215.00	6,405.00	0.99	5,752.51
Electricty 4/	42,500,000	49.7	1,056,364.45		NA	NA	958,333.83
Electrical System Losses 4/	89,400,000	49.7	2,222,093.69		NA	NA	2,015,883.40
Total	382,700,000						**6,842,659.27**
1992							
Asphalt & Road Oil	9,300,000	45.5	211,575.00	211,575.00	0.00	0.99	0.00

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Industrial Sector

	A	B	C	D	E	G	H
	Input	Input	A x B / 2000	Input	[C - D]	Input	E x G x .9072
	Consumption	**Carbon Content Coefficient 1/**	**Total Carbon**	**Stored Carbon**	**Net Potential Carbon Emissions**	**Fraction Oxidized**	**Net Carbon Emissions**
	(10^6 Btu)	**(lbs C/10^6)**	**(tons C)**	**(tons C)**	**(tons C)**		**(metric tons C)**
Distillate Fuel Oil	36,200,000	44.0	796,400.00		796,400.00	0.99	715,269.14
Kerosene	100,000	43.5	2,175.00		2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	17,900,000	37.8	338,310.00	202,275.28	136,034.72	0.99	122,176.59
Lubricants	1,100,000	44.6	24,530.00	12,265.00	12,265.00	0.99	11,015.54
Motor Gasoline	5,500,000	42.8	117,700.00		117,700.00	0.99	105,709.67
Residual Fuel Oil	400,000	44.0	8,800.00		8,800.00	0.99	7,903.53
Other Oil	2,800,000	47.4	66,360.00	3,289.40	63,070.60	0.99	56,645.47
Natural Gas	101,200,000	31.9	1,614,140.00	127,390.37	1,486,749.63	0.995	1,342,035.37
Coal	56,000,000	56.8	1,590,654.55	12,787.17	1,577,867.38	0.99	1,417,126.87
Petrochemical Feedstock	1,200,000	42.7	25,620.00	19,215.00	6,405.00	0.99	5,752.51
Electricty 4/	41,400,000	48.6	1,006,943.52		NA	NA	913,499.16
Electrical System Losses 4/	87,700,000	48.6	2,133,066.34		NA	NA	1,935,117.78
Total	360,800,000						**6,634,205.05**
1991							
Asphalt & Road Oil	10,400,000	45.5	236,600.00	236,600.00	0.00	0.99	0.00
Distillate Fuel Oil	26,800,000	44.0	589,600.00		589,600.00	0.99	529,536.27
Kerosene	100,000	43.5	2,175.00		2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	11,800,000	37.8	223,020.00	140,750.06	82,269.94	0.99	73,888.93
Lubricants	1,100,000	44.6	24,530.00	12,265.00	12,265.00	0.99	11,015.54
Motor Gasoline	6,100,000	42.8	130,540.00		130,540.00	0.99	117,241.63
Residual Fuel Oil	500,000	44.0	11,000.00		11,000.00	0.99	9,879.41
Other Oil	2,500,000	47.4	59,250.00	4,072.49	55,177.51	0.99	49,556.46
Natural Gas	98,200,000	31.9	1,566,290.00	85,286.06	1,481,003.94	0.995	1,336,848.94
Coal	62,600,000	56.2	1,759,344.55	13,989.35	1,745,355.20	0.99	1,567,552.37
Petrochemical Feedstock	1,100,000	42.7	23,485.00	17,613.75	5,871.25	0.99	5,273.13
Electricty 4/	39,900,000	47.7	952,322.01		NA	NA	863,946.52
Electrical System Losses 4/	86,000,000	47.7	2,052,623.88		NA	NA	1,862,140.38
Total	347,100,000						**6,428,833.03**
1990							
Asphalt & Road Oil	10,200,000	45.5	232,050.00	232,050.00	0.00	0.99	0.00
Distillate Fuel Oil	24,100,000	44.0	530,200.00		530,200.00	0.99	476,187.47
Kerosene	100,000	43.5	2,175.00		2,175.00	0.99	1,953.43
Liquefied Petroleum Gas	11,200,000	37.8	211,680.00	126,388.03	85,291.97	0.99	76,603.10
Lubricants	1,200,000	44.6	26,760.00	13,380.00	13,380.00	0.99	12,016.95
Motor Gasoline	5,600,000	42.8	119,840.00		119,840.00	0.99	107,631.66
Residual Fuel Oil	600,000	44.0	13,200.00		13,200.00	0.99	11,855.29
Other Oil	2,300,000	47.4	54,510.00	2,727.64	51,782.36	0.99	46,507.19
Natural Gas	90,900,000	31.9	1,449,855.00	120,825.88	1,329,029.12	0.995	1,199,666.74
Coal	53,100,000	55.9	1,484,386.36	11,489.70	1,472,896.67	0.99	1,322,849.74
Petrochemical Feedstock	2,800,000	42.7	59,780.00	44,835.00	14,945.00	0.99	13,422.52
Electricty 4/	38,900,000	49.2	957,767.53		NA	NA	868,886.70
Electrical System Losses 4/	84,800,000	49.2	2,087,883.98		NA	NA	1,894,128.34
Total	325,800,000						**6,031,709.13**

1/ Carbon content coefficient for coal was taken from Appdx F of SEDR '99

2/ EIA reports Other Oil as including 16 other petroleum products including petrochemical feedstocks- other oils equal to or greater than 401 degrees F and still gas. Petrochemical feedstocks have been subtracted for later accounting

3/ Petrochemical Feedstock includes Napthas less than 401 degrees F

4/ Carbon Content Coefficient was determined from ratio of electric utilities carbon emissions to electric utilities energy inputs

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Transportation Sector

	A	B	C	D	E	F	G
	Input	Input	A x B / 2000	Input	[C - D]	Input	E x F x .9072
	Consumption	**Carbon Content Coefficient**	**Total Carbon**	**Stored Carbon**	**Net Emissions Carbon**	**Fraction Oxidized**	**Net Carbon Emissions**
	(10^6 Btu)	**(lbs C/10^6 Btu)**	**(tons C)**	**(tons C)**	**(tons C)**		**(metric tons C)**
2000							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	73,000,000	44.0	1,606,000		1,606,000	0.99	1,442,393.57
Jet Fuel	4,400,000	43.5	95,700		95,700	0.99	85,950.85
Liquefied Petroleum Gas	0	37.8	0		0	0.99	0.00
Lubricants	3,300,000	44.6	73,590	35,870.97	37,719	0.99	33,876.52
Motor Gasoline	176,800,000	42.8	3,783,520		3,783,520	0.99	3,398,085.25
Natural Gas	8,300,000	31.9	132,385		132,385	0.995	119,499.17
Total	266,200,000						**5,087,277.79**
1999							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	74,900,000	44.0	1,647,800		1,647,800	0.99	1,479,935.32
Jet Fuel	5,000,000	43.5	108,750		108,750	0.99	97,671.42
Liquefied Petroleum Gas	0	37.8	0		0	0.99	0.00
Lubricants	3,400,000	44.6	75,820	32,358.85	43,461	0.99	39,033.67
Motor Gasoline	179,200,000	42.8	3,834,880		3,834,880	0.99	3,444,213.10
Natural Gas	7,900,000	31.9	126,005		126,005	0.995	113,740.18
Total	270,800,000						**5,182,066.12**
1998							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	73,900,000	44.0	1,625,800		1,625,800	0.99	1,460,176.50
Jet Fuel	6,700,000	43.5	145,725		145,725	0.99	130,879.70
Liquefied Petroleum Gas	100,000	37.8	1,890		1,890	0.99	1,697.46
Lubricants	3,300,000	44.6	73,590	32,727.45	40,863	0.99	36,699.80
Motor Gasoline	179,400,000	42.8	3,839,160		3,839,160	0.99	3,448,057.09
Natural Gas	8,900,000	31.9	141,955		141,955	0.995	128,137.67
Total	272,700,000						**5,213,120.65**
1997							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	72,100,000	44.0	1,586,200		1,586,200	0.99	1,424,610.63
Jet Fuel	4,500,000	43.5	97,875		97,875	0.99	87,904.28
Liquefied Petroleum Gas	300,000	37.8	5,670		5,670	0.99	5,092.39
Lubricants	3,200,000	44.6	71,360	34,229.45	37,131	0.99	33,347.99
Motor Gasoline	176,900,000	42.8	3,785,660		3,785,660	0.99	3,400,007.24
Natural Gas	11,400,000	31.9	181,830		181,830	0.995	164,131.40
Total	268,800,000						**5,122,566.35**
1996							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	73,800,000	44.0	1,623,600		1,623,600	0.99	1,458,200.62
Jet Fuel	4,600,000	43.5	100,050		100,050	0.99	89,857.71
Liquefied Petroleum Gas	400,000	37.8	7,560		7,560	0.99	6,789.85
Lubricants	3,000,000	44.6	66,900	33,450.00	33,450	0.99	30,042.38
Motor Gasoline	176,200,000	42.8	3,770,680		3,770,680	0.99	3,386,553.29
Natural Gas	12,700,000	31.9	202,565		202,565	0.995	182,848.13
Total	271,100,000						**5,161,764.40**
1995							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	66,100,000	44.0	1,454,200		1,454,200	0.99	1,306,057.74
Jet Fuel	5,900,000	43.5	128,325		128,325	0.99	115,252.28
Liquefied Petroleum Gas	200,000	37.8	3,780		3,780	0.99	3,394.92

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Transportation Sector

	A	B	C	D	E	F	G
	Input	Input	A x B / 2000	Input	[C - D]	Input	E x F x .9072
	Consumption	Carbon Content Coefficient	Total Carbon	Stored Carbon	Net Emissions Carbon	Fraction Oxidized	Net Carbon Emissions
	(10^6 Btu)	(lbs C/10^6 Btu)	(tons C)	(tons C)	(tons C)		(metric tons C)
Lubricants	3,100,000	44.6	69,130	33,411.93	35,718	0.99	32,079.40
Motor Gasoline	167,500,000	42.8	3,584,500		3,584,500	0.99	3,219,339.82
Natural Gas	11,100,000	31.9	177,045		177,045	0.995	159,812.15
Total	254,300,000						**4,843,408.72**
1994							
Aviation Gasoline	300,000	41.6	6,240		6,240	0.99	5,604.32
Distillate Fuel Oil	60,000,000	44.0	1,320,000		1,320,000	0.99	1,185,528.96
Jet Fuel	5,100,000	43.5	110,925		110,925	0.99	99,624.85
Liquefied Petroleum Gas	500,000	37.8	9,450		9,450	0.99	8,487.31
Lubricants	3,100,000	44.6	69,130	34,565.00	34,565	0.99	31,043.79
Motor Gasoline	164,700,000	42.8	3,524,580		3,524,580	0.99	3,165,523.99
Natural Gas	10,800,000	31.9	172,260		172,260	0.995	155,492.90
Total	244,500,000						**4,651,306.12**
1993			0		0		0.00
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	55,500,000	44.0	1,221,000		1,221,000	0.99	1,096,614.29
Jet Fuel	4,100,000	43.5	89,175		89,175	0.99	80,090.56
Liquefied Petroleum Gas	200,000	37.8	3,780		3,780	0.99	3,394.92
Lubricants	3,000,000	44.6	66,900	33,450.00	33,450	0.99	30,042.38
Motor Gasoline	158,500,000	42.8	3,391,900		3,391,900	0.99	3,046,360.36
Natural Gas	7,400,000	31.9	118,030		118,030	0.995	106,541.43
Total	229,100,000						**4,370,516.38**
1992							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	51,200,000	44.0	1,126,400		1,126,400	0.99	1,011,651.38
Jet Fuel	4,500,000	43.5	97,875		97,875	0.99	87,904.28
Liquefied Petroleum Gas	200,000	37.8	3,780		3,780	0.99	3,394.92
Lubricants	3,000,000	44.6	66,900	33,450.00	33,450	0.99	30,042.38
Motor Gasoline	152,900,000	42.8	3,272,060		3,272,060	0.99	2,938,728.70
Natural Gas	7,000,000	31.9	111,650		111,650	0.995	100,782.44
Total	219,200,000						**4,179,976.53**
1991							
Aviation Gasoline	400,000	41.6	8,320		8,320	0.99	7,472.42
Distillate Fuel Oil	49,200,000	44.0	1,082,400		1,082,400	0.99	972,133.75
Jet Fuel	5,000,000	43.5	108,750		108,750	0.99	97,671.42
Liquefied Petroleum Gas	200,000	37.8	3,780		3,780	0.99	3,394.92
Lubricants	2,900,000	44.6	64,670	32,335.00	32,335	0.99	29,040.97
Motor Gasoline	156,800,000	42.8	3,355,520		3,355,520	0.99	3,013,686.47
Natural Gas	6,700,000	31.9	106,865		106,865	0.995	96,463.19
Total	221,200,000						**4,219,863.14**
1990							
Aviation Gasoline	500,000	41.6	10,400		10,400	0.99	9,340.53
Distillate Fuel Oil	56,300,000	44.0	1,238,600		1,238,600	0.99	1,112,421.34
Jet Fuel	5,000,000	43.5	108,750		108,750	0.99	97,671.42
Liquefied Petroleum Gas	200,000	37.8	3,780		3,780	0.99	3,394.92
Lubricants	3,200,000	44.6	71,360	35,680.00	35,680	0.99	32,045.21
Motor Gasoline	157,000,000	42.8	3,359,800		3,359,800	0.99	3,017,530.45
Natural Gas	9,200,000	31.9	146,740		146,740	0.995	132,456.92
Total	231,400,000						**4,404,860.79**

*Motor gasoline as reported in the State Energy Data Report includes ethanol consumption.

Ethanol is a biofuel and as such is subtracted from the motor gasoline consumption in this spreadsheet.

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Electric Utilities Sector

	Input	Input	A x B / 2000	Input	C x D x .9072	(E x 2204.6) / A
	A	B	C	D	E	F
	Input	**Carbon Content Coefficient**	**Total Carbon**	**Fraction Oxidized**	**Net Carbon Emissions**	**Ia Electric Generation Emission Distribution Factor**
	(10^6 Btu)	**(lbs C/10^6 Btu)**	**(tons C)**		**(metric tons C)**	**Lbs C/ MBtu**
2000						
Natural Gas	4,700,000	31.9	74,965.00	0.995	67,668.21	
Coal 1/	374,900,000	56.0	10,495,495.91	0.99	9,426,298.75	
Petroleum	1,300,000	43.5	28,275.00	0.99	25,394.57	
Nuclear	46,400,000	0.0	0.00	NA	0.00	
Hydroelectric	9,200,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	436,700,000				**9,519,361.53**	**48.06**
1999						
Natural Gas	5,300,000	31.9	84,535.00	0.995	76,306.70	
Coal 1/	344,500,000	56.0	9,644,434.09	0.99	8,661,936.30	
Petroleum	1,700,000	43.5	36,975.00	0.99	33,208.28	
Nuclear	38,000,000	0.0	0.00	NA	0.00	
Hydroelectric	10,000,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	399,700,000				**8,771,451.29**	**48.38**
1998						
Natural Gas	6,000,000	31.9	95,700.00	0.995	86,384.94	
Coal 1/	346,000,000	55.9	9,672,272.73	0.99	8,686,938.96	
Petroleum	1,600,000	43.5	34,800.00	0.99	31,254.85	
Nuclear	39,500,000	0.0	0.00	NA	0.00	
Hydroelectric	9,800,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	403,100,000				**8,804,578.76**	**48.15**
1997						
Natural Gas	4,100,000	31.9	65,395.00	0.995	59,029.71	
Coal 1/	315,200,000	57.8	9,107,847.27	0.99	8,180,012.66	
Petroleum	1,200,000	43.5	26,100.00	0.99	23,441.14	
Nuclear	43,500,000	0.0	0.00	NA	0.00	
Hydroelectric	9,200,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	373,400,000				**8,262,483.51**	**48.78**
1996						
Natural Gas	3,400,000	31.9	54,230.00	0.995	48,951.47	
Coal 1/	309,300,000	57.8	8,937,364.09	0.99	8,026,896.94	
Petroleum	800,000	43.5	17,400.00	0.99	15,627.43	
Nuclear	41,200,000	0.0	0.00	NA	0.00	
Hydroelectric	9,500,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	364,400,000				**8,091,475.83**	**48.95**
1995						
Natural Gas	3,600,000	31.9	57,420.00	0.995	51,830.97	
Coal 1/	308,700,000	57.8	8,920,026.82	0.99	8,011,325.85	
Petroleum	900,000	43.5	19,575.00	0.99	17,580.86	
Nuclear	39,200,000	0.0	0.00	NA	0.00	
Hydroelectric	10,200,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	362,800,000				**8,080,737.67**	**49.10**
1994						
Natural Gas	2,700,000	31.9	43,065.00	0.995	38,873.23	
Coal 1/	291,000,000	57.7	8,392,704.55	0.99	7,537,722.95	
Petroleum	1,100,000	43.5	23,925.00	0.99	21,487.71	
Nuclear	42,900,000	0.0	0.00	NA	0.00	
Hydroelectric	10,900,000	0.0	0.00	NA	0.00	

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Electric Utilities Sector

	Input A	Input B	A x B / 2000 C	Input D	C x D x .9072 E	(E x 2204.6) / A F
	Input	**Carbon Content Coefficient**	**Total Carbon**	**Fraction Oxidized**	**Net Carbon Emissions**	**Ia Electric Generation Emission Distribution Factor**
	(10^6 Btu)	**(lbs C/10^6 Btu)**	**(tons C)**		**(metric tons C)**	**Lbs C/ MBtu**
Wood/Waste	300,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	348,900,000				**7,598,083.89**	**48.01**
1993						
Natural Gas	4,300,000	31.9	68,585.00	0.995	61,909.21	
Coal 1/	287,900,000	57.8	8,319,001.36	0.99	7,471,528.06	
Petroleum	700,000	43.5	15,225.00	0.99	13,674.00	
Nuclear	34,000,000	0.0	0.00	NA	0.00	
Hydroelectric	7,600,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	334,700,000				**7,547,111.27**	**49.71**
1992						
Natural Gas	2,300,000	31.9	36,685.00	0.995	33,114.23	
Coal 1/	272,300,000	57.6	7,838,526.82	0.99	7,040,000.41	
Petroleum	500,000	43.5	10,875.00	0.99	9,767.14	
Nuclear	35,700,000	0.0	0.00	NA	0.00	
Hydroelectric	10,100,000	0.0	0.00	NA	0.00	
Wood/Waste	100,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	321,000,000				**7,082,881.79**	**48.64**
1991						
Natural Gas	3,700,000	31.9	59,015.00	0.995	53,270.72	
Coal 1/	281,800,000	57.5	8,100,469.09	0.99	7,275,258.10	
Petroleum	600,000	43.5	13,050.00	0.99	11,720.57	
Nuclear	43,500,000	0.0	0.00	NA	0.00	
Hydroelectric	9,200,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	339,000,000				**7,340,249.39**	**47.74**
1990						
Natural Gas	3,500,000	31.9	55,825.00	0.995	50,391.22	
Coal 1/	272,600,000	57.5	7,832,293.64	0.99	7,034,402.22	
Petroleum	700,000	43.5	15,225.00	0.99	13,674.00	
Nuclear	31,900,000	0.0	0.00	NA	0.00	
Hydroelectric	8,900,000	0.0	0.00	NA	0.00	
Wood/Waste	200,000	0.0	0.00	NA	0.00	
Other	0	0.0	0.00	NA	0.00	
Total	317,800,000				**7,098,467.44**	**49.24**

NA = Not Applicable

1/ Emission Factor for coal taken from Appdx F of SEDR '99

2/ Interstate flows determined from the difference in Iowa retail sales and Iowa Net Generation and is multiplied by (1/1- National Rate Loss). In years with net imports, a U.S. electric generation carbon content is determined from EIA National Net Generation and National CO2 Emissions from Electric Generation (including losses due to inefficiencies) for each year

For years that electricity is imported, a national emission factor is used

For years that electricity is exported, a state emission factor is used

All Fuel Data refers to Higher Heat Value or Gross Caloric Value

Worksheet to Calculate Iowa CO_2 Emissions from Fossil Fuels, 1990- 2000

Net Interstate Flow of Electricity

	Input	Input	A x B / 2000	Input	C x D x .9072
	A	B	C	D	E
	Input	Carbon Content Coefficient	Total Carbon	Fraction Oxidized	Net Carbon Emissions
	(10^6 Btu)	(lbs C/10^6 Btu)	(tons C)		(metric tons C)
2000	-74,600,000	48.1	-1,794,130	0.99	-1,611,358
1999	-17,400,000	48.4	-421,080	0.99	-378,184
1998	-14,300,000	48.2	-344,630	0.99	-309,522
1997	4,200,000	48.8	102,480	0.99	92,040
1996	2,900,000	49	71,050	0.99	63,812
1995	-2,900,000	49.1	-71,195	0.99	-63,942
1994	-2,500,000	48	-60,000	0.99	-53,888
1993	4,900,000	49.7	121,765	0.99	109,361
1992	400,000	48.6	9,720	0.99	8,730
1991	-7,400,000	47.7	-176,490	0.99	-158,511
1990	1,700,000	49.2	41,820	0.99	37,560

FOSSIL FUEL COMBUSTION DARS SCORES

DARS SCORES: CO_2 FROM GASOLINE COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*9*	*The emission factor is based on a precise stoichiometric relationship.*	*9*	*Fuel purchases are measured using top-down statistics; states may have better data from tax records.*	*0.81*
Source Specificity	*10*	*The emission factor was developed specifically for gasoline combustion.*	*9*	*Fuel purchases are very closely correlated to the emissions process.*	*0.90*
Spatial Congruity	*9*	*U.S. emission factors are used, but the carbon coefficient for gasoline varies depending on its source.*	*9*	*States use state-level activity data to estimate state- wide emissions.*	*0.81*
Temporal Congruity	*9*	*The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.90*
				Composite Score	*0.86*

Note 1: The DARS scores for gasoline are used as a benchmark for determining DARS scores for other fuels.
Note 2: This inventory estimates gasoline emissions from the point of sale. The spacial DARS score would be lower if emissions were estimated based on VMT.

DARS SCORES: CO_2 FROM DISTILLATE FUEL OIL COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*9*	*The emission factor is based on a precise stoichiometric relationship.*	*9*	*Fuel purchases are measured using top-down statistics.*	*0.81*
Source Specificity	*9*	*The emission factor was developed specifically for distillate fuel oil combustion.*	*9*	*Fuel purchases are very closely correlated to the emissions process.*	*0.81*
Spatial Congruity	*9*	*U.S. emission factors are used, but the carbon coefficient for distillate fuel oil varies slightly depending on its source.*	*8*	*States use state-level activity data to estimate state- wide emissions, but there are minor cross-state sales by retailers.*	*0.72*
Temporal Congruity	*9*	*The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*9*	*States use annual activity data to estimate annual emissions.*	*0.81*
				Composite Score	0.79

DARS SCORES: CO_2 FROM RESIDUAL FUEL OIL COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*9*	*The emission factor is based on a precise stoichiometric relationship.*	*9*	*Fuel purchases are measured using top-down statistics.*	*0.81*
Source Specificity	*8*	*The emission factor was developed specifically for residual fuel oil combustion, but residual fuel can be more or less dense, depending on how the refinery is run.*	*9*	*Fuel purchases are very closely correlated to the emissions process.*	*0.72*
Spatial Congruity	*8*	*U.S. emission factors are used, but the carbon coefficient for residual fuel varies slightly depending on its source.*	*9*	*States use state-level activity data to estimate state-wide emissions.*	*0.72*
Temporal Congruity	*8*	*i he emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, the emission factor may vary over the course of a year.*	*9*	*States use annual activity data to estimate annual emissions.*	*0.72*
				Composite Score	*0.74*

DARS SCORES: CO_2 FROM COMBUSTION OF JET FUEL					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*9*	*The emission factor is based on a precise stoichiometric relationship.*	*9*	*Fuel purchases are measured using top-down statistics.*	*0.81*
Source Specificity	*10*	*The emission factor was developed specifically for jet fuel combustion.*	*9*	*Fuel purchases are very closely correlated to the emissions process.*	*0.90*
Spatial Congruity	*9*	*U.S. emission factors are used, but the carbon coefficient for jet fuel varies slightly depending on its source.*	*7*	*States use state-level activity data to estimate state- wide emissions. However, jet fuel is generally not burned where it is bought.*	*0.63*
Temporal Congruity	*10*	*T he emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, jet fuel is a relatively homogenous product, and the emission factor should not vary over the course of a year.*	*10*	*States use annual activity data to estimate annual emissions, and jet fuel is typically combusted in the year in which it is purchased.*	*1.00*
				Composite Score	*0.84*

DARS SCORES: CO_2 FROM KEROSENE COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*9*	*The emission factor is based on a precise stoichiometric relationship.*	*9*	*Fuel purchases are measured using top-down statistics.*	*0.81*
Source Specificity	*9*	*The emission factor was developed specifically for kerosene combustion.*	*9*	*Fuel purchases are very closely correlated to the emissions process.*	*0.81*
Spatial Congruity	*9*	*U.S. emission factors are used, but the carbon coefficient for kerosene varies slightly depending on its source.*	*9*	*States use state-level activity data to estimate state- wide emissions.*	*0.81*
Temporal Congruity	*9*	*The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*9*	*States use annual activity data to estimate annual emissions.*	*0.81*
				Composite Score	*0.81*

DARS SCORES: CO2 EMISSIONS FROM COMBUSTION OF LIQUIFIED PETROLEUM GAS					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	9	*The emission factor is based on a precise stoichiometric relationship.*	9	*Fuel purchases are measured using top-down statistics.*	0.81
Source Specificity	6	*The emission factor is based on the emission factors for the three products collectively known as LPG—propane, butane and ethane—and the national proportions of their use. In addition, although the amount of propane used each year for heating will vary, the emission factor is not changed each year.*	9	*Fuel purchases are very closely correlated to the emissions process.*	0.54
Spatial Congruity	9	*U.S. emission factors are used, but the carbon coefficient for each product in LPG varies slightly depending on its source.*	8	*States use state-level activity data to estimate statewide emissions.*	0.72
Temporal Congruity	9	*The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, the emission factor was assumed not to vary significantly over the course of a year.*	8	*States use annual activity data to estimate annual emissions.*	0.72
				Composite Score	0.70

Note 1: Data on sales of propane, butane, and ethane (which make up LPG) are available from the American Petroleum Institute. Note 2: Some ethane is used as a feedstock.

DARS SCORES: CO_2 FROM NATURAL GAS COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*10*	*The emission factor is based on a precise stoichiometric relationship.*	*8*	*Fuel purchases are measured using top-down statistics.*	*0.80*
Source Specificity	*10*	*The emission factor was developed specifically for natural gas combustion.*	*9*	*Fuel purchases are very closely correlated to the emissions process.*	*0.90*
Spatial Congruity	*10*	*Natural gas from different sources is very homogenous in the amount of carbon per BTU.*	*8*	*States use state-level activity data to estimate state-wide emissions.*	*0.80*
Temporal Congruity	*10*	*The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, natural gas produced at different times is very homogenous in the amount of carbon per BTU.*	*10*	*States use annual activity data to estimate annual emissions, and natural gas is typically combusted in the year in which it is purchased.*	*1.00*
				Composite Score	*0.88*

Note: The ratings ***shown here*** *are for measurements of natural gas based on BTU* ***content,*** *not measurements based on volume.*

DARS SCORES: CO_2 FROM COAL COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	8	*The emission factor is based on a stoichiometric relationship, but a variety of coal types are used.*	8	*Fuel purchases are measured using top-down statistics.*	0.64
Source Specificity	8	*The emission factor was developed specifically for coal combustion.*	8	*Fuel purchases are closely correlated to the emissions process. However, data are not available for the consumption of coal by rank for industrial, commercial, or residential consumers.*	0.64
Spatial Congruity	8	*U.S. emission factors are used, but the carbon coefficient for coal varies depending on the source of the coal.*	8	*States use state-level activity data to estimate state- wide emissions.*	0.64
Temporal Congruity	8	*1 he emission factor is based on stoichiometry, not on measured emissions over a particular time frame. The emission factor may vary over the course of a year.*	8	*States use annual activity data to estimate annual emissions.*	0.64
				Composite Score	0.64

Note: The emission factor scores are for state-specific emission factors (i.e., emission factors developed for the state in which the coal was produced).

DARS SCORES: CO_2 FROM OXIDATION OF LUBRICANTS					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*7*	*The emission factor is based on a stoichiometric relationship for one component of lubricants (i.e., motor oil).*	*4*	*Sales of lubricants in each state are based on national sales and each state's 1977 proportion of national sales. Oxidation of lubricants is approximated as a percentage of lubricant sales.*	*0.28*
Source Specificity	*8*	*The emission factor for oxidation of lubricants (a category comprising motor oil and other products) is based on the factor for motor oil alone; however, the range in emission factors for the different products is small.*	*8*	*Lubricant purchases are correlated to the emissions process.*	*0.64*
Spatial Congruity	9	*U.S. emission factors are used, but the carbon coefficient for each product in the "lubricants" category varies slightly depending on its source.*	*9*	*States use state-level activity data to estimate state- wide emissions.*	*0.81*
Temporal Congruity	*8*	*The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. The emission factor may vary over the course of a year.*	*9*	*States use annual activity data to estimate annual emissions.*	*0.72*
				Composite Score	*0.61*

DARS SCORES: CO_2 FROM COMBUSTION OF MISCELLANEUS PETROLUEM PRODUCTS					
	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	6	The emission factor is based on a stoichiometric relationship. A number of products are included in the "miscellaneous petroleum products" category. Moreover, the relationship is based on highly uncertain storage factors for the various products.	7	Fuel purchases are presumed to be measured using top-down statistics.	0.42
Source Specificity	4	Because of the number of products in the "miscellaneous petroleum products" category, the emission factor is not specific to any given product. Storage is estimated for broad categories of products.	8	Fuel purchases are correlated to the emissions process.	0.32
Spatial Congruity	6	U.S. emission factors are used, but the carbon coefficient for each product in "miscellaneous petroleum products" varies depending on its source.	6	States use state-level activity data to estimate state- wide emissions, but some products may be used out of state.	0.36
Temporal Congruity	7	The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. The emission factor is expected to vary over the course of a year.	8	States use annual activity data to estimate annual emissions.	0.56
				Composite Score	0.42

II. CH_4 and N_2O from Stationary Combustion of Fossil Fuels

For nitrous oxide emissions from stationary combustion sources, the analysis is largely similar to the methods in the previous section. Emissions are determined by multiplying fuel use for each sector by an emission factor provided by the EIIP. The transportation sector was excluded from this analysis because its emissions are estimated in the method for mobile combustion. For this section, it was only necessary to disaggregate fuel into three categories; coal, oil and natural gas as the small amount of nitrous oxide that is emitted from stationary sources are similar within these categories. In order to be consistent with internationally accepted methods, fuel consumption is considered as lower heating value or net calorific value. EIA reports fuel consumption as gross calorific value or higher heating value. The difference is the heat that is lost during the evaporation of moisture contained in the fuel. It was necessary to make this conversion assuming that petroleum products and coal have a lower heating value that is 95% of the higher heating value. For natural gas that contains more moisture the net heating value is 90% of the higher heating value.

Total N_2O Emissions from Stationary Combustion by Sector

	Year	Utility Sector MTCE	Industrial Sector MTCE	Commercial Sector MTCE	Residential Sector MTCE	Total MTCE
Coal	**2000**	43.70	7.48	0.71	0.08	51.97
	1999	40.16	7.76	0.96	0.13	49.00
	1998	40.33	7.86	0.69	0.08	48.96
	1997	36.74	8.03	0.91	0.12	45.80
	1996	36.05	8.01	0.56	0.08	44.70
	1995	35.98	6.99	0.22	0.03	43.23
	1994	33.92	6.71	0.09	0.01	40.74
	1993	33.56	6.19	0.16	0.03	39.95
	1992	31.74	6.17	0.15	0.03	38.09
	1991	32.85	6.53	0.52	0.10	40.00
	1990	31.77	6.19	0.56	0.13	38.65
Oil	**2000**	0.07	6.06	0.46	1.13	7.71
	1999	0.09	5.98	0.42	1.12	7.60
	1998	0.08	5.52	0.40	0.94	6.94
	1997	0.06	4.78	0.38	1.15	6.37
	1996	0.04	4.50	0.35	1.22	6.11
	1995	0.05	5.18	0.27	0.99	6.49
	1994	0.06	5.28	0.26	1.02	6.61
	1993	0.04	4.83	0.41	0.98	6.26
	1992	0.03	3.80	0.44	0.87	5.14
	1991	0.03	3.08	0.47	0.89	4.48
	1990	0.04	2.96	0.30	0.75	4.04
Natural Gas	**2000**	0.03	0.70	0.32	0.51	1.56
	1999	0.04	0.72	0.32	0.50	1.57
	1998	0.04	0.74	0.30	0.48	1.56
	1997	0.03	0.75	0.35	0.57	1.69
	1996	0.02	0.79	0.38	0.61	1.81
	1995	0.02	0.80	0.35	0.57	1.74
	1994	0.02	0.76	0.33	0.54	1.65
	1993	0.03	0.71	0.35	0.58	1.67
	1992	0.02	0.70	0.32	0.52	1.55
	1991	0.03	0.68	0.32	0.55	1.58
	1990	0.02	0.63	0.31	0.50	1.45

Commercial N_2O Emissions from Stationary Combustion

	A	B	C	D	E	F	G
	input	input	A x B	input	C x D	E/ 2205	F x 310 x (12/44)
	Coal Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	6,100	0.95	5795	0.0032	18.54	0.01	0.71
1999	8,200	0.95	7790	0.0032	24.93	0.01	0.96
1998	5,900	0.95	5605	0.0032	17.94	0.01	0.69
1997	7,800	0.95	7410	0.0032	23.71	0.01	0.91
1996	4,800	0.95	4560	0.0032	14.59	0.01	0.56
1995	1,900	0.95	1805	0.0032	5.78	0.00	0.22
1994	800	0.95	760	0.0032	2.43	0.00	0.09
1993	1,400	0.95	1330	0.0032	4.26	0.00	0.16
1992	1,300	0.95	1235	0.0032	3.95	0.00	0.15
1991	4,500	0.95	4275	0.0032	13.68	0.01	0.52
1990	4,800	0.95	4560	0.0032	14.59	0.01	0.56

	Oil Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	9,000	0.95	8550	0.0014	11.97	0.01	0.46
1999	8,200	0.95	7790	0.0014	10.91	0.00	0.42
1998	7,800	0.95	7410	0.0014	10.37	0.00	0.40
1997	7,500	0.95	7125	0.0014	9.98	0.00	0.38
1996	6,800	0.95	6460	0.0014	9.04	0.00	0.35
1995	5,300	0.95	5035	0.0014	7.05	0.00	0.27
1994	5,100	0.95	4845	0.0014	6.78	0.00	0.26
1993	8,000	0.95	7600	0.0014	10.64	0.00	0.41
1992	8,700	0.95	8265	0.0014	11.57	0.01	0.44
1991	9,300	0.95	8835	0.0014	12.37	0.01	0.47
1990	5,800	0.95	5510	0.0014	7.71	0.00	0.30

	Natural Gas Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	45,800	0.9	41220	0.0002	8.24	0.00	0.32
1999	45,800	0.9	41220	0.0002	8.24	0.00	0.32
1998	43,500	0.9	39150	0.0002	7.83	0.00	0.30
1997	50,600	0.9	45540	0.0002	9.11	0.00	0.35
1996	54,900	0.9	49410	0.0002	9.88	0.00	0.38
1995	50,600	0.9	45540	0.0002	9.11	0.00	0.35
1994	48,300	0.9	43470	0.0002	8.69	0.00	0.33
1993	50,500	0.9	45450	0.0002	9.09	0.00	0.35
1992	46,300	0.9	41670	0.0002	8.33	0.00	0.32
1991	47,000	0.9	42300	0.0002	8.46	0.00	0.32
1990	44,300	0.9	39870	0.0002	7.97	0.00	0.31

Residential N_2O Emissions from Stationary Combustion

	A	B	C	D	E	F	G
	input	input	A x B	input	C x D	E/ 2205	F x 310 x (12/44)
	Coal Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	700	0.95	665	0.0032	2.13	0.00	0.08
1999	1,100	0.95	1045	0.0032	3.34	0.00	0.13
1998	700	0.95	665	0.0032	2.13	0.00	0.08
1997	1,000	0.95	950	0.0032	3.04	0.00	0.12
1996	700	0.95	665	0.0032	2.13	0.00	0.08
1995	300	0.95	285	0.0032	0.91	0.00	0.03
1994	100	0.95	95	0.0032	0.30	0.00	0.01
1993	300	0.95	285	0.0032	0.91	0.00	0.03
1992	300	0.95	285	0.0032	0.91	0.00	0.03
1991	900	0.95	855	0.0032	2.74	0.00	0.10
1990	1,100	0.95	1045	0.0032	3.34	0.00	0.13

	Oil Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	22,100	0.95	20995	0.0014	29.39	0.01	1.13
1999	21,900	0.95	20805	0.0014	29.13	0.01	1.12
1998	18,400	0.95	17480	0.0014	24.47	0.01	0.94
1997	22,500	0.95	21375	0.0014	29.93	0.01	1.15
1996	24,000	0.95	22800	0.0014	31.92	0.01	1.22
1995	19,400	0.95	18430	0.0014	25.80	0.01	0.99
1994	20,000	0.95	19000	0.0014	26.60	0.01	1.02
1993	19,200	0.95	18240	0.0014	25.54	0.01	0.98
1992	17,000	0.95	16150	0.0014	22.61	0.01	0.87
1991	17,500	0.95	16625	0.0014	23.28	0.01	0.89
1990	14,700	0.95	13965	0.0014	19.55	0.01	0.75

	Natural Gas Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	74,200	0.9	66780	0.0002	13.36	0.01	0.51
1999	72,800	0.9	65520	0.0002	13.10	0.01	0.50
1998	69,700	0.9	62730	0.0002	12.55	0.01	0.48
1997	82,400	0.9	74160	0.0002	14.83	0.01	0.57
1996	88,600	0.9	79740	0.0002	15.95	0.01	0.61
1995	82,600	0.9	74340	0.0002	14.87	0.01	0.57
1994	78,900	0.9	71010	0.0002	14.20	0.01	0.54
1993	83,700	0.9	75330	0.0002	15.07	0.01	0.58
1992	75,200	0.9	67680	0.0002	13.54	0.01	0.52
1991	79,400	0.9	71460	0.0002	14.29	0.01	0.55
1990	71,900	0.9	64710	0.0002	12.94	0.01	0.50

Industrial N_2O Emissions from Stationary Combustion

	A	B	C	D	E	F	G
	input	input	A x B	input	C x D	E/ 2205	F x 310 x (12/44)
	Coal Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	64,200	0.95	60,990	0.0032	195.17	0.089	7.48
1999	66,600	0.95	63,270	0.0032	202.46	0.092	7.76
1998	67,400	0.95	64,030	0.0032	204.90	0.093	7.86
1997	68,900	0.95	65,455	0.0032	209.46	0.095	8.03
1996	68,700	0.95	65,265	0.0032	208.85	0.095	8.01
1995	60,000	0.95	57,000	0.0032	182.40	0.083	6.99
1994	57,600	0.95	54,720	0.0032	175.10	0.079	6.71
1993	53,100	0.95	50,445	0.0032	161.42	0.073	6.19
1992	52,900	0.95	50,255	0.0032	160.82	0.073	6.17
1991	56,000	0.95	53,200	0.0032	170.24	0.077	6.53
1990	53,100	0.95	50,445	0.0032	161.42	0.073	6.19

	Oil Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	118,800	0.95	112,860	0.0014	158.0	0.072	6.06
1999	117,300	0.95	111,435	0.0014	156.0	0.071	5.98
1998	108,300	0.95	102,885	0.0014	144.0	0.065	5.52
1997	93,800	0.95	89,110	0.0014	124.8	0.057	4.78
1996	88,200	0.95	83,790	0.0014	117.3	0.053	4.50
1995	101,600	0.95	96,520	0.0014	135.1	0.061	5.18
1994	103,500	0.95	98,325	0.0014	137.7	0.062	5.28
1993	94,800	0.95	90,060	0.0014	126.1	0.057	4.83
1992	74,600	0.95	70,870	0.0014	99.2	0.045	3.80
1991	60,400	0.95	57,380	0.0014	80.3	0.036	3.08
1990	58,100	0.95	55,195	0.0014	77.3	0.035	2.96

	Natural Gas Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	100,900	0.9	90,810	0.0002	18.2	0.008	0.70
1999	103,900	0.9	93,510	0.0002	18.7	0.008	0.72
1998	107,100	0.9	96,390	0.0002	19.3	0.009	0.74
1997	108,400	0.9	97,560	0.0002	19.5	0.009	0.75
1996	114,700	0.9	103,230	0.0002	20.6	0.009	0.79
1995	115,700	0.9	104,130	0.0002	20.8	0.009	0.80
1994	109,600	0.9	98,640	0.0002	19.7	0.009	0.76
1993	102,900	0.9	92,610	0.0002	18.5	0.008	0.71
1992	101,200	0.9	91,080	0.0002	18.2	0.008	0.70
1991	98,200	0.9	88,380	0.0002	17.7	0.008	0.68
1990	90,900	0.9	81,810	0.0002	16.4	0.007	0.63

Electric Utility N_2O Emissions from Stationary Combustion

	A	B	C	D	E	F	G
	input	input	A x B	input	C x D	E/ 2205	F x 310 x (12/44)
	Coal Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	374,900	0.95	356,155	0.0032	1,139.70	0.52	43.70
1999	344,500	0.95	327,275	0.0032	1,047.28	0.47	40.16
1998	346,000	0.95	328,700	0.0032	1,051.84	0.48	40.33
1997	315,200	0.95	299,440	0.0032	958.21	0.43	36.74
1996	309,300	0.95	293,835	0.0032	940.27	0.43	36.05
1995	308,700	0.95	293,265	0.0032	938.45	0.43	35.98
1994	291,000	0.95	276,450	0.0032	884.64	0.40	33.92
1993	287,900	0.95	273,505	0.0032	875.22	0.40	33.56
1992	272,300	0.95	258,685	0.0032	827.79	0.38	31.74
1991	281,800	0.95	267,710	0.0032	856.67	0.39	32.85
1990	272,600	0.95	258,970	0.0032	828.70	0.38	31.77

	Oil Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	1,300	0.95	1,235	0.0014	1.73	0.00	0.07
1999	1,700	0.95	1,615	0.0014	2.26	0.00	0.09
1998	1,600	0.95	1,520	0.0014	2.13	0.00	0.08
1997	1,200	0.95	1,140	0.0014	1.60	0.00	0.06
1996	800	0.95	760	0.0014	1.06	0.00	0.04
1995	900	0.95	855	0.0014	1.20	0.00	0.05
1994	1,100	0.95	1,045	0.0014	1.46	0.00	0.06
1993	700	0.95	665	0.0014	0.93	0.00	0.04
1992	500	0.95	475	0.0014	0.67	0.00	0.03
1991	600	0.95	570	0.0014	0.80	0.00	0.03
1990	700	0.95	665	0.0014	0.93	0.00	0.04

	Natural Gas Consumption	**Conversion factor to Lower Heat Value**	**Lower Heat Value**	**Emission Factor**	**Emissions N_2O**	**Emissions N_2O**	**Emissions N_2O**
	(Million Btu)		**(Million Btu)**	**(lbs N_2O/ 10^6 Btu)**	**(lbs N_2O)**	**(Metric Tons N_2O)**	**(MTCE)**
2000	4,700	0.90	4,230	0.0002	0.85	0.00	0.03
1999	5,300	0.90	4,770	0.0002	0.95	0.00	0.04
1998	6,000	0.90	5,400	0.0002	1.08	0.00	0.04
1997	4,100	0.90	3,690	0.0002	0.74	0.00	0.03
1996	3,400	0.90	3,060	0.0002	0.61	0.00	0.02
1995	3,600	0.90	3,240	0.0002	0.65	0.00	0.02
1994	2,700	0.90	2,430	0.0002	0.49	0.00	0.02
1993	4,300	0.90	3,870	0.0002	0.77	0.00	0.03
1992	2,300	0.90	2,070	0.0002	0.41	0.00	0.02
1991	3,700	0.90	3,330	0.0002	0.67	0.00	0.03
1990	3,500	0.90	3,150	0.0002	0.63	0.00	0.02

STATIONARY COMBUSTION SOURCES DARS SCORES

DARS SCORES: N2O EMISSIONS FROM STATIONARY SOURCE COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*The emission factors are based on measurements at a representative sample of stationary source combustion facilities, but have large uncertainty ranges (Dc Soete, 1 993)*	*9*	*Fuel purchases are measured using top-down statistics.*	*0.45*
Source Specificity	*7*	*The emission factors were developed specifically for the intended source category, but do not account for different emission rates from various combustion technologies.*	*5*	*Fuel purchases are somewhat correlated to the emissions process.*	*0.35*
Spatial Congruity	*9*	*The emission factors were developed for global use, but spatial variability is expected to be low.*	*8*	*States use state-level activity data to estimate state-wide emissions, but there are minor cross-state sales by retailers.*	*0.72*
Temporal Congruity	*8*	*The emissions factors were derived using sampling for only part of a year, but temporal variability is expected to be low.*	*9*	*States use annual activity data to estimate annual emissions.*	*0.72*
				Composite Score	*0.56*

III. CH_4 and N_2O from Mobile Combustion of Fossil Fuels

The processes that result in these gases are slightly less straightforward than in the previous section. Each vehicle will emit different amounts of each gas based on fuel type, engine design, age and emission control technologies. For instance, a motorcycle will not produce the same emissions per mile as a tractor-trailer. Fundamentally, they have different engines, different fuels, and different emission control technologies. For this reason, it was necessary to define vehicle emission categories (VEC), which were used to sort the entire vehicle fleet. The VECs were relatively congruent with vehicle type categories (VTC) that are used by Departments of Transportation (DOT).

In this method there are seven VECs including motorcycles, light duty gas vehicles, light duty gas trucks, light duty diesel vehicles, light duty diesel trucks, heavy-duty gas vehicles, and heavy-duty diesel vehicles. These are not to be confused with vehicle type categories (VTC), which are used by the Federal Highway Administration and DOT to identify the difference in the type of vehicle (i.e. passenger car vs. bus). The table below shows each VEC definition and the corresponding Iowa DOT VTC. It should be noted that one VTC may fall under more than one VEC. For instance "Automobiles and Multipurpose Vehicles" can fall under both "Light Duty Gas Vehicles" and "Light Duty Diesel Vehicles." Recognizing this will make understanding of the estimation method easier later on.

Vehicle Emission Categories	IA DOT Vehicle Type Category (VTC)	Vehicle Emission Category (VEC) Definition
Motorcycles (MC)	Motorcycles, Motorized Bike	
Light Duty Gas Vehicles (LDGV)	Automobiles and Multipurpose Vehicles	Powered by gasoline, rated gross vehicle weight less than 8,500 lbs, designed for transport of 12 or fewer passengers, no 4-wheel drive, no off-road abilities (ex: passenger cars)
Light Duty Gas Trucks (LDGT)	Trucks (3 and 4 ton)	Powered by gasoline, single unit 2 axle, rated gross vehicle weight less than 8,500 lbs, designed for cargo or transport of more than 11 passengers, off-road abilities (ex: most pickup trucks, passenger and cargo vans, and four-wheel drive vehicles)
Light Duty Diesel Vehicles (LDDV)	Automobiles and Multipurpose Vehicles	Powered by diesel, rated gross vehicle weight less than 8,500 lbs, designed for transport of 12 or fewer passengers, no 4-wheel drive, no off-road abilities (ex: passenger cars)
Light Duty Diesel Truck (LDDT)	Trucks (3 and 4 ton)	Powered by diesel, single unit 2 axle, rated gross vehicle weight less than 8,500 lbs, designed for cargo or transport of more than 11 passengers, off-road abilities (ex: most pickup trucks, passenger and cargo vans, and four-wheel drive vehicles)

Heavy Duty Gas Vehicles (HDGV)	Trucks (5 tons and greater), Truck Tractors, Tractors, Buses, Motor homes	Powered by gasoline, single unit 2 axle truck with 6 or more tires, rated gross vehicle weight greater than 8,500 lbs., (ex: large pickups and vans, specialized trucks using pickup and van chassis, larger "true" heavy duty trucks with gross vehicle weight of 8 tons or more)
Heavy Duty Diesel Vehicles (HGDV)	Trucks (5 tons and greater), Truck Tractors, Tractors, Buses, Motorhomes	Powered by diesel, buses and combination trucks (with single or multiple trailers), rated gross vehicle weight greater than 8,500 lbs., (ex: large trucks with gross vehicle weight ratings of 10 to 40 tons)

Within each VEC there were between one and six types of emission control technologies (CT) that were modeled while some older vehicles have no emission controls. Depending on the CT device, vehicles will produce greater or lesser emission. Generally, with the progress of technology, modern vehicles have more advanced CTs that prevent large emissions and older vehicles tend to have greater emissions.

The emission estimation method involved two broad steps. The first step was to determine the distance traveled in Iowa by vehicles in each VEC. The second step built on the first and involved using Iowa vehicle registration data along with VEC travel data to determine emissions.

The first step determines how much travel was done by each VEC and on what type of road systems. Data from the Federal Highway Administration (FHA) which detailed travel in Iowa by VTC, distance and road type (functional system) was used (Jeff Patten, Federal Highway Administration, personal contact August 15, 2002). The EIIP also provided state specific fractions of travel that facilitated translation of estimates of travel by VTC to estimates of travel by VEC (Noam Glick, ICF Consulting, personal contact, August 19, 2002). These translation fractions break up the distance traveled by a single VTC into the distance traveled by one or more VECs. For instance, the VTC "buses" can be broken into two separate VECs, "HDGV" and "HDDV." The EPA data estimated that in Iowa 5.99% of bus travel is carried out in vehicles falling under the category HDGV and 94.01% is in buses that are HDDVs (see columns K and L on the

It is recommended that for ease of understanding, the reader refer to the worksheet worksheet titled "Worksheet to Calculate Distance Traveled by Vehicle Emission Category." Total distance traveled on each road type (column A) was multiplied by the vehicle type travel fraction (columns B,E,I,M,Q) for each road type to result in the estimation of total distance traveled by VTC (columns C, F, J, N, R). The translation fractions were applied to the resulting distances to sort the VTC by VECs (columns D,G,H,K,L,O,P,S).

One unique case to note is that Iowa, unlike other states, aggregates passenger cars and light trucks when reporting to the FHA. For this reason, LDGV and LDGT had to be aggregated, as were the similar diesel categories. The translation fraction applied was the average of the fractions for the combine categories. The categories were separated below with the use of EPA MOBILE5 default fractions found in the table 13.4-1 of the Emission Inventory Improvement Program Volume VIII method (1998).

The methodology provides MOBILE5 default fractions that estimate the fraction of total travel that each VEC performs. Light duty gas vehicles that are shown account for 63.6% of the total travel in the United States. Light duty gas trucks account for 26% of total distance traveled. Together these two categories or all light duty gas sources travel 89.6% of the total distance traveled. Of this aggregate distance LDGV travel 71% and LDGT travel 29%. These percentages were applied to the aggregation of light duty gas sources to separate them into LDGV and LDGT. A similar procedure was performed to separate diesel sources.

Once the first step was complete travel distances were established for each VEC, the second step proceeded by obtaining the number and VTC of vehicles in Iowa in order to sort by emission control technology (CT) and estimate the distance traveled by vehicles with each CT. From that distance, emissions were calculated.

Obtaining data vehicle counts for the inventory year was not possible. Instead Iowa vehicle registration data was requested and granted from the Iowa DOT. The department provided unpublished records of 2002 vehicle registration counts. Names and personal information of registrants were not included in the data. The 6.2 million registration records were counted and tallied by vehicle type codes, weight class for trucks, fuel type, and model year. Fifteen percent of registrations could not be counted because they were extensively incomplete. However, not all of the 5.3 million records that were tallied were complete either. Three percent of the 5.3 million records were missing information for either or both of the attributes, fuel type and/or weight class. For these records adjustments were made based on assumptions drawn from the complete records so they could be counted.

For the 144,159 records missing only fuel type, a proxy count was taken from the complete records of the same vehicle type, model year and weight class for trucks. The fraction of each fuel type was applied to the incomplete records and they were included in the final counts. For the 16,175 truck records missing only weight class a similar procedure was followed. The proxy counts included both the complete records and the records adjusted with fuel proxy. For the 4,240 truck records missing both fuel type and weight class, the same procedure was followed to first determine the fuel type then to determine the weight class. For these proxies the previously adjusted records were also included.

Once tallies were made by VTC, fuel type, weight class (for trucks) and model years, emissions could be estimated. Counts by Iowa DOT VTCs were matched up to VECs. For each VEC a worksheet was designed to aid in emission estimation. At this point, emission estimation is based on 2 attributes. These are 1) the emission control technologies (CT) installed in vehicles and 2) the distance that is traveled by vehicles with each CT. There were six recognized CTs for the model that was used. Generally, the CTs installed in new vehicles are improved with time. Though, the improvement is not necessarily seen in CH_4 or N_2O emissions. Some newer technologies actually increase these emissions. So it is important to sort the vehicles by CT. This was done by first sorting by model year, and then applying the EIIP provided CT fractions to determine how many vehicles have each CT. From here the fraction of the number of total vehicles with each CT is applied to the total vehicle kilometers traveled (VKT) (which was determined on the worksheet to calculate distance traveled by vehicle emission categories) to determine the VKT traveled by vehicles with each CT. This distance is then multiplied by the provided emission factor to estimate emissions.

2002 Total Emissions From Iowa Mobile Sources

	CH_4	N_20
VEC	(g)	(g)
LDGV	1,148,130,892	1,110,994,809
LDDV	4,716,671	4,716,671
LDGT	790,726,592	598,213,335
LDDT	2,354,790	4,709,581
HDGV	160,144,800	123,485,973
HDDV	285,959,338	190,820,809
MC	89,406,938	1,857,626
Totals		
Grams	2,481,440,023	2,034,798,804
Metric Tons	2,481	2,035
MTCE	14,212	172,033

Worksheet to Calculate Distance Traveled by Vehicle Emission Categories

Column ID	A	B	C	D	E	F	G	H	I	J
Calculation	input	input	A x B	C x 1.0	input	A x E	F x .9822	F x 0.0179	input	A x I
		Motorcycles (MC)			Passenger Cars/ Light Duty Trucks (LDG, LDD)				Buses (HDGV	
	IA Total Distance Traveled by Functional System[a]	**Vehicle Type Travel Fraction for Motorcycles[b]**	**Total Distance Traveled by Motorcycles**	**Distance Traveled by MC_c**	**Vehicle Type Travel Fraction for Passenger Cars and Light Trucks[b]**	**Total Distance Traveled by Passenger Cars and Light Trucks**	**Distance Traveled by Passenger Cars/Lgt Trucks as LDG[c]**	**Distance Traveled by Passenger Cars/Lgt Trucks as LDD[c]**	**Vehicle Type Travel Fraction for Buses[b]**	**Total Distance Traveled by Buses**
	million km		**million km**	**million km**		**million km**	**million km**	**million km**		**million km**
Rural Interstate	7,112	0.005	36	36	0.596	4,239	4,163	76	0.004	28
Arterial	8,442	0.010	84	84	0.811	6,846	6,724	123	0.003	25
Rural Minor Arterial	4,366	0.011	48	48	0.879	3,838	3,770	69	0.002	9
Collector*	6,072	0.011	67	67	0.879	5,337	5,242	96	0.002	12
Collector*	1,446	0.011	16	16	0.879	1,271	1,249	23	0.002	3
Rural Local*	2,619	0.011	29	29	0.879	2,302	2,261	41	0.002	5
Urban Interstate	3,490	0.007	24	24	0.825	2,879	2,828	52	0.003	10
Urban Other Freeways and Expressways	0	0.000	0	0	0.000	0	0	0	0.000	0
Urban Other Principal Arterial	4,739	0.007	33	33	0.895	4,242	4,166	76	0.003	14
Urban Minor Arterial	4,658	0.006	28	28	0.971	4,523	4,442	81	0.004	19
Urban Collector**	1,405	0.006	8	8	0.971	1,364	1,340	24	0.004	6
Urban Local**	2,744	0.006	16	16	0.971	2,664	2,617	48	0.004	11

Vehicle Emission Category Distance Totals			
390		38,802	707
MC		LDG	LDD

27,550	11,253	467	235
LDGV	LDGT	LDDV	LDDT

[a] Data from Federal Highway Statistics 2000 Table VM-2, *Vehicle Miles of Travel by Functional System*

[b] Source: Jeff Patten, Federal Highway Administration, personal contact, August 15, 2002
information was previously found in table VM-4 of the *Highway Statistics* from the Federal Highway Administration.

[c] Source: Noam Glick, ICF Consulting, personal contact, August 19, 2002

Column ID	K	L	M	N	O	P	Q	R	S
Calculation	J x 0.0599	J x 0.9401	input	A x M	N x 0.4214	N x 0.5786	input	A x Q	R x 1.0
	, HDDV)		Single Unit Trucks (HDGV, HDDV)				Combination Trucks (HDDV)		
	Distance Traveled by Buses as HDGV[c]	**Distance Traveled by Buses as HDDV**[c]	**Vehicle Type Travel Fraction for Single Unit 2 axle 6 tire or more Trucks**[b]	**Total Distance Traveled by Single Unit 2 axle 6 tire or more Trucks**	**Distance Traveled by Single Unit Trucks as HDGV**[c]	**Distance Traveled by Single Unit Trucks as HDDV**[c]	**Vehicle Type Travel Fraction for Combo Trucks**[b]	**Total Distance Traveled by Combo Trucks**	**Distance Traveled by Combo Trucks as HDDV**[c]
	million km	**million km**		**million km**	**million km**	**million km**		**million km**	**million km**
Rural Interstate	2	27	0.042	299	126	173	0.353	2,511	2,511
Arterial	2	24	0.055	464	196	269	0.121	1,021	1,021
Rural Minor Arterial	1	8	0.053	231	98	134	0.055	240	240
Collector*	1	11	0.053	322	136	186	0.055	334	334
Collector*	0	3	0.053	77	32	44	0.055	80	80
Rural Local*	0	5	0.053	139	58	80	0.055	144	144
Urban Interstate	1	10	0.028	98	41	57	0.137	478	478
Urban Other Freeways and Expressways	0	0	0.000	0	0	0	0.000	0	0
Urban Other Principal Arterial	1	13	0.043	204	86	118	0.052	246	246
Urban Minor Arterial	1	18	0.015	70	29	40	0.004	19	19
Urban Collector**	0	5	0.015	21	9	12	0.004	6	6
Urban Local**	1	10	0.015	41	17	24	0.004	11	11
	9	134			828	1,137			5,089
	HDGV	HDDV			HDGV	HDDV			HDDV

Demonstration of Calculations for Estimation of CH4 and N2O Emissions from Mobile Sources

		Fraction of Vehicles with Control Technologies (CT)		Number of Vehicles with each CT	
Column ID	**A**	**B**	**C**	**D**	**E**
calculation	**input**	**input**	**input**	**A x B**	**A x C**
Model Year	2000 Iowa Distribution (# vehicles)	Uncontrolled	Non-Catalyst	Uncontrolled	Non-Catalyst
# - #	#	#		#	
# - #	#		#		#
Total # Vehicles	**SUM column A**				

	row ID	*calculation*	*row ID*	*calculation*
# MC with each CT	**F**	**SUM column D**	**G**	**SUM column E**
Fraction of MC with each CT	**H**	**F / SUM column A**	**I**	**G/ SUM column A**
Vehicle Kilometers Traveled (VKT) by MC	**J (input)**			
VKT by CT	**K**	**H x J**	**L**	**I x J**
CH4 Emission Factor (g CH4/VKT)	**M**	**input**	**N**	**input**
CH4 Emissions (g CH4)	**O**	**K x M**	**P**	**L x N**
N2O Emission Factor (g N2O/VKT)	**Q**	**input**	**R**	**input**
N2O Emissions (g N2O)	**S**	**K x Q**	**T**	**L x R**

Total Emissions from Vehicles

Column ID	**U**	**V**	**W**
calculation	**Sum Emissions**	**U/1,000,000**	**conversion**
	(g)	(metric tons)	(MTCE)
Total CH4 Emissions	**O + P**		**V x 21 x (12/44)**
Total N2O Emissions	**S + T**		**V x 310 x (12/44)**

2002 Emissions from Motorcycles (MC)

Model Year	2000 Iowa Distribution (# vehicles)	Fraction of MC with Control Technologies (CT)		Number of MC with each CT	
		Uncontrolled	Non-Catalyst	Uncontrolled	Non-Catalyst
1995 and before	154,840	1.00		154,840	
1996 and after	47,928		1.00		47,928
Total # Vehicles	202,768				

# MC with each CT	154,840	47,928
Fraction of MC with each CT	0.76	0.24
Vehicle Kilometers Traveled (VKT) by MC	389,960,000	
VKT by CT	297,785,678	92,174,322
CH4 Emission Factor (g CH4/VKT)	0.260	0.130
CH4 Emissions (g CH4)	77,424,276	11,982,662
N2O Emission Factor (g N2O/VKT)	0.005	0.004
N2O Emissions (g N2O)	1,488,928	368,697

Total Emissions from Motorcycles

	(g)	(metric tons)	(MTCE)
Total CH4 Emissions	89,406,938	89	512
Total N2O Emissions	1,857,626	2	157

2002 Emissions from Light Duty Gas Vehicles (LDGV)

Model Year	2002 Iowa Distribution (# vehicles)	Fraction of Vehicles with Control Technologies (CT)					Number of Vehicles with each CT				
		Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0: 3-way Catalyst	Tier 1: 3-way Catalyst	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0: 3-way Catalyst	Tier 1: 3-way Catalyst
1972 and before	111,067	1.00					111,067				
1973-1974	21,576		1.00					21,576			
1975	10,716		0.20	0.80				2,143	8,573		
1976-1977	45,545		0.15	0.85				6,832	38,713		
1978-1979	82,946		0.10	0.90				8,295	74,651		
1980	32,686		0.05	0.88	0.07			1,634	28,764	2,288	
1981	36,049			0.15	0.85				5,407	30,642	
1982	40,557			0.14	0.86				5,678	34,879	
1983	62,426			0.12	0.88				7,491	54,935	
1984-1993	1,666,775				1.00					1,666,775	
1994	177,083				0.60	0.40				106,250	70,833
1995	193,392				0.20	0.80				38,678	154,714
1996 and after	1,066,980					1.00					1,066,980
Total # vehicles	3,547,798										
		Number of Vehicles with each CT					111,067	40,480	169,278	1,934,447	1,292,527
		Fraction of Vehicles with each CT					0.03	0.01	0.05	0.55	0.36
		Vehicle Kilometers Traveled (VKT) by HDGV					27,549,581,599				
		VKT by CT					862,464,885	314,337,309	1,314,484,916	15,021,487,720	10,036,806,769
		CH_4 Emission Factor (g CH_4/VKT)					0.135	0.120	0.070	0.040	0.030
		CH_4 Emissions (g CH_4)					116,432,759	37,720,477	92,013,944	600,859,509	301,104,203
		N_2O Emission Factor (g N_2O/VKT)					0.010	0.010	0.032	0.051	0.029
		N_2O Emissions (g N_2O)					8,624,649	3,143,373	42,063,517	766,095,874	291,067,396

Total Emissions from Light Duty Gas Vehicle:

	(g)	(metric tons)	(MTCE)
Total CH_4 Emissions	1,148,130,892	1,148	6,576
Total N_2O Emissions	1,110,994,809	1,111	93,930

2002 Emissions from Light Duty Gas Trucks (LDGT)

Model Year	2002 Iowa Distribution (# vehicles)	Fraction of Vehicles with Control Technologies (CT)					Number of Vehicles with each CT				
		Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0: 3-way Catalyst	Tier 1: 3-way Catalyst	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0: 3-way Catalyst	Tier 1: 3-way Catalyst
1972 and before	63,375	1					63,375				
1973-1974	22,089		1					22,089			
1975	13,834		0.3	0.7				4,150	9,684		
1976	20,203		0.2	0.8				4,041	16,162		
1977-1978	54,698		0.25	0.75				13,675	41,024		
1979-1980	59,514		0.2	0.8				11,903	47,612		
1981	18,857			0.95	0.05				17,914	943	
1982	20,937			0.9	0.1				18,843	2,094	
1983	27,306			0.8	0.2				21,845	5,461	
1984	33,972			0.7	0.3				23,781	10,192	
1985	35,264			0.6	0.4				21,158	14,106	
1986	40,347			0.5	0.5				20,174	20,174	
1987-1993	317,292			0.05	0.95				15,865	301,428	
1994	51,386				0.6	0.4				30,832	20,555
1995	46,159				0.2	0.8				9,232	36,927
1996 and after	308,354					1					308,354
Total # Vehicles	1,133,589										

	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0: 3-way Catalyst	Tier 1: 3-way Catalyst
Number of Vehicles with CT	63,375	55,857	254,061	394,460	365,835
Fraction of Vehicles with each CT	0.06	0.05	0.22	0.35	0.32
Total Vehicle Kilometers Traveled (VKT) by HDGV	11,252,646,005				
VKT by CT	629,100,182	554,468,809	2,521,955,642	3,915,633,678	3,631,487,694
CH_4 Emission Factor (g CH_4/VKT)	0.135	0.140	0.090	0.070	0.035
CH_4 Emissions (g CH_4)	84,928,525	77,625,633	226,976,008	274,094,357	127,102,069
N_2O Emission Factor (g N_2O/VKT)	0.012	0.012	0.042	0.085	0.040
N_2O Emissions (g N_2O)	7,549,202	6,653,626	105,922,137	332,828,863	145,259,508

Total Emissions from Light Duty Gas Trucks

	(g)	(metric tons)	(MTCE)
Total CH_4 Emissions	790,726,592	791	4,529
Total N_2O Emissions	598,213,335	598	50,576

2002 Emissions from Light Duty Diesel Vehicles (LDDV)

Model Year	2002 Iowa Distribution (# vehicles)	Fraction of Vehicles with Control Technologies (CT)			Number of Vehicles with each CT		
		Uncontrolled	Moderate	Advanced	Uncontrolled	Moderate	Advanced
1982 and before	4,810	1.00			4,810		
1983-1995	5,270		1.00			5,270	
1996 and after	720			1.00			720
Total # vehicles	10,800						

Number of Vehicles with each CT	4,810	5,270	720
Fraction of Vehicle with each CT	0.45	0.49	0.07
Vehicle Kilometers Traveled (VKT) by HDGV		471,667,111	
VKT by CT	210,052,428	230,154,489	31,460,195
CH_4 Emission Factor by CT (g/VKT)	0.010	0.010	0.010
CH_4 Emissions (g CH_4)	2,100,524	2,301,545	314,602
N_2O Emission Factor by CT (g/VKT)	0.010	0.010	0.010
N_2O Emissions (g N_2O)	2,100,524	2,301,545	314,602

Total Emissions from Light Duty Diesel Vehicles

	(g)	(metric tons)	(MTCE)
Total CH_4 Emissions	4,716,671	5	27
Total N_2O Emissions	4,716,671	5	27

Vehicle Kilometers for Iowa were estimated for an aggregate of Automobiles and Light Duty Trucks
so from VKT by LDD

2002 Emissions from Light Duty Diesel Trucks (LDDT)

Model Year	2002 Iowa Distribution (# vehicles)	Fraction of vehicles with Control Technologies (CT)			Number of vehicles with each CT		
		Uncontrolled	Moderate	Advanced	Uncontrolled	Moderate	Advanced
1982 and before	5,063	1.00			5,063		
1983-1995	21,852		1.00			21,852	
1996 and after	12,453			1.00			12,453
Total # vehicles	39,369						

Number of Vehicles with each CT	5,063	21,852	12,453
Fraction of Vehicles with each CT	0.13	0.56	0.32
Vehicle Kilometers Traveled (VKT) by LDDT	235,479,027		
VKT by CT	30,285,344	130,705,497	74,488,186
CH_4 Emission Factor (g CH_4/VKT)	0.010	0.010	0.010
CH_4 Emissions (g CH_4)	302,853	1,307,055	744,882
N_2O Emission Factor (g N_2O/VKT)	0.020	0.020	0.020
N_2O Emissions (g N_2O)	605,707	2,614,110	1,489,764

Total Emissions from Light Duty Diesel Trucks

	(g)	(metric tons)	(MTCE)
Total CH_4 Emissions	2,354,790	2	13
Total N_2O Emissions	4,709,581	5	398

2002 Emissions from Heavy Duty Gas Vehicles (HDGV)

Model Year	2002 Iowa Distribution (# vehicles)	Fraction of Vehicles with Control Technologies (CT)				Number of Vehicles with each CT			
		Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0 3-way	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0 3-way Catalyst
1981 before	70,482	1.00				70,482			
1982-1984	10,377	0.95		0.05		9,858		519	
1985-1986	7,527		0.95	0.05			7,151	376	
1987	3,882		0.70	0.15	0.15		2,717	582	582
1988-1989	10,065		0.60	0.25	0.15		6,039	2,516	1,510
1990 and after	51,574		0.45	0.30	0.25		23,208	15,472	12,893
Total # vehicles	153,906								

	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0 3-way Catalyst
Number of Vehicles with each CT	80,339.70	39,115.41	19,465.88	14,985.45
Fraction of Vehicles with each CT	0.52	0.25	0.13	0.10
Vehicle Kilometers Traveled (VKT) by HDGV	836,722,359			
VKT by CT	436,771,988	212,653,462	105,827,510	81,469,399
CH_4 Emission Factor (g/VKT)	0.270	0.125	0.090	0.075
CH_4 Emissions (g CH_4)	117,928,437	26,581,683	9,524,476	6,110,205
N_2O Emission Factor (g/VKT)	0.027	0.026	0.870	0.173
N_2O Emissions (g N_2O)	11,792,844	5,528,990	92,069,933	14,094,206

Total Emissions from Heavy Duty Gas Vehicles

	(g)	(metric tons)	(MTCE)
Total CH_4 Emissions	160,144,800	160	917
Total N_2O Emissions	123,485,973	123	10,440

2002 Emissions from Heavy Duty Diesel Vehicles (HDDV)

Model Years	2002 Iowa Distribution (# vehicles)	Fraction of Vehicles with Control Technologies (CT)			Number of Vehicles with each CT		
		Uncontrolled	Moderate	Advanced	Uncontrolled	Moderate	Advanced
1982 and before	19,150	1.00			19,150		
1983-1990	44,396		1.00			44,396	
1991 and after	103,274			1.00			103,274
Total # vehicles	166,820						

	Uncontrolled	Moderate	Advanced
Number of Vehicles with each CT	19,150	44,396	103,274
Fraction of Vehicles with each CT	0.11	0.27	0.62
Vehicle Kilometer Traveled (VKT) by HDDVs		6,360,693,641	
VKT by CT	730,186,198	1,692,786,856	3,937,720,587
CH_4 Emission Factor by CT (g/VKT)	0.060	0.050	0.040
CH_4 Emissions (g CH_4)	43,811,172	84,639,343	157,508,823
N_2O Emission Factor by CT (g/VKT)	0.030	0.030	0.030
N_2O Emissions (g N_2O)	21,905,586	50,783,606	118,131,618

Total Emissions from Heavy Duty Diesel Vehicles

	(g)	(metric ton)	(MTCE)
Total CH_4 Emissions	285,959,338	286	1,638
Total N_2O Emissions	190,820,809	191	16,133

MOBILE COMBUSTION SOURCES DARS SCORES

DARS SCORES: CH4 EMISSIONS FROM HIGHWAY VEHICLES					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*8*	*The emission factors are based on a sophisticated model that uses measured inputs.*	6	*Vehicle miles traveled are estimated based on sampling.*	*0.48*
Source Specificity	*10*	*The emission factors were developed specifically for the various types of vehicles and their emission control technologies.*	9	*Vehicle miles traveled are very closely correlated to the emission activity.*	*0.90*
Spatial Congruity	*7*	*Emission factors were developed for the U.S., not for individual states; spatial variability is expected to be moderate.*	*10*	*States use state-level data on vehicle miles traveled.*	*0.70*
Temporal Congruity	*7*	*Emission factors were developed based on assumptions reflecting conditions at one point during the year; temporal variability is expected to be low to moderate.*	*7*	*As of late 1998, FHWA data on vehicle miles traveled were available only for 1994; temporal variability over a four-year period is expected to be low to moderate.*	*0.49*
				Composite Score	*0.64*

DARS SCORES: N2O EMISSIONS FROM GASOLINE FUELED HIGHWAY VEHICLES					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*8*	*The emission factors arc based on measurement of emissions from a small sample of vehicles.*	6	*Vehicle miles traveled are estimated based on sampling.*	*0.48*
Source Specificity	*10*	*The emission factors were developed specifically for the various types of vehicles and their emission control technologies.*	*9*	*Vehicle miles traveled are very closely correlated to the emission activity.*	*0.90*
Spatial Congruity	*7*	*Emission factors were developed for the U.S., not for individual states; spatial variability is expected to be moderate.*	*10*	*States use state-level data on vehicle miles traveled.*	*0.70*
Temporal Congruity	*7*	*Emission factors were developed based on testing over less than a full year; temporal variability is expected to be low to moderate.*	*7*	*As of late 1998, FHWA data on vehicle miles traveled were available only for 1994; temporal variability over a four-year period is expected to be low to moderate.*	*0.49*
				Composite Score	*0.64*

DARS SCORES: N_2O EMISSIONS FROM DIESEL FUELED HIGHWAY VEHICLES					
	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	8	The emission factors are based on a sophisticated model.	6	Vehicle miles traveled are estimated based on sampling.	0.48
Source Specificity	7	The emission factors were developed specifically for the various types of vehicles, but assumed moderate control for all vehicles; the expected variability is low to moderate.	9	Vehicle miles traveled are very closely correlated to the emission activity.	0.63
Spatial Congruity	7	Emission factors were developed for Europe, not for states in the U.S.; spatial variability is expected to be moderate.	10	States use state-level data on vehicle miles traveled.	0.70
Temporal Congruity	7	Emission factors were developed based on assumptions reflecting conditions at one point during the year; temporal variability is expected to be low to moderate.	7	As of late 1998, FHWA data on vehicle miles traveled were available only for 1994; temporal variability over a four-year period is expected to be low to moderate.	0.49
				Composite Score	0.58

IV. CH_4 from Natural Gas Systems

The method used is a simplified version of a complex methodology used by the EPA for the U.S. inventory. The complex method very accurately takes into account approximately 100 components of the entire natural gas system including the areas of natural gas production, processing, storage, transmission and distribution. The simplified method aggregates these components into a few fundamental activities. In doing so, the accuracy of the method is hindered. Because Iowa is a state that does not produce or process natural gas, the method admittedly over estimates CH_4 releases by assigning some emissions from production and processing activities. It is uncertain to what degree the overestimation is and there is no feasible method that can reduce this inaccuracy. At best, the method can deduce a maximum emission scenario.

According to the American Gas Association, Iowa has 25,131 miles of transmission and distribution pipelines. The Iowa Utilities Board provided reports showing that Iowa has 16,229 miles of main distribution pipeline broken down by the various fortifications (Cynthia Munyon, Iowa Utilities Board, personal contact, November 8, 2002). State specific data was unavailable on numbers of transmission and storage stations. These were estimated from the methodology based on factors for the number of stations per mile of pipeline. The number of customer connections was also provided by the IUB. These were broken down into protected and unprotected steel connections based on EIIP fractions. It is estimated that about 13% of customer connections are made of unprotected steel and about 47% are protected steel. The remaining 40% are assumed to be plastic or copper. An EIIP provided emission factor was applied to each of the variables listed in the worksheet to determine CH_4 emissions.

2000 CH_4 Emissions from Natural Gas Transmission and Distribution

	A	B	C	D	E	F
	input	input	A x B	input	(A or C) x D	E x 21 x (12/44)
	Value [a]	**Method for Estimation**	**Estimated Value**	**Emission Factor**	**Methane Emissions**	**Methane Emissions**
	(units)		**(units)**	**unit)**	**(metric tons CH_4)**	**(MTCE)**
Gas Transmission Emissions						
Miles of Transmission Pipeline, **L**	8,902			0.68	6,053	34,669
Transmission Stations		**L***.006	53.19	891	47,392	271,426
Storage Stations		**L***.0014	12.08	914	11,041	63,236
LNG Storage Stations				914	0	0
Total					64,486	369,331
Gas Distribution Emissions						
Miles of Distribution Pipeline, **M**	16,229			0.7	11,360	65,064
Miles Cast Iron Main Pipeline	41			4.63	190	1,087
Miles Unprotected steel main pipeline	256			2.16	553	3,167
Miles Protected steel main pipeline		**M***.53	8,601.37	0.11	946	5,419
Miles Plastic main pipeline		**M***.3	4,868.70	0.42	2,045	11,711
Customer Connections, **H**	862,331			0.014	12,073	69,143
Unprotected Steel Customer Connections		**H***0.1246	107,446.44	0.033	3,546	20,307
Protected Steel Customer Connections		**H***0.4656	401,501.31	0.0035	1,405	8,048
Total					32,118	183,947
Total						**553,278**

[a] All values came from the Cynthia Munyon, Iowa Utilties Board, personal contact November 8, 2002

NATURAL GAS SYSTEMS DARS SCORES

DARS SCORES: CH_4 EMISSIONS FROM NATURAL GAS SYSTEMS					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*7*	*The factors were based on measurement of emissions from a small sample of sources over typical loads*	*9*	*Data on each activity are based on intermittent measurement*	*0.63*
Source Specificity	*10*	*An emission factor was developed for each of approximately 100 components of natural gas systems which were identified as methane emission sources*	*9*	*The activities measured were identified as methane emission sources and thus are highly correlated to emissions*	*0.90*
Spatial Congruity	*8*	*The factors were developed for the entire U.S., not for any state. Assuming variability within the U.S. is low to moderate.*	*9*	*Activity Data are sometimes scaled based on national ratios of one activity to another; spatial variability is expected to be low.*	*0.72*
Temporal Congruity	*8*	*The emission factors are based on measured emissions over a period of less than a year. However, temporal variability is expected to be low.*	*10*	*States use activity data from a given year to estimate emissions in that year.*	*0.80*
				Composite Score	*0.76*

DARS SCORES: CO_2 EMISSIONS FROM OIL SYSTEMS					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*2*	*Because emissions are not measured, the highest possible score is 5, Because of the wide range for each emission factor, we assigned a score of 2.*	*10*	*Data on each activity are based on continuous measurement.*	*0.20*
Source Specificity	*7*	*An emission factor was developed for each activity (e.g., production, refining, and distribution), but the emission factor aggregates emissions at a higher level than where they occur.*	*7*	*The activities measured (production, transportation, refining, and consumption) are highly correlated to emissions, but are aggregated at a higher level than where emissions occur.*	*0.49*
Spatial Congruity	*8*	*The factors were developed for the entire U.S., not for any state. Variability within the U.S. is assumed to be low to moderate.*	*5*	*States use state-level activity data to estimate statewide emissions, but these data (e.g., oil refined) are poor proxies for the desired activity level (e.g., oil stored).*	*0.40*
Temporal Congruity	*9*	*The emission factors are not based on measured emissions over a particular time frame. However, the emission factors should not vary significantly over the course of a year, so the score is 9.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.90*
				Composite Score	*0.50*

APPENDIX B
AGRICULTURE

I. N_2O and CO_2 from Agricultural Soils

N_2O and CO_2 from direct emissions from agricultural cropping practices

Application of synthetic and organic fertilizers. Emissions from fertilizer application were estimated using data from the Iowa Fertilizer Distribution Reports from the Iowa Department of Agriculture & Land Stewardship (IDALS). The semi annual reports present quantities of commercial fertilizer sales and is based on inspection fees collected and tonnage reports filed by licensees and therefore does not account for manure that is applied to the farm where it was generated. The assumption was understood that data in these reports are the best representation of quantities of commercial fertilizers applied in a given period. Reported figures aggregate synthetic and organic fertilizers sold in Iowa by nutrient content. Nitrogen application was calculated directly from the nutrient content and tonnage distributed on the fertilizer worksheet provided below. It was not possible to segregate figures for organic or synthetic fertilizer.

Before the emission calculation could be performed, the quantity of unvolatilized nitrogen was determined. Organic fertilizers were assumed to volatilize 20% of the nitrogen as NO_x and NH_3. For synthetics the volatilization was assumed to be 10%. It was assumed that 100% of fertilizer applied was synthetic with only 10% loss of nitrogen to volatilization. This is probably inaccurate, as a portion of the fertilizer is known to be organic. This assumption will yield a maximum of direct N_2O emissions. The emission factors provided by the EIIP for synthetic and organic fertilizers were the same (0.0125 kg N_2O-N/ kg unvolatilized nitrogen). This factor was used to calculate emissions from total unvolatilized nitrogen applied.

Field application of managed manure must account for only the nitrogen that remains after emission and volatilization within the management system. In order to estimate the nitrogen applied as managed manure, figures from the manure management section of this inventory were used. In that section, it was calculated that a total of 2.1×10^8 kg of Kejdahl nitrogen was excreted from the livestock populations in 2000. It is assumed that 20% of this nitrogen was volatilized during management, leaving 1.7×10^8 kg nitrogen to be managed and land applied. After application, it is assumed that another 20% volatilizes as NO_x and NH_3 leaving 1.38×10^8 kg nitrogen that could be emitted. The emission factor used was that for organic fertilizers (0.0125 kg N_2O-N/ kg unvolatilized nitrogen).

Application of animal waste through daily spread operations. The EIIP estimates that 8% of manure from dairy cows is applied through daily spread. Again, the unvolatilized nitrogen must be determined and is based on population data, typical animal mass, Kjeldahl nitrogen excretion factor, and a volatilization fraction. Population data was taken from the National Agricultural Statistics Service (NASS) reports. Other parameters were provided by the EIIP. From the sum of these parameters, N_2O emissions were determined with an emission factor also provided by EIIP for unvolatilized applied nitrogen from daily spread operations (0.0125 kg N_2O-N/ kg unvolatilized N).

Incorporation of crop residues into the soil. N_2O is emitted from the decomposition of crop residues left in the fields. In order to estimate emissions from this source it was necessary to estimate the quantity of residue nitrogen remaining after harvest. By using the annual production of the specified crops quantity of crop residue biomass was determined. The mass ratio of crop product to residue and a residue dry matter factor were used for this calculation. Crop production data was taken from the NASS reports.

Some crop residues are burned, used in construction or as fodder. This is taken into consideration by subtracting the fraction of biomass that is consumed for these "other uses." Only 3% of corn, wheat, and soybean residues were assumed to be consumed by these other activities. Factors for nitrogen content of residues were provided by the EIIP and are used to determine the total nitrogen returned to the soil. Once this figure is known, emissions are calculated using the emission factor 0.0125 kg N20-N/ kg N in crop residues.

Production of nitrogen-fixing crops. Cultivation of nitrogen fixing crops results in emissions of N_2O from the soil. To estimate soil nitrogen amendments from nitrogen fixation, aboveground dry matter nitrogen was assumed to be a reasonable proxy. Legume production data was taken from NASS reports. That data was multiplied by 1 + the mass ratio of crop matter to residue matter, the fraction of dry matter in aboveground biomass, and the fraction of nitrogen in nitrogen-fixing crops to yield subsurface nitrogen inputs. This figure was then multiplied by the provided emission factor (0.0125 kg N20-N/ kg N inputs) to calculate N_2O emissions.

Cultivation of histosol soils. Histosols are rich and highly organic soils that become mineralized releasing N_2O as they are cultivated. According to figures from the Natural Resources and Conservation Service (NRCS), Iowa has 64,477 acres of histosols and 95% of these are in cultivation. The EIIP estimates 8 kg N_2O-N/ha-yr is released from the cultivation of these soils.

Direct N_2O emissions from animal production

Direct deposition of animal wastes onto agricultural soils. This section accounts for N_2O emissions from the direct deposition of animal waste onto pasture, range and paddock. Iowa 2000 average animal populations and state specific manure management fractions along with typical animal mass and Kjeldahl nitrogen excretion figures were used to calculate the quantity of nitrogen that was excreted directly to the land. From this, the 20% fraction of nitrogen that volatilizes was discounted. Then emissions were calculated with the provided emission factor (0.02 kg N_2O-N/kg N).

Indirect N_2O emissions from nitrogen applied to agricultural soils

NO_x and NH_3 volatilization from fertilizer application. Volatilization of NO_x and NH_3 from fertilizer and manure results in atmospheric redeposition of nitrogen onto the soil, followed by denitrification and emissions of N_2O. This section accounts for these indirect emissions.

First, the amount of nitrogen that volatilized from fertilizer applications was determined with the same assumption that was used before to calculate direct emissions from agricultural cropping practices. That is, 100% of the fertilizer applied is synthetic and from that 10% of the nitrogen volatilizes. This assumption could undercount as much as 45 tons of nitrogen volatilizing per year. Organic fertilizers volatilize by a greater amount, 15% of nitrogen is lost as NO_x and NH_3. As before, fertilizer data was taken from the Iowa Fertilizer Distribution Report from IDALS.

The other source of nitrogen volatilization is manure. Year 2000 average animal population data from the NASS, typical animal mass and a kjeldahl nitrogen excretion factor were used to determine the total amount of nitrogen available for volatilization from livestock manure. Of this total, 20% was considered to be volatilized.

The quantity of volatilized nitrogen from these two indirect sources was then multiplied by an emission factor provided by EIIP. For every 1 kg of nitrogen volatilized as NH_3 and/or NO_x, .01 kg of N_2O-N are emitted. Later, the resulting N_2O-N figure was converted to kg N_2O and MTCE.

Nitrogen leaching and runoff from agricultural fields. Much of the nitrogen applied to fields is lost to leaching and runoff. This addition of nitrogen to the ground and surface water results in elevated N_2O emissions from denitrifiying bacteria. The EIIP estimates that 30% of the applied nitrogen is lost to leaching and runoff. This loss is calculated from the unvolatilized applied nitrogen discussed above. The EIIP provides the same emission factor (0.025 kg N_2O-N/kg N) for synthetic and organic fertilizers and manure nitrogen lost to leaching and runoff. The sum of these parameters yields the total kg N_2O-N emissions. Later, this total was converted to kg N_2O emissions then MTCE N_2O.

CO_2 from agricultural application of lime ($CaCO_3$)

Agricultural application of lime. Agricultural application of limestone and dolomite to the soils results in a release of CO_2 over several years. Some of the carbon is also leached to the groundwater, however, in this methodology that avenue is not addressed and it is assumed that 100% of the carbon is converted to CO_2. It is also assumed that all of the carbon is released in the year of application.

Total limestone and dolomite consumption data for 1997 through 2000 was taken from the United States Geological Survey *Minerals Yearbook* "Stone, Crushed" Reports (2000). Total consumption figures were used to estimate the portion of agricultural lime consumption as limestone and dolomite. Because year 2000 data on dolomite consumption was withheld, the average of the 3 previous years was used to determine year 2000 dolomite consumption.

The EIIP methodology suggests that the USGS report does not report all agricultural uses of lime specifically. Instead, there is a general category labeled "other uses" that accounts for some unspecified agricultural lime uses. The quantity of these unspecified agricultural uses for limestone and dolomite are estimated from the proportion of Iowa's specified agricultural use to the U.S. total specified use. That ratio is then multiplied by the U.S. unspecified use (from the "other uses" category). This calculation is performed separately for each limestone and dolomite. This assumes that the fraction of U.S. specified use that is consumed by Iowa specified agricultural uses equals the fraction of the U.S. unspecified uses consumed by Iowa unspecified agricultural uses.

Once the total quantities for agricultural uses of limestone and dolomite were determined, the totals were multiplied by the carbon to lime ratio, to determine the carbon available for emission as CO_2. It was assumed that 12% of the composition of limestone is carbon and 13% of dolomite is carbon. Since other inventories have reported in units of CO_2 equivalents, the carbon weight was multiplied by the ratio of CO_2 to carbon (44/12) to report consistent units with those reports. This inventory reports in the units of metric tons carbon equivalents (MTCE), therefore the CO_2 equivalents units were multiplied by the ratio of carbon to CO_2 (12/44) to yield MTCE.

2000 Summary of Greenhouse Gas Emissions from Agricultural Soils

Type of Emission	Gas Emitted	Total Gas Emissions (kg gas/yr)	Total Emissions from Agricultural Soils (MTCE)
Direct Emissions from Ag Cropping Practices	N_2O	54,546,632	4,611,670
Direct Emissions from Animals on Ag Soil	N_2O	3,895,373	329,336
Indirect Emissions from Nitrogen applied to Ag Soils	N_2O	15,806,296	1,336,350
Total N_2O			**6,277,356**
Total Emission Liming Soils	CO_2	815,998,955	222,545
Total CO_2			**222,545**
Total Greenhouse Gases			**6,499,902**

2000 Direct N_2O Emissions from Agricultural Cropping Practices

Application of Synthetic + Organic Fertilizers

A	B	C
input	input	A x B
Total Use (calculated on "fertilizer" worksheet)	**Fraction of Synth and Org Fertilizer N not Emitted as NOx and NH3**	**Unvolatilized Applied N from Synthetic and Org. Fertilizer**
(kg N/yr)	**(Kg N/ Kg N)**	**(kg N/yr)**
897,772,281.43	0.9	807,995,053.29

Organic Fertilizer Application (Manure)

D	E	F
input	input	D x E
Applied N from Animal Manure	**1- Fraction that Volatilizes**	**Unvolatilized Applied N from Animal Manure**
(kg N/yr)		**(kg N/yr)**
173,005,002	0.8	138,404,002

Application of Animal Waste Through Daily Spread Operations

	G	H	I	J	K	L	M
	input	input	input	input	G x H x (I/1000) x J x 365	input	K x L
Animal Type	**IA Average Population 2000**	**Fraction of Manure Managed as Daily Spread**	**Typical Animal Mass (TAM)**	**Kjeldahl Nitrogen Excretion Factor**	**Total Kjeldahl N Excreted**	**1- Fraction that Volatilizes**	**Unvolatilized Applied N from Daily Spread Operations**
	(head)		**(kg/head)**	**(kg/day/1000 kg TAM)**	**(kg/yr)**		**(kg N/yr)**
Milk Cows	215,702	0.08	640	0.45	1,813,968	0.8	1,451,174

Incorporation of Crop Residue into the Soil

	N	O	P	Q	R	S	T	U
	input	N x conversion factor	input	input	O x P x Q	input	input	R x (S-1) x T
Crop Residue	**Production**	**Production**	**Mass Ratio Crop/Residue**	**Residue Dry Matter**	**Crop Residue Biomass**	**Fraction for Other Uses**	**N Content of Residue**	**Total N Returned to Soil**
	(Bushels)	**(kg)**		**(kg)**	**(kg)**		**(kg N/ kg dry biomass)**	**(kg N/yr)**
Corn for Grain	1,728,000,000	43,891,200,000	1	0.4	17,556,480,000	0.03	0.0094	160,079,985
All Wheat	846,000	23,011,200	1.3	0.83	24,829,085	0.03	0.0058	139,688
Soybeans for Beans	464,580,000	12,636,576,000	2.1	0.86	22,821,656,256	0.03	0.03	664,110,197
Dry Edible Beans 1/	98,472	2,678,438	2.1	0.86	4,837,260	0	0.03	145,118
Barley	260,264	5,673,755	1.2	0.93	6,331,911	0	0.0077	48,756
Sorghum	84,584	2,148,434	1.4	0.91	2,737,104	0	0.0108	29,561
Oats	14,293,977	177,960,014	1.3	0.92	212,840,176	0	0.007	1,489,881
Rye	55,205	1,402,207	1.6	0.9	2,019,178	0	0.0048	9,692
Millet	1,602	39,249	1.4	0.89	48,904	0	0.007	342
Other Crops 2/	0							
								826,053,219.97

1/ units are in hundredweight

2/ Other crops are not reported in Iowa. Includes Peanuts and nuts, dry edible peas, austrian winter peas, lentils, wrinkled seed peas & rice.

3/ Fraction burned, used as fuel, fodder or construction

Production of N-fixing Crops

V	W	X	Y	Z	A1	B1
input	V x conversion factor	W x 0.85	input	input	input	X x Y x Z x A1

N fixing crops	Production	Units	Production	Production	1 + Mass Ratio Crop: Residue	Fraction Dry Matter Aboveground Biomass	Fraction of N in N-fixing Crops	N input from N-fixing Crops
			kg/year	kg dry biomass/yr			(kg N/ kg dry biomass)	(kg N/yr)
Soybean	464,580,000	Bushel	12,636,576,000	10,741,089,600.00	3.1	0.87	0.03	869,061,559.54
Dry edible beans	98,472	CWT	2,678,438	2,276,672.64	3.1	0.86	0.03	182,088.28
Hay, All 5/	6,000,000	tons	5,443,108,800	4,626,642,480.00	1.0	0.85	0.03	117,979,383.24
Other N fixing Crops 6/	0							
								987,223,031.05

5/ Includes Alfalfa, Red clover, Wht Clvr, Birdsfoot Trefoil, Arrowleaf Clvr, Crimson Clvr, Hairy Vetch

6/ Other N fixing Crops are not reported in Iowa. Includes Peanuts, dry edible peas, austrian winter peas, lentils, wrinkled seed peas.

Direct N2O Emissions from Cultivated Histosols

C1	D1	E1
input	input	C1 x D1
Area of Cultivated Histosols	**Emission Factor for Direct Soil Emissions**	**Direct Emissions from Histosols**
(hectares)	(kg N2O-N/ha/yr)	(kg N2O-N/yr)
24,676.50	8	197,412.00

Summary of Direct N_2O Emissions

	F1	G1	H1	I1	J1
	input	input	F1 x G1	H1 x (44/28)	(I1/1000) x 310 x (12/44)
	Amount of N input	**Emission Factor for Direct Emissions**	**Direct Soil Emissions**	**Direct Soil Emissions**	**Direct Soil Emissions**
	(kg N/yr)	(kg-N20-N/kg N)	(kg N2O-N/yr)	(kg N2O/yr)	(MTCE)
Unvolatilized Applied N from Synthetic Fertilizer & Organic Fertilizer (column C)	807,995,053	0.0125	10,099,938	15,871,331	1,341,849
Unvolatilized Applied N from Manure (F)	138,404,002	0.0125	1,730,050	2,718,650	229,850
Unvolatilized Applied N Daily Spread Operations (M)	1,451,174	0.0125	18,140	28,505	2,410
N in Crop Residues Returned to Soils (U)	826,053,220	0.0125	10,325,665	16,226,045	1,371,838
N fixation from N-fixing Crops (B1)	987,223,031	0.0125	12,340,288	19,391,881	1,639,495
Cultivation of Histosols (E1)			197,412	310,219	26,228
Subtotal			**34,514,081**	**54,546,632**	**4,585,442**

2000 Direct N_2O Emissions from Animal Production on Agricultural Soil

	A	B	C	D	E	F
	input	input	input	input	B x (C/1000) x D x	input
Animal Type	**2000 Iowa Average Population**	**Manure Deposited on Pasture, Range and Paddock**	**Typical Animal Mass (TAM)**	**Kjeldahl N per day per 1000 kg mass**	**Total Kjeldahl N Excreted by Animal Type**	**Fraction of Excreted N that volatilizes**
	(head)		**(kg/head)**	**(kg/day/1000 kg)**	**(kg/yr)**	
Beef Cows	1,030,817	0.87	500	0.34	55,647,096	0.2
Breeding Bulls	67,054	0.87	680	0.34	4,922,947	0.2
Growing Calves	712,984	0.87	181	0.34	13,933,151	0.2
Growing Steers&	1,173,609	0.87	387	0.34	49,037,174	0.2
Steers & Heifers On	563,345	0.87	387	0.34	23,538,373	0.2
Sheep	300,944	0.99	70	0.42	3,197,136	0.2
Goats 1/	12,275	1.0	64	0.42	120,432	0.2
Equine 1/ 2/	100,000	0.92	450	0.3	4,533,300	0.2

	G	H	I	J	K
	E x (1-F)	input	G x H	I x (44/28)	J x (12/44) x 310
	Unvolatilized Applied N from waste deposited on Pasture, Range, and Paddock	**Emission factor for Direct Emissions**	**Total Direct N2O Emissions from Animal Production**	**Total Direct Emissions of N2O**	**Total Direct Emissions**
	(kg N)	**(kg N2O-N/kg N)**	**(kg N2O-N)**	**(kg N2O/yr)**	**MTCE**
Beef Cows	44,517,677	0.02	890,354	1,399,127	118,290
Breeding Bulls	3,938,357	0.02	78,767	123,777	10,465
Growing Calves	11,146,521	0.02	222,930	350,319	29,618
Growing Steers& Heifers	39,229,739	0.02	784,595	1,232,935	104,239
Steers & Heifers On	18,830,699	0.02	376,614	591,822	50,036
Sheep	2,557,709	0.02	51,154	80,385	6,796
Goats 1/	96,346	0.02	1,927	3,028	256
Equine 1/ 2/	3,626,640	0.02	72,533	113,980	9,637
	123,943,687		Total	3,895,373	329,336

1/ Not calculated off of an average population. Info unavailable for calc of avg.

2/ Category is comparable to "Horses/Mules" for 1990 inventory includes horses, ponies, mules, burros, and donkeys

2000 Indirect Emissions from Nitrogen Applied to Agricultural Soils

NO_x and NH_3 Volatilization from Fertilizer Application

	A	B	C
	input	input	A x B
	Total Application of Fertilizer in IA	**Fraction of Fertilizer N applied that Volatilizes**	**Volatilized N from Fertilizer**
	(kg N/ yr)		**(kg N/yr)**
Synthetic + Organic	897,772,281	0.1	89,777,228
		Total N excreted that volatilizes	89,777,228

NO_x and NH_3 Volatilization from Livestock Manure

	D	E	F	G
	input	input	input	D x (E/1000) x F x 365
Animal Type	**2000 Iowa Average Population**	**Typical Animal Mass (TAM)**	**Kjeldahl N per day per 1000 kg mass**	**Total Kjeldahl N Excreted by Animal**
	(head)	**(kg/head)**	**(kg/day/1000 kg mass)**	**(kg/yr)**
Dairy Cattle	215,702	640	0.45	22,674,578
Beef Cows	1,030,817	500	0.34	63,962,195
Breeding Bulls	67,054	680	0.34	5,658,560
Growing Calves	712,984	181	0.34	16,015,117
Growing Steers & Heifers	1,173,609	387	0.34	56,364,567
On Feed Steers & Heifers	563,345	387	0.34	27,055,601
Market Swine	14,209,836	46	0.52	124,063,236
Breeding Swine	1,160,000	181	0.52	39,850,408
Chickens:Layers	27,282,126	1.6	0.84	13,383,520
Chickens: Broilers	17,200,000	0.7	1.1	4,834,060
Turkeys	7,100,000	3.4	0.62	5,462,882
Sheep	300,944	70	0.42	3,229,430
Goats	12,275	64	0.42	120,432
Horses/Mules	100,000	450	0.3	4,927,500
			Total kg N excreted	387,602,087
			Volatilization factor	0.2
			Total N excreted that volatilizes	77,520,417

Indirect N_2O Emissions Resulting from Atmospheric Redeposition of NO_x and NH_3

	H	I	J
	C	input	H x I
Source	**Total Amount of N that Volatilizes**	**Emission Factor**	**N_2O Emissions**
	(kg NH_3-N + NO_x-N/kg N)	**(kg N_2O-N/kg NH_3-N + NO_x-N)**	**(kg N_2O-N/yr)**
Fertilizer	89,777,228	0.01	897,772
Livestock Excretion	77,520,417	0.01	775,204
		Subtotal	1,672,976

Emissions from Leaching and Runoff of Nitrogen from Agricultural Fields

	K	L	M	N	O
	(A x 0.9) or (G x 0.8)	input	K x L	input	M x N
	Unvolatilized Applied N from Fertilizer	**Fraction of Unvolatilized N that Leaches or Runs off**	**N Leaching or Running off**	**Emission Factor**	**Total N2O-N Emissions**
	(kgN/yr)		**(kg N/yr)**	**(kgN2O-N/kgN)**	**(kg N2O-N/yr)**
Synth + Organic	807,995,053	0.30	242,398,516	0.025	6,059,963
Manure	310,081,669	0.30	93,024,501	0.025	2,325,613
				Subtotal	8,385,575

Total Indirect N2O Emissions from Agricultural Soils

	P	Q	R
		P x (44/28)	Q/ 1000 x 310 x (12/44)
Source of Indirect Emission	**Indirect Soil Emissions**	**Total Indirect N2O Emissions**	**Total Indirect N2O Emissions**
	(kg N2O-N/yr)	**(kg N2O/yr)**	**MTCE**
Atmospheric Deposition (J)	1,672,976	2,628,963	222,267
Leaching/Runoff (O)	8,385,575	13,177,333	1,114,084
	Subtotal	15,806,296	**1,336,350**

2000 CO_2 Emissions from Agricultural Lime Application

Estimation of Specified Limestone and Dolomite Application to Agricultural Soils

	A	B	C	D	E	F	G	H
	input	input	A + B	A / C	B / C	input	F x D	F x E
Year	IA Total Limestone 1/	IA Total Dolomite 1/	Total IA Limestone & Dolomite	Fraction of Total as Limestone	Fraction of Total as Dolomite	IA total Ag Use of Limestone & Dolomite 2/	IA total Ag Use as Limestone	IA total Ag use of Dolomite
	(10^3 m tons)	(10^3 m tons)	(10^3 m tons)	fraction	fraction	(10^3 m tons)	(10^3 m tons)	(10^3m tons)
2000	40,100	withheld	40,100	(avg '97-'99) 0.999	0.001	997	996	1
1999	42,000	53	42,053	0.999	0.001	1,300	1,298	2
1998	41,700	72	41,772	0.998	0.002	1,010	1,008	2
1997	37,200	41	37,241	0.999	0.001	896	895	1

Estimation of Unspecified Agricultural Uses of Limestone and Dolomite

	I	J	K	L	M	N	O	P	Q
	input	input	input	G / J	H / J	K x L	K x M	N + G	H + I
	Total U.S. Use 2/	U.S. Total Specified Use of Limestone & Dolomite 2/	U.S. Total Unspecified Use of Limestone & Dolomite 2/	Ratio of IA Specified Ag Limestone Use to US specified Use	Ratio of IA Specified Ag Dolomite Use to US specified Use	IA Limestone Uspecified Use for Ag	IA Dolomite Uspecified Use for Ag	IA Specified + Unspecified Limestone Ag Use	IA Specified + Unspecified Dolomite Ag Use
	(10^3 m tons)	(10^3 m tons)	(10^3 m tons)	fraction	fraction	(10^3 m tons)	(10^3 m tons)	(10^3 m tons)	(10^3 m tons)
2000	1,100,000	601,000	499,000	0.0017	0.0000023	827	1	1,823	2
1999	1,080,000	615,000	465,000	0.0021	0.0000027	982	1	2,280	3
1998	1,060,000	604,000	456,000	0.0017	0.0000029	761	1	1,769	3
1997	1,010,000	589,000	421,000	0.0015	0.0000017	640	1	1,535	2
							4 year Average	1,852	3
								1,851,805	2,527

Summary CO_2 Emissions from Limestone and Dolomite Application to Agricultural Soi

	R	S	T	U	V
	Q x 1000	input	R x S	T x (44/12)	U x (12/44)
	IA Ag Use of Lime	Carbon to Lime Ratio	C available for emission	CO_2 Emissions	CO_2 Emissions
	(m tons)		(m tons C)	(m tons CO_2 Equiv)	(MTCE)
Limestone	1,851,805	0.12	222,217	814,794	222,217
Dolomite	2,527	0.13	329	1,205	329
					222,545

1/ From "Stone, Crushed" Report from USGS Minerals Yearbook for approriate year, table 8

2/ From "Stone, Crushed" Report from USGS Minerals Yearbook for approriate year, table 15

Iowa 2000 Commercial Fertilizer Application Worksheet

	A	B	C
	input	input	A x (B/100)
	Consumption 1/ 7/99 to 6/00	**Nitrogen Content**	**Total Nitrogen**
	tons	**%**	**tons**
Anhydrous Ammonia	644,389	82	528,399.0
Ammonium Nitrate	20,577	33.5	6,893.3
Ammonium Sulfate	11,635	21	2,443.4
Ammonium Thiosulfate	10,086	14	1,412.0
Urea	189,146	46	87,007.2
Nitrogen Solution 28%	544,933	28	152,581.2
Nitrogen Solution 30%	0	30	0.0
Nitrogen Solution 32%	367,971	32	117,750.7
Ammonium Phosphates			
08-24-00 liquid	7,755	8	620.4
10-30-00 liquid	7,815	10	781.5
10-34-00 liquid	48,500	10	4,850.0
11-37-00	0	11	0.0
11-52-00 dry	149,997	11	16,499.7
18-46-00 dry	372,588	18	67,065.8
Triple Super Phosphate	13,011	0	0.0
Phosphoric Acid	72	0	0.0
Muriate of Potash	650,918	0	0.0
Mixtures and Suspensions			
02-06-35 suspens	20,653	2	413.1
03-09-27	0	3	0.0
03-10-30 suspens	24,455	3	733.7
04-10-10 liquid	5,051	4	202.0
06-18-06 liquid	1,567	6	94.0
07-21-07 liquid	10,375	7	726.3
07-23-05 liquid	1,016	7	71.1
09-18-09 liquid	3,384	9	304.6
05-20-35 dry	736	5	36.8
06-24-24 dry	2,217	6	133.0
08-32-16 dry	765	8	61.2
09-23-30 dry	5,238	9	471.4
10-20-20	0	10	0.0
10-26-26 dry	483	10	48.3
23-09-12 dry	108	23	24.8
20-10-10	0	20	0.0
Totals			
			989,624.5 Tons
			1,979,248,950.0 Lbs
			897,772,281.4 Kg

1/ Data from IDALS fertilizer Bureau, "Iowa Fertilizer Distribution"

Iowa 1990 Commercial Fertilizer Application

	A	B	C
	input	input	A x (B/100)
	Consumption 89-'91	**Nitrogen Content**	**Total Nitrogen**
	Avg tons/yr	**%**	**tons**
Anhydrous Ammonia	634,870	82	520,593.4
Ammonium Nitrate	26,401	33.5	8,844.3
Ammonium Sulfate	8,906	21	1,870.3
Ammonium Thiosulfate	8,449	14	1,182.9
Urea	176,747	46	81,303.6
Nitrogen Solution 28%	511,608	28	143,250.2
Nitrogen Solution 30%	1,544	30	463.2
Nitrogen Solution 32%	159,098	32	50,911.4
Ammonium Phosphates			
08-24-00 liquid	9,718	8	777.4
10-30-00 liquid	10,187	10	1,018.7
10-34-00 liquid	42,735	10	4,273.5
11-37-00	1,131	11	124.4
11-52-00 dry	87,474	11	9,622.1
18-46-00 dry	398,599	18	71,747.8
Triple Super Phosphate	36,380	0	0.0
Phosphoric Acid	1,541	0	0.0
Muriate of Potash	688,779	0	0.0
Mixtures and Suspensions			
02-06-35 suspens	18,828	2	376.6
03-09-27	1,327	3	39.8
03-10-30 suspens	26,857	3	805.7
04-10-10 liquid	3,843	4	153.7
06-18-06 liquid	1,817	6	109.0
07-21-07 liquid	19,400	7	1,358.0
07-23-05 liquid	3,769	7	263.8
09-18-09 liquid	4,829	9	434.6
05-20-35 dry	1,618	5	80.9
06-24-24 dry	12,300	6	738.0
08-32-16 dry	4,088	8	327.0
09-23-30 dry	6,577	9	591.9
10-20-20	337	10	33.7
10-26-26 dry	1,744	10	174.4
23-09-12 dry	1,583	23	364.1
20-10-10	371	20	74.2
Totals			
			901,908.8 Tons
			############ Lbs
			818,197,958.9 Kg

AGRICULTURAL SOILS DARS SCORES

DARS SCORES: DIRECT N2O EMISSIONS FROM AGRICULTURAL SOILS					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*Since the factor is derived from field measurements, applying the DARS formula the score would be 5. However, emissions vary across soil types, climates, and management practices.*	6	*The value of 6 is a composite value, based on use of top-down statistics for fertilizer purchases; estimates of manure use based on sample data; estimates of nitrogen from crop residues based on crop production; and estimates of histosol area cultivated.*	*0.18*
Source Specificity	*7*	*The emission factor was developed specifically for N_2O from fertilizer use, but not for emissions from legume cultivation, crop residue incorporation, or manure application. Variability is expected to be low to moderate.*	9	*Data on fertilizer purchases are used as a proxy for fertilizer use; other data are source specific estimates.*	*0.63*
Spatial Congruity	*3*	*The emission factor is a global value. Because the variance of emissions across regions and across states is expected to be high.*	*10*	*States use state-level activity data to estimate statewide emissions.*	*0.30*
Temporal Congruity	*5*	*The emission factor is based on measured emissions over a crop year or calendar year. The emission factor is expected to vary significantly over time.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.50*
				Composite Score	*0.40*

DARS SCORES: DIRECT N2O EMISSIONS FROM ANIMAL PRODUCTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*IPCC (1997) did not document the source of the factor; it stated only that the factor was "derived on the basis of a very limited amount of information."*	*7*	*The value of 7 is a composite value, based on animal populations, default values for nitrogen excretion, and estimates of amount managed using daily spread or equivalent, based on sampling.*	*0.35*
Source Specificity	*10*	*The emission factor was developed specifically for N_2O emissions from animal production.*	*10*	*Data on animal populations are used to estimate nitrogen excretion.*	*1.00*
Spatial Congruity	*3*	*The emission factor is a global value. The variance of emissions across regions is expected to be high.*	*9*	*State values for animal populations are used; values for nitrogen excretion are global average values, but spatial variability is expected to be low.*	*0.27*
Temporal Congruity	*5*	*It is unknown whether the emission factor is base< on measured emissions over a particular time frame. However, emissions are expected to vary significantly over the course of a year.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.50*
				Composite Score	*0.53*

DARS SCORES: INDIRECT N2O EMISSIONS FROM MANURE AND FERTILIZER					
	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	3	The emission factor is based on reported N_2O emissions from nitrogen deposited on soil (i.e., it is based on direct emissions, not indirect emissions).	7	1 he value ot / is a composite value, based on use of top-down statistics for fertilizer purchases; estimates of manure use based on sample data; and default values for (1) NOx and NH_3 volatilization, and (2) fraction of nitrogen that leaches.	0.21
Source Specificity	6	The emission factor is based on reported N_2O emissions from nitrogen deposited on soil (i.e., it is based on direct emissions, not indirect emissions). Variability is expected to be moderate to high.	9	Data on fertilizer purchases are used as a proxy for fertilizer use; other data are source specific estimates.	0.54
Spatial Congruity	3	The emission factors are global values. The variance of emissions across regions is expected to be high.	5	State values for fertilizer use are used; values for (1) NOx and NH_3 volatilization and (2) fraction of nitrogen that leaches are global, and spatial variability is expected to be moderate to high.	0.15
Temporal Congruity	3	It is unknown whether the emission factor is based on measured emissions over a particular time frame. However, emissions are expected to be highly varied over the course of a year.	7	States use annual activity data to estimate annual emissions. However, there is a lag time between application of nitrogen and indirect emissions due to leaching; temporal variability is expected to be low to moderate.	0.21
				Composite Score	0.28

DARS SCORES: CO2 EMISSIONS FROM AGRICULTURAL USE OF LIMESTONE					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*Because the emission factors for each type of limestone are not based on measurement, the highest possible score is 5. The emission factors are based on mass balance.*	*8*	*Data on limestone purchases are used. Assuming use of top-down statistics on limestone sales is assumed; the breakdown between limestone and dolomite sales must be estimated.*	*0.40*
Source Specificity	*10*	*The emission factor was developed specifically for CO_2 from agricultural use of limestone.*	*9*	*The activity measured (limestone purchases) is very closely correlated with the emissions process.*	*0.90*
Spatial Congruity	*9*	*The emission factor is a global value. The variance of emissions across regions is expected to be low.*	*10*	*States use state-level activity data to estimate statewide emissions.*	*0.90*
Temporal Congruity	*9*	*The emission factor is not based on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*7*	*States use annual activity data to estimate annual emissions. However, there is a lag time between application of lime and CO_2 emissions; temporal variability is expected to be low to moderate.*	*0.63*
				Composite Score	*0.71*

II. CH_4 from Enteric Fermentation in Domesticated Animals

The methods used for the current inventory are the same as those used for the National EPA greenhouse gas inventory and were provided in the Volume VIII EIIP document. To calculate emissions from cattle, the EPA designed digestion model for feeding systems in the United States, which generated emission factors based on feed input characteristics (Emission Inventory Improvement Program, 1999). The emission factors used for Iowa are specified to the feeding systems of the North Central region of the United States. For non-cattle animals the quantity of CH_4 produced likely varies across the country as well, however, emissions factors for these animals are not geographically specific and were taken from the scientific literature (Crutzen et al, 1986). This is because emissions from these animals are relatively small in comparison to cattle, and models to specify geographic variability among non-cattle have not been developed. Because of the vast quantity, uncertainty surrounding emissions from cattle would dominate the domesticated animals category.

Animal population data was taken from 1997 agricultural census and the USDA National Agricultural Statistics Service reports found at http://www.usda.gov/nass/ and cited on the *Worksheet for Calculating 2000 Iowa Livestock Average Population* (National Agriculture Statistics Service, 1997). Because populations can significantly fluctuate depending on the time of year, *average* animal populations were used for cattle, swine and sheep. The Iowa average livestock populations were determined using the U.S. inventory populations for January and July. The U.S. January populations were divided by the average of U.S. January and U.S. July populations. The fraction was applied to Iowa January inventories to determine an average population. This was then multiplied by the appropriate emission factor to determine emissions. For weanling and yearling system steers/heifers the total number animals slaughtered in 2000 was the population used. For other animals, the annual population was used because further data was unavailable.

Year 2000 CH_4 Emissions from Enteric Fermentation in Domesticated Animals

	A	B	C	D
	input	input	A x B /2000	C x .9072 x 21x (12/44)
Livestock Type	**IA Average Population 1990**	**North Central Emission Factor**	**CH4 Emissions**	**CH4 Emissions**
	head	**lbs CH_4/head/yr**	**tons**	**MTCE**
Dairy Cattle				
Replacements (0-12 mo)	105,875	41.60	2,202	11,442
Replacements (12-24 mo)	105,875	126.30	6,686	34,739
Mature Cows	215,702	246.50	26,585	138,131
Beef Cattle				
Replacements (0-12 mo)	129,786	44.80	2,907	15,105
Replacements (12-24 mo)	129,786	133.80	8,683	45,113
Mature Cows	1,030,817	130.90	67,467	350,544
Weanling System Steers/ Heifers 1/	125,840	49.70	3,127	16,248
Yearling System Steers/ Heifers 1/	503,360	103.40	26,024	135,214
Bulls	67,054	220.00	7,376	38,324
Other Livestock				
Swine	15,369,836	3.30	25,360	131,766
Sheep	300,944	17.60	2,648	13,760
Goats 2/	12,275	11.00	68	351
Equine 2/	100,000	39.60	1,980	10,288
Buffalo 3/				
			TOTAL	**941,024**

1/ Number of head Slaughtered in 2000

2/ Not calculated off of an average population. Info unavailable for calc of avg.

3/ Data was not found for this animal

Year 1990 CH_4 Emissions from Enteric Fermentation in Domesticated Animals

Livestock Type	A input IA Average Population 2000 head	B input North Central Emission Factor lbs CH_4/head/yr	C A x B /2000 CH4 Emissions tons	D C x .9072 x 21x (12/44) CH4 Emissions MTCE
Dairy Cattle				
Replacements (0-12 mo)	123,936	41.60	2,578	13,394
Replacements (12-24 mo)	123,936	126.30	7,827	40,665
Mature Cows	284,787	246.50	35,100	182,372
Beef Cattle				
Replacements (0-12 mo)	145,982	44.80	3,270	16,990
Replacements (12-24 mo)	145,982	133.80	9,766	50,743
Mature Cows	1,122,661	130.90	73,478	381,777
Weanling System Steers/ Heifers 1/	287,720	49.70	7,150	37,149
Yearling System Steers/ Heifers 1/	1,150,880	103.40	59,500	309,152
Bulls	80,741	220.00	8,882	46,146
Other Livestock				
Swine	13,500,799	3.30	22,276	115,743
Sheep	490,000	17.60	4,312	22,404
Goats 2/	11,784	11.00	65	337
Equine 2/	49,300	39.60	976	5,072
Buffalo 3/				
			TOTAL	**1,221,943**

1/ Number of head Slaughtered in 1990

2/ Not calculated off of an average population. Info unavailable for calc of avg.

3/ Data was not found for this animal

Worksheet for Calculating 2000 Iowa Livestock Average Population

		A		B		C		D	E	F
		input		input		input		B + C / 2	D/B	E x A
Animal Type	**Corresponding GHG Inventory Section[f]**	**IA January Population, 2000**	**Data Source**	**US January Population, 2000**	**Data Source**	**U.S. July Population, 2000**	**Data Source**	**Average U.S. Population**	**National Fraction**	**2000 Iowa Average Population (head)**
Mature Milk Cows	DA, MM, AS	215,000	1	9,190,000	1	9,250,000	2	9,220,000	1.0033	215,702
Dairy Replacement (0-12 mos)	DA	110,000	1	4,000,000	1	3,700,000	2	3,850,000	0.9625	105,875
Dairy Replacement (12-24 mos)	DA	110,000	1	4,000,000	1	3,700,000	2	3,850,000	0.9625	105,875
Beef Cows	DA, MM, AS	1,025,000	1	33,569,000	1	33,950,000	2	33,759,500	1.0057	1,030,817
Beef Replacement (0-12 mos)	DA	140,000	1	5,503,000	1	4,700,000	2	5,101,500	0.9270	129,786
Beef Replacement (12-24 mos)	DA	140,000	1	5,503,000	1	4,700,000	2	5,101,500	0.9270	129,786
Breeding Bulls	DA, MM, AS	70,000	1	2,293,000	1	2,100,000	2	2,196,500	0.9579	67,054
Growing Calves	MM, AS	510,000	1	16,815,000	1	30,200,000	2	23,507,500	1.3980	712,984
Growing Heifers, Steers/Bullocks/ Bulls	MM, AS	1,289,366	1,2,3,4,5	24,917,000	3,5	20,443,000	4, 2	22,680,000	0.9102	1,173,609
Feedlot-Fed Steers and Heifers on High-Grain Diets	MM, AS	590,696	1,2,3,4,5	11,414,000	3,5	10,357,000	4, 2	10,885,500	0.9537	563,345
Weanling System Steer/Heifer[cd]	DA	125,840	12							125,840
Yearling System Steer/Heifer[cd]	DA	503,360	12							503,360
Market Swine[e]	DA, MM, AS	14,240,000	8	53,109,000	13	52,884,000	13	52,996,500	0.9979	14,209,836
Breeding Swine[e]	DA, MM, AS	1,160,000	8	6,234,000	13	6,234,000	13	6,234,000	1.0000	1,160,000
Layers:Chicken	MM, AS	27,407,000	6	328,557,000	6	325,563,000	6	327,060,000	0.9954	27,282,126
Broilers:Chicken[ad]	MM, AS	17,200,000	7	6,665,000	7					17,200,000
Turkeys[d]	MM, AS	7,100,000	8	269,969,000	8					7,100,000
Sheep	DA, MM, AS	270,000	8	6,915,000	8	8,500,000	9	7,707,500	1.1146	300,944
Goats[d]	DA, MM, AS	12,275	10							12,275
Equine[bd]	DA, MM, AS	100,000	11							100,000

[a] December 1, 1995 through November 30, 1996

[b] Equine includes horses, ponies, mules, burros, and donkeys

[c] Number of Head Slaughtered for all of 2000

[d] Not calculated off of an average population. Info unavailable for calc of avg.

[e] January data comes from Dec 1 1999, July data comes from June 1 2000

[f] DA= Domesticated Animals, MM= Manure Management, AS= Agricultural Soils

Data Source Numbers

1 "Cattle" NASS released Jan 26, 2001
2 "Cattle" NASS released July 20, 2001
3 "Cattle on Feed" NASS released Jan 18, 2002
4 "Cattle on Feed" NASS released July 20, 2002
5 "Cattle" NASS released Feb. 1, 2002
6 "Chicken and Eggs 2000 Summary" NASS POU 2-4 (01)
7 "Poultry Production and Value 1997 Summary" NASS Pou 3-1(4-98) [1996 is the final year that NASS reported Broiler populations from Iowa]
8 "2001 Iowa Agriculture Statistics" compiled by Iowa Agriculture Statistics"
9 "Sheep" NASS released July 21, 2000
10 "1997 Census of Agriculture" Volume 1, Geographic Area Series Part 51 USDA
11 "Equine" NASS released March 2, 1999
12 "Livestock Slaughter" NASS releases Feb 25, 2000 through Jan 19, 2001
13 "Quarterly Hogs and Pigs" NASS released June 29, 2001

Worksheet for Calculating 1990 Iowa Livestock Average Population

		A		B		C		D	E	F
		input		input		input		B + C / 2	D/B	E x A
Animal Type	Corresponding GHG Inventory Section[g]	IA January Population, 1990	Data Source	US January Population, 1990	Data Source	U.S. July Population, 1990	Data Source	Average U.S. Population	National Fraction	2000 Iowa Average Population (head)
Mature Milk Cows	DA, MM, AS	285,000	100	10,015,000	100	10,000,000	100	10,007,500	0.9993	284,787
Dairy Replacement (0-12 mos)	DA	125,000	100	4,171,000	100	4,100,000	100	4,135,500	0.9915	123,936
Dairy Replacement (12-24 mos)	DA	125,000	100	4,171,000	100	4,100,000	100	4,135,500	0.9915	123,936
Beef Cows	DA, MM, AS	1,115,000	100	32,454,000	100	32,900,000	100	32,677,000	1.0069	1,122,661
Beef Replacement (0-12 mos)	DA	150,000	100	5,283,000	100	5,000,000	100	5,141,500	0.9732	145,982
Beef Replacement (12-24 mos)	DA	150,000	100	5,283,000	100	5,000,000	100	5,141,500	0.9732	145,982
Breeding Bulls	DA, MM, AS	80,000	100	2,160,000	100	2,200,000	100	2,180,000	1.0093	80,741
Growing Calves	MM, AS	870,000	100	18,418,000	100	29,400,000	100	23,909,000	1.2981	1,129,375
Growing Heifers, Steers/Bullocks/ Bulls[a]	MM, AS	1,431,103	100	22,876,000	100	21,341,000	100	22,108,500	0.9664	1,383,089
Feedlot-Fed Steers and Heifers on High-Grain Diets[a]	MM, AS	618,897	100	2,986,708	100	2,548,840	100	2,767,774	0.9267	573,530
Weanling System Steer/Heifer[abc]	DA	287,720	101							287,720
Yearling System Steer/Heifer[abc]	DA	1,150,880	101							1,150,880
Market Swine[d]	DA, MM, AS	11,820,000	102	46,931,000	102	46,735,000	102	46,833,000	0.9979	11,795,318
Breeding Swine[d]	DA, MM, AS	1,680,000	102	6,857,000	102	7,065,000	102	6,961,000	1.0152	1,705,481
Layers:Chicken	MM, AS	8,140,000	103	272,979,000	103	267,499,000	103	270,239,000	0.9900	8,058,296
Broilers:Chicken[ce]	MM, AS	9,450,000	104							9,450,000
Turkeys[d]	MM, AS	8,800,000	104							8,800,000
Sheep[d]	DA, MM, AS	490,000	105							490,000
Goats[d]	DA, MM, AS	11,784	106							11,784
Equine[df]	DA, MM, AS	49,300	106							49,300

[a] Populations are calculated on separate sheet from the sources indicated
[b] Number of Head Slaughtered for all of 1995 is earliest data available
[c] Not calculated off of an average population. Info unavailable for calc of avg.
[d] January data comes from Dec 1 1989, July data comes from June 1, 1990
[e] December 1, 1995 through November 30, 1996
[f] Equine includes horses, ponies, mules, burros, and donkeys
[g] DA= Domesticated Animals, MM= Manure Management, AS= Agricultural Soils

Data Source Numbers

100 "Cattle Final Estimates 1989-93" NASS released Jan, 1995
101 "Livestock Slaughter" NASS releases Feb 24, 1995 through Jan 26, 1996
102"Hogs & Pigs Final Estimates 1988-92" NASS Statistical Bulletin Number 904
103 "Chicken and Eggs Final Estimates 1988-93" NASS Statistical Bulletin Number 908
104 "Poultry Production and Value Final Estimates 1988-93 " NASS Statistical Bulletin Number 910
105 "Sheep and Goats Final Estimates 1989-93" NASS Statistical Bulletin Number 906
106 "Iowa Greenhouse Gas Action Plan"

DOMESTICATED ANIMALS DARS SCORES

DARS SCORES: CH_4 EMISSIONS FROM CATTLE					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*4*	*Because the emission factors are not based on measurement, the highest possible score is 5. Since the factors are derived from a model, applying the DARS formula the score would be 3; however, the model is sophisticated.*	*8*	*Data on annual average animal populations are estimated based on state and national data.*	*0.32*
Source Specificity	*10*	*The emission factors were developed specifically for the intended emission source (i.e., eight categories of cattle were modeled).*	*9*	*The activity measured, average animal population, is very closely correlated to the emissions activity.*	*0.90*
Spatial Congruity	*7*	*The emission factor was developed for five regions of the U.S. (each larger than a state). However, spatial variability for the emissions factor within each region is assumed to be moderate.*	*10*	*States use state-level activity data to estimate state-wide emissions.*	*0.70*
Temporal Congruity	*7*	*The emission factors are based on a model, not on measured emissions over a particular time frame. Temporal variability is expected to be low to moderate.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.70*
				Composite Score	*0.66*

DARS SCORES: CH_4 EMISSIONS FROM DOMESTICATED ANIMALS OTHER THAN CATTLE					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*Because the emission factor is not based on measurement, the highest possible score is 5. Since the factor is derived from a model, applying the DARS formula the score would be 3. The model uses only one emission factor for each species (i.e., it does not adjust for animal mass).*	*8*	*Data on annual average animal populations are estimated based on state and national data.*	*0.24*
Source Specificity	*10*	*The emission factors were developed specifically for the intended emission source (i.e., an emission factor was developed for each species).*	*9*	*The activity measured, average animal population, is very closely correlated to the emissions activity.*	*0.90*
Spatial Congruity	*7*	*A single global emission factor was developed for each species. Spatial variability for the emission factors is assumed to be moderate.*	*10*	*States use state-level activity data to estimate state-wide emissions.*	*0.70*
Temporal Congruity	*7*	*The emission factors are based on a model, not on measured emissions over a particular time frame. Temporal variability is expected to be low to moderate.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.70*
				Composite Score	*0.64*

III. CH_4 and N_2O from Manure Management

Methane emissions from manure management were estimated for each animal type by manure management system on the worksheet titled "Year 2000 CH_4 Emissions from Manure Management." Average animal populations in the inventory year were used. For an explanation of "average population" see the method for enteric fermentation from domesticated animals. A fractional breakdown was provided by the EIIP estimating the part of animal manure that is handled in each manure system by animal type (Fraction of Waste System Usage, column A). The EIIP determined these fractions by obtaining information from staff of the USDA agricultural extension office. These fractions were multiplied by average populations to give estimates of the number of animals with manure going into each management system (Number of Animals using System, column C). Emissions were estimated based on the typical animal mass, a volatile solid emission factor, the factor for the maximum CH_4 producing capacity of the manure, and a CH_4 conversion factor for each manure management system. The EIIP obtained these factors from the American Society of Agricultural Engineers, literature review and EPA sponsored analysis.

Nitrous oxide emissions were estimated on the worksheet titled "2000 N_2O Emissions from Manure Management" by aggregating management systems into two groups. Solid storage, drylot and other systems were aggregated into one group. The second group consisted of anaerobic lagoons, and liquid systems. First the quantity of nitrogen that is managed in all systems is estimated from average animal populations (column A), typical animal mass estimates (column B), a Kjeldahl nitrogen excretion factor for each animal type based on animal mass (column C), and the EIIP provide fraction for livestock manure that is handled in all management systems (column D). That is, all manure that is not either applied through daily spread or deposited directly to pasture, range, or paddock. Once the amount of manure nitrogen excreted into all systems was known, a 20% volatilization correction factor was applied to remove the N that escapes as NH_3 and NO_x from the stock that is being managed.

At this point, the total managed manure is multiplied by the fraction representing the total manure that is managed in one of the two groups of systems (columns H and N). The managed N is multiplied by the N_2O emission factor specific to the group (columns J and P). These emission factors have been established by the IPCC for the Revised 1996 Guidelines for National Greenhouse Gas Inventories. From here, emissions are converted to the appropriate unit.

Year 2000 N_2O Emissions from Manure Management

column label	A	B	C	D	E	F	G
calculation	input	input	input	input	A x (B/1000) x C x D x 365	input	E x F
Animal Type	**Iowa Average Population 2000**	**Typical Animal Mass, TAM 1/**	**Kjeldahl N per day per 1000 kg mass 1/**	**Fraction of Manure Managed**	**Total Kjeldahl N Managed**	**Volatilization Correction Factor**	**Unvolatilized N**
	head	**kg**	**kg/day**	**fraction**	**kg/yr**		**kg N**
Milk Cows	215,702	604.0	0.44	0.92	19,249,723	0.80	15,399,778
Beef Cows	1,030,817	590.0	0.34	0.13	9,811,801	0.80	7,849,441
Breeding Bulls	67,054	750.0	0.31	0.13	739,748	0.80	591,798
PreWeaned Calves	712,984	159.0	0.30	0.13	1,613,743	0.80	1,290,994
Heifers & Steers Not on Feed	117,609	369.0	0.31	0.13	638,359	0.80	510,687
Steers and Heifers On Feed	563,345	420.0	0.30	0.13	3,368,071	0.80	2,694,457
Market Swine	14,209,836	53.8	0.47	0.96	124,475,985	0.80	99,580,788
Breeding Swine	1,160,000	198.0	0.24	0.96	19,315,169	0.80	15,452,135
Layers	27,282,126	1.8	0.62	1.00	11,113,101	0.80	8,890,481
Broilers	17,200,000	0.9	1.10	1.00	6,215,220	0.80	4,972,176
Turkeys	7,100,000	6.8	0.74	1.00	13,040,428	0.80	10,432,342
Sheep	300,944	27.0	0.42	0.01	12,456	0.80	9,965
Goats	12,275	64.0	0.45	0.00	0	0.80	0
Horses/Mules	100,000	450.0	0.30	0.00	0	0.80	0
					209,593,803.94		167,675,043

1/ Factor comes from USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000 Table L-2

Emissions from Manure Managed in Solid Storage, Drylot and Other Undefined Systems & Litter, Deep P

column label	H	I	J	K	L	M
calculation	input	G x H	input	I x J	K x (44/28)	L/1000 x 310 x (12/44)
Animal Type	**Fraction of Manure Managed in Solid Storage Drylot & Other Systems**	**Amount Manure Nitrogen Managed in These Systems**	**N_2O Emission Factor**	**N2O-N Emission**	**Total N_2O Emissions**	**Emissions from Solid Storage Drylot & Other Systems**
	fraction	**kg N**	**kg N_2O-N/kg N**	**kg N_2O-N**	**kg N_2O/yr**	**MTCE**
Milk Cows	0.69	10,625,847	0.02	212,517	333,955	28,234
Beef Cows	0.13	1,020,427	0.02	20,409	32,071	2,711
Breeding Bulls	0.13	76,934	0.02	1,539	2,418	204
PreWeaned Calves	0.13	167,829	0.02	3,357	5,275	446
Heifers & Steers Not on Feed	0.13	66,389	0.02	1,328	2,087	176
Steers and Heifers On Feed	0.13	350,279	0.02	7,006	11,009	931
Market Swine	0.43	42,819,739	0.02	856,395	1,345,763	113,778
Breeding Swine	0.43	6,644,418	0.02	132,888	208,825	17,655
Layers	0.94	8,357,052	0.02	167,141	262,650	22,206
Broilers	1.00	4,972,176	0.02	99,444	156,268	13,212
Turkeys	1.00	10,432,342	0.02	208,647	327,874	27,720
Sheep	0.01	100	0.02	2	3	0
Goats	0.00	0	0.02	0	0	0
Horses/Mules	0.00	0	0.02	0	0	0
				1,710,671		

Emissions from Manure Managed in Anaerobic Lagoons, Liquid Slurry, Pit Storag

column label	N	O	P	Q	R	S
calculation	input	G x N	input	O x P	Q x (44/28)	(R/1000) x 310 x (12/44)
Animal Type	**Fraction Manure Managed in Anaerobic Lagoons and Liq Slurry**	**Amount Manure Nitrogen Managed in These Systems**	**N_2O Emission Factor**	**N2O-N Emission**	**Total N_2O Emissions**	**Emissions from Anaerobic Lagoons & Liq Slurry**
	fraction	**(kg N)**	**(kg N_2O-N/kg N)**	**(kg N_2O-N)**	**(kg N_2O/yr)**	**(MTCE)**
Milk Cows	0.23	3,541,949	0.001	3,542	5,566	471
Beef Cows	0.00	0	0.001	0	0	0
Breeding Bulls	0.00	0	0.001	0	0	0
PreWeaned Calves	0.00	0	0.001	0	0	0
Heifers & Steers Not on Feed	0.00	0	0.001	0	0	0
Steers and Heifers On Feed	0.00	0	0.001	0	0	0
Market Swine	0.53	52,777,818	0.001	52,778	82,937	7,012
Breeding Swine	0.53	8,189,632	0.001	8,190	12,869	1,088
Layers	0.06	533,429	0.001	533	838	71
Broilers	0.00	0	0.001	0	0	0
Turkeys	0.00	0	0.001	0	0	0
Sheep	0.00	0	0.001	0	0	0
Goats	0.00	0	0.001	0	0	0
Horses/Mules	0.00	0	0.001	0	0	0
				65,043		

Summary of N_2O Emissions from Manure Management, 2000

column label	T	U	V	
calculation	M	S	T + U	
Animal Type	**Emissions from Solid Storage Drylot & Other Systems (MTCE)**	**Emissions from Anaerobic Lagoons & Liq Slurry (MTCE)**	**Total Emissions from All Systems (MTCE)**	
Milk Cows	28,234	471	28,705	
Beef Cows	2,711	0	2,711	
Breeding Bulls	204	0	204	
PreWeaned Calves	446	0	446	
Heifers & Steers Not on Feed	176	0	176	
Steers and Heifers On Feed	931	0	931	
Market Swine	113,778	7,012	120,790	
Breeding Swine	17,655	1,088	18,743	
Layers	22,206	71	22,277	
Broilers	13,212	0	13,212	
Turkeys	27,720	0	27,720	
Sheep	0	0	0	
Goats	0	0	0	
Horses/Mules	0	0	0	
	227,275	8,641	235,916	MTCE

1990 N_2O Emissions from Manure Management

column label	A	B	C	D	E	F	G
calculation	input	input	input	input	A x (B/1000) x C x D x 365	input	E x F
Animal Type	**Iowa Average Population 2000**	**Typical Animal Mass, TAM 1/**	**Kjeldahl N per day per 1000 kg mass 1/**	**Fraction of Manure Managed**	**Total Kjeldahl N Managed**	**Volatilization Correction Factor**	**Unvolatilized N**
	head	**kg**	**kg/day**	**fraction**	**kg/yr**		**kg N**
Milk Cows	284,787	604.0	0.44	0.92	25,414,982	0.80	20,331,986
Beef Cows	1,122,661	590.0	0.34	0.13	10,686,015	0.80	8,548,812
Breeding Bulls	80,741	750.0	0.31	0.13	890,745	0.80	712,596
PreWeaned Calves	1,129,375	159.0	0.30	0.13	2,556,188	0.80	2,044,950
Heifers & Steers Not on Feed	1,383,088	369.0	0.31	0.13	7,507,135	0.80	6,005,708
Steers and Heifers On Feed	573,530	420.0	0.30	0.13	3,428,967	0.80	2,743,173
Market Swine	11,795,318	53.8	0.47	0.96	103,325,177	0.80	82,660,142
Breeding Swine	1,705,481	198.0	0.24	0.96	28,397,978	0.80	22,718,382
Layers	8,058,296	1.8	0.62	1.00	3,282,466	0.80	2,625,973
Broilers	9,450,000	0.9	1.10	1.00	3,414,758	0.80	2,731,806
Turkeys	8,800,000	6.8	0.74	1.00	16,162,784	0.80	12,930,227
Sheep	490,000	27.0	0.42	0.01	20,282	0.80	16,225
Goats	11,784	64.0	0.45	0.00	0	0.80	0
Horses/Mules	49,300	450.0	0.30	0.00	0	0.80	0
					205,087,476.51		164,069,981

1/ Factor comes from USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000 Table L-2

Emissions from Manure Managed in Solid Storage, Drylot and Other Undefined Systems & Litter, Deep Pit

column label	H	I	J	K	L	M
calculation	input	G x H	input	I x J	K x (44/28)	L/1000 x 310 x (12/44)
Animal Type	**Fraction of Manure Managed in Solid Storage Drylot & Other Systems**	**Amount Manure Nitrogen Managed in These Systems**	**N_2O Emission Factor**	**N2O-N Emission**	**Total N_2O Emissions**	**Year 2000 Emissions from Solid Storage Drylot & Other Systems**
	fraction	**kg N**	**kg N_2O-N/kg N**	**kg N_2O-N**	**kg N_2O/yr**	**MTCE**
Milk Cows	0.69	14,029,070	0.02	280,581	440,914	37,277
Beef Cows	0.13	1,111,346	0.02	22,227	34,928	2,953
Breeding Bulls	0.13	92,637	0.02	1,853	2,911	246
PreWeaned Calves	0.13	265,844	0.02	5,317	8,355	706
Heifers & Steers Not on Feed	0.13	780,742	0.02	15,615	24,538	2,075
Steers and Heifers On Feed	0.13	356,613	0.02	7,132	11,208	948
Market Swine	0.43	35,543,861	0.02	710,877	1,117,093	94,445
Breeding Swine	0.43	9,768,904	0.02	195,378	307,023	25,957
Layers	0.94	2,468,415	0.02	49,368	77,579	6,559
Broilers	1.00	2,731,806	0.02	54,636	85,857	7,259
Turkeys	1.00	12,930,227	0.02	258,605	406,379	34,357
Sheep	0.01	162	0.02	3	5	0
Goats	0.00	0	0.02	0	0	0
Horses/Mules	0.00	0	0.02	0	0	0
				1,601,593		

Emissions from Manure Managed in Anaerobic Lagoons, Liquid Slurry, Pit Storage

column label	N	O	P	Q	R	S
calculation	input	G x N	input	O x P	Q x (44/28)	(R/1000) x 310 x (12/44)
Animal Type	**Fraction Manure Managed in Anaerobic Lagoons and Liq Slurry fraction**	**Amount Manure Nitrogen Managed in These Systems (kg N)**	**N_2O Emission Factor (kg N_2O-N/kg N)**	**N2O-N Emission (kg N_2O-N)**	**Total N_2O Emissions (kg N_2O/yr)**	**Year 2000 Emissions from Anaerobic Lagoons & Liq Slurry (MTCE)**
Milk Cows	0.23	4,676,357	0.001	4,676	7,349	621
Beef Cows	0.00	0	0.001	0	0	0
Breeding Bulls	0.00	0	0.001	0	0	0
PreWeaned Calves	0.00	0	0.001	0	0	0
Heifers & Steers Not on Feed	0.00	0	0.001	0	0	0
Steers and Heifers On Feed	0.00	0	0.001	0	0	0
Market Swine	0.53	43,809,875	0.001	43,810	68,844	5,820
Breeding Swine	0.53	12,040,743	0.001	12,041	18,921	1,600
Layers	0.06	157,558	0.001	158	248	21
Broilers	0.00	0	0.001	0	0	0
Turkeys	0.00	0	0.001	0	0	0
Sheep	0.00	0	0.001	0	0	0
Goats	0.00	0	0.001	0	0	0
Horses/Mules	0.00	0	0.001	0	0	0
				60,685		

Summary of N_2O Emissions from Manure Management, 1990

column label	T	U	V	
calculation	M	S	T + U	
Animal Type	**Year 2000 Emissions from Solid Storage Drylot & Other Systems (MTCE)**	**Year 2000 Emissions from Anaerobic Lagoons & Liq Slurry (MTCE)**	**Total Emissions from All Systems (MTCE)**	
Milk Cows	37,277	621	37,899	
Beef Cows	2,953	0	2,953	
Breeding Bulls	246	0	246	
PreWeaned Calves	706	0	706	
Heifers & Steers Not on Feed	2,075	0	2,075	
Steers and Heifers On Feed	948	0	948	
Market Swine	94,445	5,820	100,266	
Breeding Swine	25,957	1,600	27,557	
Layers	6,559	21	6,580	
Broilers	7,259	0	7,259	
Turkeys	34,357	0	34,357	
Sheep	0	0	0	
Goats	0	0	0	
Horses/Mules	0	0	0	
	212,783	8,062	220,845	MTCE
	780,204	29,562	809,766	CO2 Equiv

2000 CH_4 Emissions from Manure Management

	column label	A	B	C	D	E	F	G	H	I	J	K
	calculation	input	input	A x B	input	input	((C x D)/1000) x E x 365	input	F x G	input	H x I	J x 0.66
Animal Type	Manure System	Fraction of Waste System Usage	2000 IA Avg Pop	Number of Animals using System	Typical Animal Mass (TAM) 4/	Volatile Solids Emission Factor 4/	Total Volatile Solids Produced	Max CH4 producing capacity of Manure (Bo) 4/	Maximum Potential Methane Emissions	CH4 Conversion Factor for System 5/	Methane Emissions	Methane Emissions
		fraction	(Total head)	(head)	kg	kg/day/ 1000 kg mass	kg	(m3 CH4/kg vs)	(m3 CH4)	fraction	(m3 CH4)	(kg)
Female Cattle												
Milk Cows												
	Daily Spread	0.08	215,702	17,256.15	604	8.46	32,184,297	0.24	7,724,231	0.002	15,448.46	10,195.99
	Soild Storage	0.65	215,702	140,206.20	604	8.46	261,497,411	0.24	62,759,379	0.009	564,834.41	372,790.71
	Liquid/Slurry	0.20	215,702	43,140.37	604	8.46	80,460,742	0.24	19,310,578	0.2627	5,072,888.84	3,348,106.64
	Anaerobic Lag(	0.03	215,702	6,471.06	604	8.46	12,069,111	0.24	2,896,587	0.6981	2,022,107.18	1,334,590.74
	Other	0.04	215,702	8,628.07	604	8.46	16,092,148	0.24	3,862,116	0.1	386,211.56	254,899.63
											Milk Cow Total	5,320,583.70
Beef Cows												
	Pasture/Range	0.87	1,030,817	896,810.57	590	6.04	1,166,494,067	0.17	198,303,991	0.009	1,784,735.92	1,177,925.71
	Drylot	0.13	1,030,817	134,006.18	590	6.04	174,303,711	0.17	29,631,631	0.011	325,947.94	215,125.64
											Beef Cow Total	1,393,051.35
Male Cattle												
Breeding Bulls												
	Pasture/Range	0.87	67,054	58,337.05	750	6.04	96,457,391	0.17	16,397,757	0.009	147,579.81	97,402.67
	Drylot	0.13	67,054	8,717.03	750	6.04	14,413,173	0.17	2,450,239	0.011	26,952.63	17,788.74
											Breeding Bull Total	115,191.41
Young Cattle												
Growing Calves												
	Pasture/Range	0.87	712,984	620,296.03	159	6.41	230,752,822	0.17	39,227,980	0.009	353,051.82	233,014.20
	Drylot	0.13	712,984	92,687.91	159	6.41	34,480,307	0.17	5,861,652	0.011	64,478.17	42,555.59
											Growing Calves Total	275,569.79
Growing Heifers, Steers/Bullocks/ Bulls (Not on Feed)												
	Pasture/Range	0.87	1,173,609	1,021,039.83	369	6.08	836,113,997	0.17	142,139,379	0.009	1,279,254.42	844,307.91
	Drylot	0.13	1,173,609	152,569.17	369	6.08	124,936,574	0.17	21,239,218	0.011	233,631.39	154,196.72
											Growing Heifers, Steers/Bullocks/ Bulls (Not on Feed) Tota	998,504.63
Feedlot-Fed Steers and Heifers on High-Grain Diets (on feed)												
	Pasture/Range	0.87	563,345	490,110.26	420	5.44	408,728,433	0.33	134,880,383	0.009	1,213,923.45	801,189.48
	Drylot	0.13	563,345	73,234.87	420	5.44	61,074,364	0.33	20,154,540	0.011	221,699.94	146,321.96
											Feedlot-Fed Steers and Heifers on High-Grain Diets (on feed) Total	947,511.44
Swine												
Market												
	Drylot	0.30	14,209,836	4,262,950.80	90.75	5.40	762,506,549	0.48	366,003,144	0.011	4,026,034.58	2,657,182.82
	Anaerobic Lag(	0.03	14,209,836	426,295.08	90.75	5.40	76,250,655	0.48	36,600,314	0.6981	25,550,679.46	16,863,448.45
	Pit Storage < 1	0.11	14,209,836	1,563,081.96	90.75	5.40	279,585,735	0.48	134,201,153	0.13135	17,627,321.41	11,634,032.13
	Pit Storage > 1	0.39	14,209,836	5,541,836.04	90.75	5.40	991,258,514	0.48	475,804,087	0.2627	124,993,733.61	82,495,864.19
	Other	0.13	14,209,836	1,847,278.68	90.75	5.40	330,419,505	0.48	158,601,362	0.2	31,720,272.46	20,935,379.82
											Market Swine Total	134,585,907.40
Breeding												
	Drylot	0.30	1,160,000	348,000.00	198	2.60	65,389,896	0.48	31,387,150	0.011	345,258.65	227,870.71
	Anaerobic Lag(	0.03	1,160,000	34,800.00	198	2.60	6,538,990	0.48	3,138,715	0.6981	2,191,136.95	1,446,150.39
	Pit Storage < 1	0.11	1,160,000	127,600.00	198	2.60	23,976,295	0.48	11,508,622	0.13135	1,511,657.46	997,693.92
	Pit Storage > 1	0.39	1,160,000	452,400.00	198	2.60	85,006,865	0.48	40,803,295	0.2627	10,719,025.62	7,074,556.91
	Other	0.13	1,160,000	150,800.00	198	2.60	28,335,622	0.48	13,601,098	0.2	2,720,219.67	1,795,344.98
											Breeding Swine Total	11,541,616.91
Poultry												
Chickens: Layers												
	Deep Pit Stacks	0.90	27,282,126	24,553,913.26	1.8	9.70	156,479,634	0.39	61,027,057	0.2627	16,031,807.92	10,580,993.23
	Liquid/Slurry	0.04	27,282,126	1,091,285.03	1.8	9.70	6,954,650	0.39	2,712,314	0.2627	712,524.80	470,266.37
	Anaerobic Lag(	0.02	27,282,126	545,642.52	1.8	9.70	3,477,325	0.39	1,356,157	0.6981	946,733.08	624,843.83
	Other	0.04	27,282,126	1,091,285.03	1.8	9.70	6,954,650	0.39	2,712,314	0.1	271,231.37	179,012.70
											Chicken: Layers Total	11,855,116.13

Animal Type	Manure System	Fraction of Waste System Usage	2000 IA Avg Pop	Number of Animals using System	Typical Animal Mass (TAM) 4/	Volatile Solids Emission Factor 4/	Total Volatile Solids Produced	Max CH4 producing capacity of Manure (Bo) 4/	Maximum Potential Methane Emissions	CH4 Conversion Factor for System 5/	Methane Emissions	Methane Emissions
		fraction	**(Total head)**	**(head)**	**kg**	**kg/day/ 1000 kg mass**	**kg**	**(m3 CH4/kg vs)**	**(m3 CH4)**	**fraction**	**(m3 CH4)**	**(kg)**
Chickens: Broilers 1/												
	Litter	1.00	17,200,000	17,200,000.00	0.9	15.00	84,753,000	0.36	30,511,080	0.1	3,051,108.00	2,013,731.28
											Chickens:Broilers Total	2,013,731.28
Turkeys												
	Litter	1.00	7,100,000	7,100,000.00	6.8	9.70	170,935,340	0.36	61,536,722	0.1	6,153,672.24	4,061,423.68
											Turkeys Total	4,061,423.68
Other Animals												
Sheep												
	Pasture/Range	0.99	300,944	297,934.16	27	0.00	0	0	0	0.009	0.00	0.00
	Other	0.01	300,944	3,009.44	27	0.00	0	0	0	0.1	0.00	0.00
											Sheep Total	0.00
Goats 2/												
	Pasture/Range	1.00	12,275	12,275.00	64	0.00	0	0	0	0.009	0.00	0.00
											Goats Total	0.00
Equine 2/ 3/												
	Pasture/Range	0.92	100,000	92,000.00	450	0.00	0	0	0	0.009	0.00	0.00
	Paddock	0.08	100,000	8,000.00	450	0.00	0	0	0	0.009	0.00	0.00
											Equine Total	0.00

Total Kg	173,108,208
Total lbs	380838057.00
Total tons	190419.03
CO2 Equiv.	3,627,711
MTCE	**989,375.73**

1/ December 1, 1995 through November 30, 1996
2/ 2000 Populations are not averages
3/ Equine includes horses, ponies, mules, burros, and donkeys data from 1999 NASS "Equine" Report (1999 Data)
4/ Factor comes from USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000 Table L-2
5/ Liquid/Slurry Deep Pit and Anaerobic Lagoon Factor comes from USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000 Table L-4

1990 CH_4 Emissions from Manure Management

Animal Type	Manure System	Fraction of Waste System Usage	1990 IA Avg Pop	Number of Animals using System	Typical Animal Mass (TAM) 4/	Volatile Solids Emission Factor 4/	Total Volatile Solids Produced	Max CH4 producing capacity of Manure (Bo) 4/	Maximum Potential Methane Emissions	CH4 Conversion Factor for System 5/	Methane Emissions	Methane Emissions
	column label	A	B	C	D	E	F	G	H	I	J	K
	calculation	input	input	A x B	input	input	((C x D)/1000) x E x 365	input	F x G	input	H x I	J x 0.66
		fraction	(Total head)	(head)	kg	kg/day/ 1000 kg mass	kg	(m3 CH4/kg vs)	m3 cH4	fraction	(m^3 CH_4)	(kg)
Female Cattle												
Milk Cows												
	Daily Spread	0.08	284,787	22,782.93	604	8.46	42,492,243	0.24	10,198,138	0.002	20,396.28	13,461.54
	Soild Storage	0.65	284,787	185,111.27	604	8.46	345,249,476	0.24	82,859,874	0.009	745,738.87	492,187.65
	Liquid/Slurry	0.20	284,787	56,957.31	604	8.46	106,230,608	0.24	25,495,346	0.2627	6,697,627.37	4,420,434.06
	Anaerobic Lag	0.03	284,787	8,543.60	604	8.46	15,934,591	0.24	3,824,302	0.6981	2,669,745.15	1,762,031.80
	Other	0.04	284,787	11,391.46	604	8.46	21,246,122	0.24	5,099,069	0.1	509,906.92	336,538.57
											Milk Cow Total	7,024,653.62
Beef Cows												
	Pasture/Range	0.87	1,122,661	976,715.47	590	6.04	1,270,427,485	0.17	215,972,673	0.009	1,943,754.05	1,282,877.67
	Drylot	0.13	1,122,661	145,945.99	590	6.04	189,833,992	0.17	32,271,779	0.011	354,989.57	234,293.11
											Beef Cow Total	1,517,170.79
Male Cattle												
Breeding Bulls												
	Pasture/Range	0.87	80,741	70,244.44	750	6.04	116,145,677	0.17	19,744,765	0.009	177,702.89	117,283.90
	Drylot	0.13	80,741	10,496.30	750	6.04	17,355,101	0.17	2,950,367	0.011	32,454.04	21,419.67
											Breeding Bull Total	138,703.57
Young Cattle												
Growing Calves												
	Pasture/Range	0.87	1,129,375	982,556.31	159	6.41	365,515,221	0.17	62,137,588	0.009	559,238.29	369,097.27
	Drylot	0.13	1,129,375	146,818.76	159	6.41	54,617,217	0.17	9,284,927	0.011	102,134.20	67,408.57
											Growing Calves Total	436,505.84
Growing Heifers, Steers/Bullocks/ Bulls (Not on Feed)												
	Pasture/Range	0.87	1,383,088	1,203,286.94	369	6.08	985,353,386	0.17	167,510,076	0.009	1,507,590.68	995,009.85
	Drylot	0.13	1,383,088	179,801.50	369	6.08	147,236,713	0.17	25,030,241	0.011	275,332.65	181,719.55
											Growing Heifers, Steers/Bullocks/ Bulls (Not on Feed) Tota	1,176,729.40
Feedlot-Fed Steers and Heifers on High-Grain Diets (on feed)												
	Pasture/Range	0.87	573,530	498,971.52	420	5.44	416,118,296	0.33	137,319,038	0.009	1,235,871.34	815,675.08
	Drylot	0.13	573,530	74,558.96	420	5.44	62,178,596	0.33	20,518,937	0.011	225,708.30	148,967.48
											Feedlot-Fed Steers and Heifers on High-Grain Diets (on feed) Total	964,642.56
Swine												
Market												
	Drylot	0.30	11,795,318	3,538,595.40	90.75	5.40	632,942,367	0.48	303,812,336	0.011	3,341,935.70	2,205,677.56
	Anaerobic Lag	0.03	11,795,318	353,859.54	90.75	5.40	63,294,237	0.48	30,381,234	0.6981	21,209,139.18	13,998,031.86
	Pit Storage < 1	0.11	11,795,318	1,297,484.98	90.75	5.40	232,078,868	0.48	111,397,857	0.13135	14,632,108.46	9,657,191.58
	Pit Storage > 1	0.39	11,795,318	4,600,174.02	90.75	5.40	822,825,077	0.48	394,956,037	0.2627	103,754,950.87	68,478,267.57
	Other	0.13	11,795,318	1,533,391.34	90.75	5.40	274,275,026	0.48	131,652,012	0.2	26,330,402.45	17,378,065.62
											Market Swine Total	111,717,234.19
Breeding												
	Drylot	0.30	1,705,481	511,644.30	198	2.60	96,138,987	0.48	46,146,714	0.011	507,613.85	335,025.14
	Anaerobic Lag	0.03	1,705,481	51,164.43	198	2.60	9,613,899	0.48	4,614,671	0.6981	3,221,502.10	2,126,191.38
	Pit Storage < 1	0.11	1,705,481	187,602.91	198	2.60	35,250,962	0.48	16,920,462	0.13135	2,222,502.65	1,466,851.75
	Pit Storage > 1	0.39	1,705,481	665,137.59	198	2.60	124,980,683	0.48	59,990,728	0.2627	15,759,564.26	10,401,312.41
	Other	0.13	1,705,481	221,712.53	198	2.60	41,660,228	0.48	19,996,909	0.2	3,999,381.87	2,639,592.03
											Breeding Swine Total	16,968,972.72
Poultry												
Chickens: Layers												
	Deep Pit Stacks	0.90	8,058,296	7,252,466.40	1.8	9.70	46,219,243	0.39	18,025,505	0.2627	4,735,300.12	3,125,298.08
	Liquid/Slurry	0.04	8,058,296	322,331.84	1.8	9.70	2,054,189	0.39	801,134	0.2627	210,457.78	138,902.14
	Anaerobic Lag	0.02	8,058,296	161,165.92	1.8	9.70	1,027,094	0.39	400,567	0.6981	279,635.66	184,559.54
	Other	0.04	8,058,296	322,331.84	1.8	9.70	2,054,189	0.39	801,134	0.1	80,113.35	52,874.81
											Chicken: Layers Total	3,501,634.57

Animal Type	Manure System	Fraction of Waste System Usage	1990 IA Avg Pop	Number of Animals using System	Typical Animal Mass (TAM) 4/	Volatile Solids Emission Factor 4/	Total Volatile Solids Produced	Max CH4 producing capacity of Manure (Bo) 4/	Maximum Potential Methane Emissions	CH4 Conversion Factor for System 5/	Methane Emissions	Methane Emissions
	column label	A	B	C	D	E	F	G	H	I	J	K
	calculation	input	input	A x B	input	input	((C x D)/1000) x E x 365	input	F x G	input	H x I	J x 0.66
		fraction	(Total head)	(head)	kg	kg/day/ 1000 kg mass	kg	(m3 CH4/kg vs)	m3 cH4	fraction	(m^3 CH_4)	(kg)
Chickens: Broilers 1/												
	Litter	1.00	9,450,000	9,450,000.00	0.9	15.00	46,564,875	0.36	16,763,355	0.1	1,676,335.50	1,106,381.43
											Chickens:Broilers Total	1,106,381.43
Turkeys												
	Litter	1.00	8,800,000	8,800,000.00	6.8	9.70	211,863,520	0.36	76,270,867	0.1	7,627,086.72	5,033,877.24
											Turkeys Total	5,033,877.24
Other Animals												
Sheep												
	Pasture/Range	0.99	490,000	485,100.00	27	0.00	0	0	0	0.009	0.00	0.00
	Other	0.01	490,000	4,900.00	27	0.00	0	0	0	0.1	0.00	0.00
											Sheep Total	0.00
Goats 2/												
	Pasture/Range	1.00	11,784	11,784.00	64	0.00	0	0	0	0.009	0.00	0.00
											Goats Total	0.00
Equine 2/ 3/												
	Pasture/Range	0.92	49,300	45,356.00	450	0.00	0	0	0	0.009	0.00	0.00
	Paddock	0.08	49,300	3,944.00	450	0.00	0	0	0	0.009	0.00	0.00
											Equine Total	0.00

	149,586,506
Total lbs	329090313
Total tons	164545.1565
CO2 Equiv.	3,134,783
MTCE	**854,940.73**

1/ December 1, 1995 through November 30, 1996

2/ 2000 Populations are not averages

3/ Equine includes horses, ponies, mules, burros, and donkeys

4/ Factor comes from USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000 Table L-2

5/ Liquid/Slurry Deep Pit and Anaerobic Lagoon Factor comes from USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000 Table L-4

MANURE MANAGEMENT DARS SCORES

DARS SCORES: CH4 EMISSIONS FROM MANURE MANAGEMENT					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*Because the emission factor is not based on measurement, the highest possible score is 5. Since the factor is derived from laboratory and field measurements, applying the DARS formula the score would be 5. However, only a few measurements have been taken.*	*8*	*Data on annual average animal populations are estimated based on state and national data.*	*0.24*
Source Specificity	*10*	*The emission factors were developed specifically for the intended emission source (i.e., emission factors were developed for each manure management system).*	*7*	*The activity measured, average animal population, is highly correlated to the emissions activity.*	*0.70*
Spatial Congruity	*6*	*Methane conversion factors are developed for each type of manure management system in each state, but the factors account in only a rough way for the state-by-state variability in average temperature. For lagoons, a single factor is used that does not account for temperature differences among states.*	*8*	*States use state-level activity data or proxy data for similar states to estimate state-wide emissions; spatial variability is expected to be low to moderate.*	*0.48*
Temporal Congruity	*3*	*The emission factors are based on field and laboratory tests that presumably did not cover an entire year. The temporal variability over the course of a year is expected to be high.*	*7*	*States use annual activity data to estimate annual emissions, but the percentage breakdowns for manure management systems are based on data from the early 1990s.*	*0.21*
				Composite Score	*0.41*

DARS SCORES: N2O EMISSIONS FROM MANURE MANAGEMENT					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*IPCC 1997 states that the emission factors (kg N2O-N per kg N excreted) were based on a very limited amount of information; no further information is provided regarding how the emission factors were developed.*	*8*	*Data on annual average animal populations are estimated based on state and national data.*	*0.24*
Source Specificity	*10*	*Emission factors were developed for each type of manure management system.*	*7*	*The activities measured— average animal population and percentage of manure managed using each management system-are highly correlated to the emissions activity.*	*0.70*
Spatial Congruity	*7*	*Single, global emission factors were developed; spatial variability is expected to be moderate.*	*8*	*States use state-level activity data or proxy data for similar states to estimate state-wide emissions; spatial variability is expected to be low to moderate.*	*0.56*
Temporal Congruity	*7*	*Assuming that the limited amount of information used was generated by less than full-year measurements; temporal variability is expected to be low to moderate.*	*7*	*States use annual activity data to estimate annual emissions, but the percentage breakdowns for manure management systems are based on data from the early 1990s.*	*0.49*
				Composite Score	*0.50*

IV. CH_4 and N_2O from Burning Agricultural Wastes

To find the amount of dry matter combusted (column G), the crop production data (column A) was multiplied by the ratio of residue to crop biomass (column B), the fraction of the residue that is burned in Iowa each year (column C) (assumed to be 3%), the fraction of dry matter content of the residue (column D), the fraction of dry biomass that burns (column E) (burning efficiency) and the fraction of carbon that is released (oxidized) during burning (column F) (combustion efficiency). Each of these factors was provided by the EIIP methodology and updated factors were found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000.* The product was then converted to short tons by division by 2000 lbs/ ton.

From the quantity of dry matter combusted, CH_4 and N_2O emissions were calculated. To calculate the total carbon released during combustion, the quantity of combusted dry matter was multiplied by it's carbon content (column I). The total carbon released was multiplied by a fraction representing the part of total released carbon that is in the CH_4 form (column J). For every 1000 atoms of carbon released, 5 carbon atoms are in a CH_4 molecule. The mass of CH_4-C emissions were then expanded to establish the mass of CH_4 emissions by multiplying by the atomic weight ratio of CH_4 and carbon (column L). Methane emissions were converted to metric tons of carbon equivalents (column M). The same calculations were used to estimate N_2O emissions with numbers specific to N content, N_2O-N fraction of total N released, and conversions to MTCE.

Year 2000 CH_4 and N_2O Emissions from Burning Agricultural Wastes

	A	B	C	D	E	F	G
	input	input	input	input	input	input	AxBxCxDxExF/2000
Crop Type	Year 2000 Crop Production[a]	Ratio Residue/Crop	Fraction of Residue Burned	Fraction of Dry Matter	Burning Efficiency	Combustion Efficiency	Dry Matter (DM) Combusted
	lbs						tons
All Corn[b]	96,999,552,000	1	0.03	0.91	0.93	0.88	1,083,597.52
Soybeans[b]	27,858,881,312	2.1	0.03	0.87	0.93	0.88	624,826.01
Wheat	50,731,012	1.3	0.03	0.85	0.93	0.88	688.17
Rice	0	1.4	0.03	0.85	0.93	0.88	0
Sugar Cane	0	0.8	0.03	0.62	0.93	0.88	0

	H	I	J	K	L	M
	input	G x H	input	I x J	K x (16/12)	L x 0.9072 x 21 x (12/44)
	Carbon Content	Total Carbon Released	CH_4-C Emission Ratio	CH_4-C Emission	CH_4 Emissions	CH_4 Emissions
	tons C/ton DM	tons C	ton CH4-C /ton C	tons CH_4-C	tons CH_4	MTCE
All Corn[b]	0.4478	485,235	0.005	2,426	3,235	16,808
Soybeans[b]	0.4500	281,172	0.005	1,406	1,874	9,739
Wheat	0.4428	305	0.005	2	2	11
Rice	0.3806	0	0.005	0	0	0
Sugar Cane	0.4235	0	0.005	0	0	0
					Total CH_4	**26,558**

	N	O	P	Q	R	S
	input	G x N	input	O x P	Q x (44/28)	R x 0.9072 x 310 x (12/44)
	Nitrogen Content	Total Nitrogen Released	N_2O-N Emission Ratio	N_2O-N Emissions	N_2O Emissions	N_2O Emissions
	tons N/ton DM	tons N	ton N_2O-N /ton N	tons N_2O-N	tons N2O	(MTCE)
All Corn[b]	0.0058	6,285	0.007	44	69	5,303
Soybeans[b]	0.0230	14,371	0.007	101	158	12,125
Wheat	0.0062	4	0.007	0	0	4
Rice	0.0072	0	0.007	0	0	0
Sugar Cane	0.0040	0	0.007	0	0	0
					Total N_2O	**17,431**

[a] Production Data is from NASS "Annual Crop Summary for 2001: Iowa", (January 11, 2002)

[b] Figures for Carbon and Nitrogen Contents taken from the EPA U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2000

Year 1990 CH_4 and N_2O Emissions from Burning Agricultural Wastes

	A	B	C	D	E	F	G
	input	input	input	input	input	input	AxBxCxDxExF/2000
Crop Type	Year 1990 Crop Production[a]	Ratio Residue/Crop	Fraction of Residue Burned	Fraction of Dry Matter	Burning Efficiency	Combustion Efficiency	Dry Matter (DM) Combusted
	lbs						tons
All Corn[b]	82,792,266,648	1	0.03	0.91	0.93	0.88	924,885.66
Soybeans[b]	20,005,699,980	2.1	0.03	0.87	0.93	0.88	448,692.88
Wheat	167,299,980	1.3	0.03	0.85	0.93	0.88	2,269.42
Rice	0	1.4	0.03	0.85	0.93	0.88	0
Sugar Cane	0	0.8	0.03	0.62	0.93	0.88	0

	H	I	J	K	L	M
	input	G x H	input	I x J	K x (16/12)	L x 0.9072 x 21 x (12/44)
	Carbon Content	Total Carbon Released	CH_4-C Emission Ratio	CH_4-C Emission	CH_4 Emissions	CH_4 Emissions
	tons C/ton DM	tons C	ton CH4-C /ton C	tons CH_4-C	tons CH_4	MTCE
All Corn[b]	0.4478	414,164	0.005	2,071	2,761	14,346
Soybeans[b]	0.4500	201,912	0.005	1,010	1,346	6,994
Wheat	0.4428	1,005	0.005	5	7	35
Rice	0.3806	0	0.005	0	0	0
Sugar Cane	0.4235	0	0.005	0	0	0
					Total CH_4	**21,375**

	N	O	P	Q	R	S
	input	G x N	input	O x P	Q x (44/28)	R x 0.9072 x 310 x (12/44)
	Nitrogen Content	Total Nitrogen Released	N_2O-N Emission Ratio	N_2O-N Emissions	N_2O Emissions	N_2O Emissions
	tons N/ton DM	tons N	ton N_2O-N /ton N	tons N_2O-N	tons N2O	(MTCE)
All Corn[b]	0.0058	5,364	0.007	38	59	4,526
Soybeans[b]	0.0230	10,320	0.007	72	114	8,707
Wheat	0.0062	14	0.007	0	0	12
Rice	0.0072	0	0.007	0	0	0
Sugar Cane	0.0040	0	0.007	0	0	0
					Total N_2O	**13,245**

[a] Production Data is from NASS "Annual Crop Summary for 2001: Iowa", (January 11, 2002)

[b] Figures for Carbon and Nitrogen Contents taken from the EPA U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2000

BURNING AGRICULTURAL CROP WASTES DARS SCORE

DARS SCORES: GREENHOUSE GAS EMISSIONS FROM BURNING OF AGRICULTURAL CROP WASTES					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*4*	*Because the emission factors for each crop are not based on measurement, the highest possible score is 5.*	*4*	*The amount of crop residues burned is estimated to be three percent for each crop in each state (based on state inventory data reports). The DARS formula does not apply to this scenario.*	*0.16*
Source Specificity	*5*	*The emission factors were developed for crop residues in general; expected variability is high.*	*5*	*The activity measured (crop production) is somewhat correlated to the emission process (crop burning).*	*0.25*
Spatial Congruity	*9*	*The emission factor was developed for a region larger than the one it is applied to; it is not based on state-level crop burning and emissions. However, spatial variability is assumed to be low.*	*10*	*States use state-level activity data to estimate state-wide emissions.*	*0.90*
Temporal Congruity	*9*	*The emission factor is based on mass balance, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.90*
				Composite Score	*0.55*

APPENDIX C
INDUSTRIAL PROCESSES

I. CO_2 from Industrial Processes

Cement and masonry cement manufacture. Because detailed data was not available, average production estimates were drawn from Iowa's clinker capacity as reported by the Portland Cement Association (H. Van Oss, U.S. Geological Survey, personal communication, September 24, 2002). An 85% capacity utilization rate was assumed. A maximum emission scenario was assumed where all clinker went to masonry cement making. Emissions were calculated from the EIIP provide factors.

Limestone use. The *U. S. Geological Survey Minerals Yearbook* reports that Iowa's chemical and metallurgical industries consumed 1.3 million short tons of crushed limestone and dolomite in 1999 (2000). Data for 2000 was withheld to protect proprietary information. It is noted that this data includes consumption by cement manufacture, for which emissions have already been quantified. It is not known how much of the total went to cement manufacture or to what aspects of cement manufacture. The difference represents an unavoidable double counting of CO_2 from limestone used in cement production. Emission estimation consisted of multiplying production data by an average of two emission factors from EIIP for dolomite (0.13 tons C/ton dolomite limestone) and calcite (0.12 tons C/ ton calcite limestone). This was done because consumption data for the different types of limestone was unavailable.

Lime manufacture. Today, Iowa has only one manufacturer of lime. For this reason, the USGS is unable to disclose proprietary production data that was needed to estimate emissions. Instead of calculating emissions based on the production data, a U.S. government source estimated these emissions with an undisclosed EPA methodology.

CO_2 manufacture. State specific data was unavailable. Instead, emissions were estimated by applying a fraction of the state to national population to the reported U.S. emissions in the National 2000 inventory(EPA, 2002). The national inventory assumes that 100% of the CO_2 used in all applications except for enhanced oil recovery is eventually released to the atmosphere

II. N_2O from Industrial Processes

Nitric acid production. Because state specific production data was unavailable, the figures were estimated from the states anhydrous ammonia production. The EPA estimates that 70 percent of nitric acid (HNO_3) produced is consumed as an intermediate for the production of ammonium nitrate (NH_4NO_3), a major component of commercial fertilizer (Environmental Protection Agency, 1998a). It was assumed that those plants that produced anhydrous ammonia produced nitric acid as an early intermediate. We assumed that the fraction of the national anhydrous ammonia capacity in Iowa can be applied to the national nitric acid production (capacity). For 2000 Iowa had 4% of the national anhydrous ammonia capacity (United States Geological Survey, 2000a). Iowa production of nitric acid was estimated to be

338,681 metric tons. This assumption does not necessarily account for all nitric acid production. The remaining 30% of nitric acid that is not associated with ammonium nitrate production is not considered. The emission factor chosen came from the U.S. EPA national inventory (Environmental Protection Agency, 2002). It assumes 20% of plants are equipped with Non-Selective Catalytic Reduction, a technology that is known to destroy 80-90% of N_2O Emissions.

III. Hydrofluorocarbons, Perfluorocarbons and Sulfur Hexafluoride from Industrial Processes

Substitutes for ozone depleting substances. Because state level data was unavailable, national data from the EPA U.S. inventory for 1990-2000 was used as a proxy. National per capita emissions were figured, then multiplied by the year 2000 population of Iowa.

Electricity transmission and distribution. State level data was not available for estimating SF_6 emission. Instead they were estimated by applying the fraction of U.S. electrical generation in Iowa to the U.S. SF_6 emissions (EPA, 2002). The emission estimates for Iowa are highly uncertain especially because not all electric utilities use SF_6. It is more common in urban areas where space occupied by electrical distribution and transmission facilities are more valuable

Other Industries. The production of adipic acid, primary aluminum, and HFC-23 from HCFC-22 are all processes that generate greenhouse gases as a part of their manufacturing processes. These industries are not found in Iowa. Soda ash manufacture and consumption are known to occur in Iowa, however, data on these activities was not available, nor was a method of estimation. CO_2 emissions for these activities were not calculated.

2000 Greenhouse Gas Emissions from Industrial Processes

CO_2 Emissions

Activity	A input Production Unit (short tons)	B input Emission Factor (ton C/ ton production)	C A x B x (44/12) CO_2 Emissions (short tons CO_2)	D C x (12/44) x 0.9072 Carbon Emissions (MTCE)		CO_2 Emis (MTCE)
Cement Clinker Capacity 1/	2,365,811	0.138	1,199,466.18	296,770		296,770
Masonry Cement Capacity 1/	2,365,811	0.006	52,994.17	13,112		13,112
Limestone Use 2/	1,245,599	0.125	570,899.54	141,251		141,251
Lime Manufacture 3/				34,091		34,091
	A input U.S. Emissions (MTCE)	**B** input IA 2000 Population (people)	**C** input U.S. 2000 Population (people)	**D** B/ C IA Fractional Population (fraction)	**E** D x A Carbon Emissions (MTCE)	
CO_2 Manufacture	381,822.00	2,926,324	281,421,906	0.0104	3,970	3,970
Soda Ash Manufacture	@					
Primary Aluminum Production	*					
					Total CO_2 Emissions	489,194

N_2O Emissions

Activity	A input Production Unit (metric ton)	B input Emission Factor (metric ton N_2O/ metric ton)	C A x B N_2O Emissions (metric tons N_2O)	D C x (12/44) x 310 N_2O Emissions (MTCE)	N_2O Emis (MTCE)
Nitric Acid Production	338,680	0.008	2709	229,071	229,071
Adipic Acid Production	*				
				Total N_2O Emissions	229,071

Other Greenhouse Gas Emissions

Activity	A input 2000 U.S. Emissions (MTCE)	B input 2000 U.S. Population (people)	C A / B U.S. Per Capita Emissions (MTCE/Person)	D input IA Population (people)	E C x D HFC and PFC Emissions (MTCE)	Other Emis (MTCE)
HFC's and PFC's from sbst ODS	15,763,636	281,421,906	0.0560	2,926,324	163,916	163,916
	A input U.S. Emissions of SF6 from Utilities (MTCE)	**B** input U.S. Electricity Generation (megawatt hours	**C** input IA Electricity Generation (megawatt hours	**D** B / C IA Generation/ U.S. Generation (fraction)	**E** A x D SF_6 Emissions (MTCE)	
Electric Utilities SF6	3,927,273	3,800,000,000	38,842,106	0.010	40,143	40,143
HFC-23 Production	*					
					Total Emissions of Other Greenhouse Gases	204,059

TOTAL EMISSIONS OF GREENHOUSE GASES FROM PRODUCTION PROCESSES	**922,323**

@ Activity is known to occur, but data was unavailable
# It is not known that activity occurs
* It is known that activity does not occur

1/ Cement production was estimated from Iowa's clincker capacity as reported by the Portland Cement Association. This was upon direction by Hendrick Van Oss, cement specialist at the USGS
2/ Limestone use data came from USGS Minerals Yearbook- 2000, table 4 "Iowa: Crushed stone sold or used by producers in 1999, by use and district
3/ Emissions were estimated by an undisclosed EPA method from a government source

1990 Greenhouse Gas Emissions from Industrial Processe

CO_2 Emissions

Activity	A input Production Unit short tons	B input Emission Factor ton C/ ton production	C A x B x (44/12) CO_2 Emissions short tons CO_2	D C x (12/44) x 0.9072 Carbon Emissions MTCE		CO_2 Emissions MTCE
Cement Clinker	2,120,000	0.138	1,074,840	265,935		265,935
Masonry Cement	15,000	0.006	336	83		83
Limestone Use	3,000,000	0.125	1,375,000	340,200		340,200
Lime Manufacture	2,750,000	0.214	2,158,750	534,114		534,114
	A input U.S. Emissions MTCE	B input IA 1990 Population people	C input U.S. 1990 Population people	D B/ C IA Fractional Population fraction	E D x A Carbon Emissions MTCE	
CO_2 Manufacture	218,184	2,776,755	248,709,873	0.0112	2,436	2,436
Soda Ash Manufacture and Consumption	@					
Primary Aluminum Production	*					
					Total CO_2 Emissions	1,142,768

N_2O Emissions

	A input Production Unit metric ton	B input Emission Factor (m ton C/ m ton)	C A x B N_2O Emissions m tons N_2O	D C x (12/44) x 310 N_2O Emissions MTCE	N_2O Emissions MTCE
Nitric Acid Production	@				
Adipic Acid Production	*				
				Total N_2O Emissions	0

Other Greenhouse Gas Emissions

	A input 1990 U.S. Emissions MTCE	B input 1990 U.S. Population people	C A / B U.S. Per Capita Emissions MTCE/Person	D input 1990 IA Population people	E C x D HFC and PFC Emissions MTCE	Other Emissions (MTCE)
HFC's and PFC's from ODS	245,455	248,709,873	0.001	2,776,755	2,740.41	2,740
	A input of SF6 from Utilities MTCE	B input U.S. Electricity Generation megawatt hours	C input IA Electricity Generation megawatt hours	D B / C IA Generation/ U.S. Generation fraction	E A x D SF_6 Emissions MTCE	
SF_6 from Electric Utilities	8,509,091	3,071,000,000	29,866,280	0.01	82,753.14	82,753
HFC-23 Production	*					
					Total Emissions of Other Greenhouse Gases	85,494

TOTAL EMISSIONS OF GREENHOUSE GASES FROM PRODUCTION PROCESSES	**1,228,262**

@ Activity is known to occur, but data was unavailable
# It is not known that activity occurs
* It is known that activity does not occur

INDUSTRIAL PROCESSES DARS SCORES

DARS SCORES: CO2 EMISSIONS FROM CEMENT PRODUCTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*9*	*Because the emission factor is not based on measurement, the highest possible score is 5. However, the emission factor is based on a precise stoichiometric relationship.*	*9*	*Data on clinker and cement production (from which CC>2 is emitted as a by-product) are aggregated from intermittent measurements.*	*0.81*
Source Specificity	*10*	*The emission factor was developed specifically for the intended emission source.*	*10*	*The activity measured (clinker and cement production) is the activity from which COj is emitted.*	*1.00*
Spatial Congruity	*9*	*The emission factor was developed for a region larger than the one it is applied to; it is not based on state-level production and emissions. However, spatial variability for the emissions factor is assumed to be low.*	*10*	*States use state-level activity data to estimate statewide emissions.*	*0.90*
Temporal Congruity	*9*	*The emission factor is based on mass balance, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*10*	*States use annual activity (fata to estimate annual emissions.*	*0.90*
				Composite Score	*0.90*

DARS SCORES: CO2 EMISSIONS FROM LIME PRODUCTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*8*	*Because the emission factor is not based on measurement, the highest possible score is 5. The emission factor is based on a precise stoichiometric relationship. Applying the DARS formula, the score would be 5. However, the relationship is precise, although some carbon dioxide is reabsorbed when lime is used for certain purposes.*	*9*	*Data on lime production (from which CO_2 is emitted as a by-product) are aggregated from intermittent measurements.*	*0.72*
Source Specificity	*7*	*Although the emission factor was developed specifically for the intended emission source, the data source does not account for all lime production. Thus, the emission factor is based on a subset of emission sources. Variability in emissions across sources is assumed to be low to moderate.*	*9*	*The data source for the activity measured (lime production) does not account for all lime production. Assuming the lime production activity reported is very closely correlated to all lime production activity, the highest score possible is 9.*	*0.63*
Spatial Congruity	*9*	*The emission factor was developed for a region larger than the one it is applied to; it is not based on state-level production and emissions. However, spatial variability for the emissions factor is assumed to be low.*	*10*	*States use state-level activity data to estimate statewide emissions.*	*0.90*
Temporal Congruity	*7*	*The emission factor is based on mass balance, not on measured emissions over a particular time frame. The use of pollution control equipment introduces additional variability, assumed to be low to moderate.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.70*
				Composite Score	*0.74*

DARS SCORES: CO2 EMISSIONS FROM LIMESTONE USE					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*8*	*Because the emission factor is not based on measurement, the highest possible score is 5. The emission factor is based on a precise stoichiometric relationship. Applying the DARS formula, the score would be 5. However, the relationship is precise, although some carbon may not be released as CO2 when lime is used for certain purposes.*	*6*	*Data for limestone consumption (from which CO_2 is emitted as a by-product) are based on a proxy (limestone sales).*	*0.48*
Source Specificity	*10*	*The emission factor was developed specifically for the intended emission source.*	*10*	*Limestone consumption - the activity measured with a proxy - is the activity from which CO_2 is emitted.*	*1.00*
Spatial Congruity	*9*	*The emission factor was developed for a region larger than the one it is applied to; it is not based on state-level production and emissions. However, spatial variability for the emissions factor is assumed to be low.*	*3*	*States may need to estimate the state-level activity data based on national-level data; in that case, spatial variability is expected to be high.*	*0.27*
Temporal Congruity	*9*	*The emission factor is based on stoichiometry, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.90*
				Composite Score	*0.66*

DARS SCORES: CO_2 EMISSIONS FROM SODA ASH MANUFACTURE AND CONSUMPTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*Because the emission factors are not based on measurement, the highest possible score is 5. The emission factors are based on a stoichiometric relationship. Applying the DARS formula, the score would be 5. However, the relationship is precise, although CO2 emissions from consumption are less for some uses.*	*7.5*	*Data on soda ash manufacture are aggregated from intermittent measurements, suggesting a score of 9. Data for soda ash consumption are based on a proxy (sales), suggesting a score of 6. The composite score is 7.5.*	*0.38*
Source Specificity	*10*	*The emission factor was developed specifically for the intended emission source.*	*10*	*The activities measured (either directly or by proxy) are the activities from which CQj is emitted.*	*1.00*
Spatial Congruity	*9*	*The emission factor was developed for a region larger than the one it is applied to; it is not based on state-level production and emissions. However, spatial variability for the emissions factor is assumed to be low.*	*10*	*States use state-level activity data to estimate statewide emissions.*	*0.90*
Temporal Congruity	*9*	*The emission factor is based on mass balance, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.90*
				Composite Score	*0.79*

DARS SCORES: CO2 EMISSIONS FROM CARBON DIOXIDE MANUFACTURE					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	3	The U.S. GHG inventory emission factor (CO2 emitted equals 20 percent of CO2 consumed for uses other than enhanced oil recovery) is based on an estimate by the Freedonia Group that 20 percent of CO2 is produced from natural wells.	3	The Freedonia Group's method for determining U.S. CO2 consumption is not described in the U.S. GHG inventory.	0.09
Source Specificity	10	The emission factor was developed specifically for the intended source category.	5	State population is somewhat correlated to the emission process.	0.50
Spatial Congruity	7	The emission factor was developed for the U.S. as a whole; spatial variability is expected to be moderate.	10	States use state population data to estimate state emissions.	0.70
Temporal Congruity	10	The emission factor was developed to estimate annual emissions.	8	States may use population data from the Census Bureau's most recent census data; temporal variability is expected to be low.	0.80
				Composite Score	*0.52*

DARS SCORES: CO2 EMISSIONS FROM NITRIC ACID PRODUCTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*Because the emission factor is based on measurement, the lowest possible score is 5. However, the measurement was from a single plant, and a large range in emissions was measured at that plant.*	*9*	*Data on nitric acid production (from which N2O is emitted as a by-product) are aggregated from intermittent measurements.*	*0.27*
Source Specificity	*10*	*The emission factor was developed specifically for the intended emission source.*	*10*	*The activity measured (nitric acid production), is the activity from which N_2O is emitted.*	*1.00*
Spatial Congruity	*9*	*The emission factor was developed for a region larger than the one it is applied to; it is not based on state-level production and emissions. However, spatial variability for the emissions factor is assumed to be low.*	*10*	*States use state-level activity data to estimate statewide emissions.*	*0.90*
Temporal Congruity	*$*	*Because the emission factor is based on mass balance, not on measured emissions over a particular time frame. However, the emission factor should not vary significantly over the course of a year.*	*10*	*States use annual activity data to ~~estimate~~ annual emissions.*	*0.90*
				Composite Score	*0.77*

DARS SCORES: EMISSIONS OF HFC'S AND PFC'S FROM CONSUMPTION OF SUBSTITUTES FOR OZONE DEPLETING SUBSTANCES					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*National vintaging model estimate is based on a crude mass balance approach that estimates leak rates for equipment containing ODS substitutes, and release profiles for such uses as solvents and sterilants.*	*3*	*Per-capita national estimate (based on a vintaging model) and state population are used to estimate state emissions.*	*0.09*
Source Specificity	*10*	*The emission factor was developed specifically for the intended source category.*	*5*	*State population is somewhat correlated to the emission process.*	*0.50*
Spatial Congruity	*9*	*The emission factor was developed for the U.S. as a whole; spatial variability is expected to be low.*	*5*	*States use state population data and national consumption data to estimate state emissions; spatial variability is expected to be moderate to high.*	*0.45*
Temporal Congruity	*10*	*The emission factor was developed to estimate annual emissions.*	*8*	*States may use population data from the Census Bureau's most recent census data; temporal variability is expected to be low.*	*0.80*
				Composite Score	*0.46*

DARS SCORES: EMISSIONS OF SF6 FROM ELECTRIC UTILITIES					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*The emission factor used in the U.S. greenhouse gas inventory, to estimate U.S. emissions from this sector, was based on mass balance.*	*6*	*Electricity consumption is used as a proxy for the number of transformers from which SF6 would leak.*	*0.30*
Source Specificity	*7*	*The emission factor was based on atmospheric concentrations of SF6, as emitted from all sources. Expected variability is low to moderate.*	*5*	*Electricity consumption is somewhat correlated to the emissions process.*	*0.35*
Spatial Congruity	*7*	*The emission factor was developed based on global emissions, not U.S. emissions. Spatial variability is expected to be moderate.*	*10*	*States use state data on electricity consumption to estimate state emissions.*	*0.70*
Temporal Congruity	*7*	*The emission factor was based on total emissions since 1950; temporal variability is expected to be low to moderate.*	*10*	*States use annual data on electricity consumption to estimate annual emissions.*	*0.70*
				Composite Score	*0.51*

APPENDIX D
WASTE

I. CH_4, CO_2 and N_2O from Solid Waste Disposal

Waste is assumed to produce biogas for 30 years. For this reason, it is necessary to know how much waste has been placed in landfills in the past. Because data on Iowa landfilling quantities only began to be collected in 1989, waste in place (WIP) over the past 30 years was estimated on the worksheet titled "Estimation of Waste in Place from 1960 – 2000." This was done by back casting state population and EPA national per capita landfilling rates to estimate waste quantities for 1970-1988. Historical Iowa population data was taken from the U.S. census website for 1970, 1980, 1990 and 2000. Uniform population growth was assumed across decades to estimate annual populations. Annual populations were multiplied by the United States per capita municipal solid waste landfilling rates as presented in the updated EIIP State Workbook for 2002. The same approach was taken to estimate WIP for 1990.

The first step on worksheet "CH_4, CO_2 and N_2O Emissions from Municipal Landfills, Industrial Landfills and Waste Incineration" was to estimate the WIP in small vs. large MSW landfills. As directed in the state workbook, it was assumed that 81% was in landfills containing more than 1.1 million tons of WIP (column B_1) and 19% of the total waste was in landfills with less than 1.1 millions tons WIP (column C_1).

High moisture content can affect the microbial environment and result in more biogas production. Emission factors were provided for arid and non-arid states (column B_2). Iowa is considered a non-arid state with more than 25 inches of rain per year and therefore delivers more moisture content to the landfill producing more biogas per ton of waste than arid states.

For lack of state specific data, emissions from industrial landfills were estimated based on the assumption that they produce an additional 7% of CH_4 emissions (column B_4). Of course, this is a very rough estimate that leaves much uncertainty about the amount of emissions coming from industrial landfills.

Biogas can be flared, collected and burned for energy, or naturally oxidized. Each of these processes converts CH_4 to CO_2. These activities essentially cancel out the excess global warming potential that is counted in the inventory from the anaerobic decomposition of organic matter. Thus, for landfills that participate in flaring and energy recovery, there are essentially no CH_4 emissions to count. There are 4 landfills known to be collecting gas for energy projects; Des Moines Metro, Cedar Rapids Bluestem, Scott County and Johnson County. The 28,000 tons of CH_4 recovered from these sites were credited to the inventory, though data for CH_4 recovery from Johnson County was not available (column E_6). The EPA assumes that 10% of the net CH_4 emissions are oxidized in the landfill and surrounding soils. Only the remaining 90% is available as CH4 emissions (column E_7).

When the waste has decomposed to a point where no more biogas is produced, the movement of carbon out of the landfill is assumed to have stopped. This results in the sequestering the carbon in the landfill. Once the carbon is sequestered in the landfill, it can no longer escape as a greenhouse gas. The EPA assumes that 0.18 tons of carbon for every one ton of municipal solid waste is sequestered in this way. Thus 18% of the MSW is considered to be carbon that is trapped in the landfill (column D_8). This carbon is subtracted from landfill emissions.

Finally, waste incineration is a disposal method that produces CO_2 and N_2O emissions. This source represents only a very small amount of emissions because incineration is not common in Iowa. From their annual survey, *Biocycle* magazine estimates that less than 1% of Iowa MSW is burned (Goldstein & Madates, 2001). In this inventory, 1% waste incineration is assumed (column B_9). Emissions were determined by multiplying 1% of the waste in the inventory year by the appropriate emission factor provided by the EIIP (columns D_9 and F_9).

CH_4, CO_2 and N_2O Emissions from Municipal Landfills, Industrial Landfills and Waste Incineration

2000, 1990 recalculated

Estimate Fraction of Waste in Place (WIP) in Large Versus Small MSW Landfills

Column Label	A_1	B_1	C_1	D_1	E_1
Calculation	input	input	input	A_1 x B_1	A_1 x C_1
	Waste in Place (WIP)	Fraction of WIP in Landfills w/ more than 1.1 million tons	Fraction of WIP in Landfills w/ less than 1.1 millions tons	WIP in Large Landfills	WIP in Small Landfills
Year	tons			tons	tons
2000	73,831,353	0.81	0.19	59,803,396	14,027,957
1990 recalc	67,406,850	0.81	0.19	54,599,548	12,807,301

Estimate Methane Generated from WIP at Small MSW Landfill

	A_2	B_2	C_2	D_2
	E_1	input	A_2 x B_2	C_2 x .0077
	WIP in Small Landfills	Non Arid Emission Factor	Methane Produced	Methane Produced
	tons	ft^3 CH_4/ton/day	ft^3 CH_4/day	tons CH_4/ yr
2000	14,027,957	0.35	4,909,785	37,805
1990 recalc	12,807,301	0.35	4,482,556	34,516

Estimate Methane Generated from WIP at Large MSW Landfills

	A_3	B_3	C_3	D_3	E_3	F_3
	E_1	input	A_3/B_3	input	B_3 x (C_3 x D_3)	E_3 x .0077
	WIP in Large Landfills	Number of Large Landfills	Avg WIP at Large Landfills, Wavg	Non Arid Emission Factor and Correction Factor	Methane Production	Methane Produced
	tons	landfills	avg tons/ landfill		ft^3/day	tons CH_4/yr
2000	59,803,396	15	3,986,893	417,957 + 0.26	21,818,238	168,000
1990 recalc	54,599,548	15	3,639,970	417,957 + 0.26	20,465,238	157,582

Estimate Methane Generated from Industrial Landfills

	A_4	B_4	C_4
	F_3 + D_2	input	A_4 x B_4
	Total CH_4 Produced at Small and Large Landfills	Fraction of CH_4 generated in industrial landfills	Total CH_4 Produced at Industrial Landfills
	tons/year		tons/year
2000	205,806	0.07	14,406
1990 recalc	192,098	0.07	13,447

Gross CH_4 from Landfills in 2000 unadjusted oxidation

	A_5	B_5	C_5	D_5
	F_3	D_2	C_4	A_5 + B_5 + C_5
	CH_4 from Large Landfills	CH_4 from Small Landfills	CH_4 from Industrial Landfills	Unadjusted Gross CH_4 Emissions from Landfills
	tons CH_4/yr	tons CH_4/yr	tons CH_4/yr	tons CH_4/yr
2000	168,000	37,805	14,406	220,212
1990 recalc	157,582	34,516	13,447	205,545

Estimation of Methane Recovered at four Iowa Landfill Gas to Energy Projects

	A_6	B_6	C_6	D_6	E_6
	input	input	input	input	A_6 + B_6 + C_6 + D_6
	Metro	Bluestem	Scott Co	Johnson Co	Total
	tons CH_4	tons CH_4	tons CH_4	tons CH_4	tons CH_4
2000	14,240	10,415	3,949	Not Available	28,604
1990 recalc		10,585			10,585
				difference	18,019

Adjustment for Oxidation of CH_4

	A_7	B_7	C_7	D_7	E_7
	D_5	E_6	A_7 - B_7	input	C_7 x D_7
	CH_4 Emissions from Landfills	CH_4 Recovered from Landfills	Net CH_4 Emissions from Landfills	Unoxidized Fraction	Unoxidized Landfill CH_4
	tons CH_4	tons CH_4	tons CH_4		tons CH_4
2000	220,212	28,604	191,608	0.9	172,447
1990 recalc	205,545	10,585	194,960	0.9	175,464

Estimation Carbon Sequestration in Landfill

	A_8	B_8	C_8	D_8
	input	input	A_8 x B_8	C_8 x .9072
	MSW Landfilled in Inventory Year	Fraction of Carbon Sequestered	Carbon Sequestered	Carbon Sequestered
	tons	tons C/ ton MSW	tons	metric tons
2000	2,531,456	0.18	455,662	413,377
1990 recalc	2,533,551	0.18	456,039	413,719

Estimation Emissions from Incinerated Waste

	A_9	B_9	C_9	D_9	E_9	F_9	G_9
	input	input	A_9 x B_9	input	input	C_9 x D_9	C_9 x E_9
	MSW Landfilled in Inventory Year	Fraction of Waste Incinerated	MSW Incinerated	CO2 Emission Factor	N2O Emission Factor	Nonbiogenic CO2 Emissions	N2O Emissions
	tons		tons	ton CO_2 / ton waste	ton N_2O / ton waste	tons CO_2	tons N_2O
2000	2,531,456	0.01	25,315	0.4	0.0001	10,126	3
1990 recalc	2,533,551	0.01	25,336	0.4	0.0001	10,134	3

Net Total Emissions from Solid Waste

	1990 Recalculated		2000	
	Tons	MTCE	Tons	MTCE
Landfill CH_4 (E_7)	175,464	911,672	172,447	895,999
C Sequestration (D_8)	-456,039	-413,719	-455,662	-413,377
Incineration CO_2 (F_9)	10,134	2,507	10,126	2,505
Incineration N2O (G_9)	3	194	3	194
Net Total		**500,655**		**485,322**

Estimation of Waste in Place from 1960 - 2000 (tons)

	A	B	C	D	
	input	input	A x B = C	C x 1.638	
	Estimated Iowa Population (people)	**MSW Landfilling Rate** (tons/ person)	**Estimate of Waste Landfilled** (tons)	**Adjusted Estimate of Iowa Waste Landfilled** (tons)	
1960	2,757,537	0.31	854,836	**1,400,222**	
1961	2,764,221	0.32	884,551	**1,448,894**	
1962	2,770,905	0.33	914,399	**1,497,785**	
1963	2,777,589	0.34	944,380	**1,546,895**	
1964	2,784,273	0.36	1,002,338	**1,641,830**	
1965	2,790,957	0.37	1,032,654	**1,691,487**	
1966	2,797,640	0.38	1,063,103	**1,741,363**	
1967	2,804,324	0.39	1,093,686	**1,791,458**	
1968	2,811,008	0.41	1,152,513	**1,887,817**	
1969	2,817,692	0.42	1,183,431	**1,938,459**	
1970	2,824,376	0.43	1,214,482	**1,989,321**	
1971	2,833,319	0.44	1,246,660	**2,042,030**	
1972	2,842,262	0.45	1,279,018	**2,095,032**	
1973	2,851,206	0.47	1,340,067	**2,195,029**	
1974	2,860,149	0.48	1,372,871	**2,248,763**	
1975	2,869,092	0.49	1,405,855	**2,302,791**	
1976	2,878,035	0.50	1,439,018	**2,357,111**	
1977	2,886,978	0.51	1,472,359	**2,411,724**	
1978	2,895,922	0.52	1,505,879	**2,466,630**	
1979	2,904,865	0.53	1,539,578	**2,521,829**	
1980	2,913,808	0.54	1,573,456	**2,577,321**	
1981	2,900,103	0.55	1,595,056	**2,612,703**	
1982	2,886,397	0.55	1,587,519	**2,600,355**	
1983	2,872,692	0.55	1,579,981	**2,588,008**	
1984	2,858,987	0.55	1,572,443	**2,575,661**	
1985	2,845,282	0.55	1,564,905	**2,563,314**	
1986	2,831,576	0.56	1,585,683	**2,597,348**	
1987	2,817,871	0.56	1,578,008	**2,584,777**	
1988	2,804,166	0.56	1,570,333	**2,572,205**	
TOTAL (1970- 1988)			*28,023,170*	**Actual Tonnage[a]**	Ratio of Estimated Tonnage to Actual Tonnage
FY 1989	2,790,460	0.56	1,562,658	2,385,135	1.5
FY 1990	2,776,755	0.56	1,554,983	2,533,551	1.6
FY 1991	2,791,397	0.55	1,535,269	2,444,272	1.6
FY 1992	2,806,040	0.53	1,487,201	2,087,821	1.4
FY 1993	2,820,682	0.52	1,466,755	2,116,133	1.4
FY 1994	2,835,325	0.50	1,417,662	2,187,859	1.5
FY 1995	2,849,967	0.46	1,310,985	2,351,130	1.8
FY 1996	2,864,609	0.46	1,317,720	2,360,704	1.8
FY 1997	2,879,252	0.47	1,353,248	2,262,906	1.7
FY 1998	2,893,894	0.47	1,360,130	2,244,634	1.7
FY 1999	2,908,537	0.48	1,396,098	2,423,799	1.7
FY 2000	2,923,179	0.46	1,344,662	2,531,456	1.9
Total (1989- 2000)			*17,107,371*	**27,929,400**	AVG 1.638

2000 Total Waste in Place (estimated for 1970-1988 + actual for 1989-2000) (tons)	**73,831,353**
1990 Total Waste in Place (estimated for 1960-1988 + actual for 1989-1990) (tons)	**67,406,850**

[a] Source: Nina Kroger, Iowa Department of Natural Resources Waste Bureau, personal contact, October 29, 2002

MUNICIPAL SOLID WASTE DARS SCORES

DARS SCORES: CH_4 EMISSIONS FROM LANDFILLS					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	3	The factors are derived from a model which in turn draws from a limited set of measurements.	6	If a state uses the Workbook formula for waste in place, the activity level is estimated based on state and national data.	0.18
Source Specificity	10	The emission factors were developed specifically for landfills.	7	The activity data are highly correlated to the emissions process.	0.70
Spatial Congruity	5	Emission factors were developed for arid and non-arid regions; but even within these regions, spatial variability is probably moderate to high.	7	If a state uses the EIIP formula for waste in place, the national average per capita waste landfilled is used instead of state-specific data; spatial variability is expected to be moderate.	0.35
Temporal Congruity	8	The emission factor is based on a model that estimates average annual emissions over a 30-year time frame. Temporal variability is expected to be low.	8	If a state uses the EIIP formula for waste in place, the state's current population and population growth rate is used to estimate waste placed over the past 30 years.	0.64
				Composite Score	*0.47*

DARS SCORES: LANDFILL CARBON SEQUESTRATION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*The sequestration factor is based on laboratory research data.*	*10*	*The amount of waste disposed is measured by weighing garbage trucks before and after they tip their waste at the facility*	*0.50*
Source Specificity	*6*	*The sequestration factor was developed for a subset of the source category; expected variability is moderate.*	*7*	*The activity data are highly correlated to the sequestration process.*	*0.42*
Spatial Congruity	*5*	*The sequestration factor was developed for waste from a North Carolina community; spatial variability is expected to be moderate to high.*	*10*	*States use state-level activity data to estimate state-wide emissions.*	*0.50*
Temporal Congruity	*5*	*The laboratory research was intended to simulate long-term degradation of organic wastes in a landfill; temporal variability is expected to be moderate to high.*	*10*	*States use activity data for a given year to estimate carbon sequestration associated with that year.*	*0.50*
				Composite Score	*0.48*

DARS SCORES: CO2 EMISSIONS FROM WASTE COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*The emission factor is based on an imprecise mass balance relationship.*	*10*	*The amount of waste combusted is measured by weighing garbage trucks before and after they tip their waste at the combustor.*	*0.50*
Source Specificity	*10*	*The emission factor was developed specifically for waste combustion.*	*9*	*The amount of waste combusted is very closely correlated to the emissions process.*	*0.90*
Spatial Congruity	*7*	*The emission factor is based on U.S. data, but the content of nonbiogenic carbon in waste varies depending on its source. Spatial variability is expected to be moderate.*	*10*	*States use state-level activity data to estimate state-wide emissions.*	*0.70*
Temporal Congruity	*7*	*The emission factor is based on mass balance, not on measured emissions over a particular time frame. The variability of the emission factor is expected to be low to moderate.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.70*
				Composite Score	*0.70*

DARS SCORES: N2O EMISSIONS FROM WASTE COMBUSTION					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*The emission factor was derived by averaging widely-varying measurements made throughout the world.*	*10*	*The amount of waste combusted is generally measured accurately by weighing garbage trucks before and after they tip their waste at the combustor.*	*0.30*
Source Specificity	*10*	*The emission factor was developed specifically for waste combustion.*	*6*	*The amount of waste combusted is correlated to the emissions process.*	*0.60*
Spatial Congruity	*5*	*The emission factor is based on global, not U.S., data; moreover, the emission level depends on the nature of the waste combusted.*	*10*	*States use state-level activity data to estimate state-wide emissions.*	*0.50*
Temporal Congruity	*9*	*The emission factor is based on an average of short-term measurements, not on year-long measurements. However, the emission factor is not believed to vary significantly over the course of a year.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.90*
				Composite Score	*0.58*

II. CH_4 and N_2O from Municipal Wastewater Treatment

The estimation method is based on the default IPCC methodology also used by the EPA for the national greenhouse gas inventory. The state population was multiplied by a per capita BOD generation rate (column B) to determine the total BOD generated and delivered to municipal treatment systems. It was assumed that 16.25% of wastewater and sludge was treated anaerobically (column E) and with a methane emission factor 0.6 kg CH_4/kg BOD_5 (column G). To determine the nitrogen content of the wastes, the annual per capita consumption of protein (column Q) was used from the online United Nations Food and Agricultural Organization database (2004). For 2000, 41.9 kg of protein were consumed annually by per capita in the United States. It was assumed that 16% of protein is nitrogen (column R), thus 6.7 kg of nitrogen were consumed in 2000 per American. This number was multiplied by the state population to determine the amount of nitrogen consumed and released as waste (column U). With an emission factor of 0.01 kg N_2O-N/kg sewage-N, the nitrous oxide emissions were determined. State population data came from the U.S. Census Bureau 2000 census (2001). The remaining information was taken from the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990- 2000 (EPA, 2002).

2000 CH_4 and N_2O Emissions from Municipal Wastewater Treatment

CH_4 Emissions from Municipal Wastewater Treatment

A	B	C	D	E	F	G	H	I
input	input	A x B	input	input	C x (1-D) x E x 365	input	F x G	H/ 2205 x 21 x (12/44)
2000 IA Population	**Wastewater BOD Generation Rate**	**BOD Generated**	**Fraction of BOD removed as Sludge**	**Fraction of Wastewater BOD Treated Anaerobically**	**Quantity of BOD Treated Anaerobically**	**CH_4 Emission Factor**	**CH_4 Emissions**	**CH_4 Emissions**
people	kg BOD/capita/day	kg BOD/day			kg BOD/year	kg CH_4/kg BOD	kg CH_4	MTCE
2,926,324	0.065	190,211	0.90	0.1625	1,128,189	0.6	676,914	3,877

CH_4 Emissions from Municipal Sludge Treatment

J	K	L	M	N	O	P
C	input	input	J x K x L x 365	input	M x N	O/2205 x 21 x (12/44)
BOD Generated	**Fraction of BOD removed as sludge**	**Fraction of Sludge BOD Treated Anaerobically**	**Quantity of BOD Treated Anaerobically**	**Methane Emission Factor**	**CH_4 Emissions**	**CH_4 Emissions**
kg BOD/day			kg BOD/yr	kg CH_4/kg BOD	kg CH_4	MTCE CH_4
190,211	0.90	0.1625	10,153,704	0.6	6,092,222	34,892

N_2O Emissions from Wastewater and Sludge Treatment

Q	R	S	T	U	V	W	X	Y
input	input	Q x R	input	S x T	input	U x V	W/1000 x (44/28)	X x 310 x (12/44)
Annual Per Capita Consumption of Protein (2000)	**Fraction of nitrogen in protein**	**Annual per capita consumption of nitrogen in protein**	**State Population**	**State Annual Consumption N in protein**	**Emission Factor**	**State Annual Emissions of N_2O from wastewater**	**N_2O Emissions**	**N_2O Emissions**
kg		kg	people	kg	kg N2O-N/kg sewage-N	kg N_2O-N	metric tons	MTCE
41.90	0.16	6.70	2,926,324	19,618,076	0.01	196,181	308	26,064

Total CH_4 (MTCE)	**38,769**
Total N_2O (MTCE)	**26,064**

1990 CH_4 and N_2O Emissions from Municipal Wastewater Treatment

CH_4 Emissions from Municipal Wastewater Treatment

A	B	C	D	E	F	G	H	I
input	input	A x B	input	input	C x (1-D) x E x 365	input	F x G	H/ 2205 x 21 x (12/44)
2000 IA Population	**Wastewater BOD Generation Rate**	**BOD Generated**	**Fraction of BOD removed as Sludge**	**Fraction of Wastewater BOD Treated Anaerobically**	**Quantity of BOD Treated Anaerobically**	**CH_4 Emission Factor**	**CH_4 Emissions**	**CH_4 Emissions**
people	kg BOD/capita/day	kg BOD/day			kg BOD/year	kg CH_4/kg BOD	kg CH_4	MTCE
2,776,755	0.065	180,489	0.90	0.1625	1,070,526	0.6	642,315	3,679

CH_4 Emissions from Municipal Sludge Treatment

J	K	L	M	N	O	P
C	input	input	J x K x L x 365	input	M x N	O/2205 x 21 x (12/44)
BOD Generated	**Fraction of BOD removed as sludge**	**Fraction of Sludge BOD Treated Anaerobically**	**Quantity of BOD Treated Anaerobically**	**Methane Emission Factor**	**CH_4 Emissions**	**CH_4 Emissions**
kg BOD/day			kg BOD/yr	kg CH_4/kg BOD	kg CH_4	MTCE CH_4
180,489	0.90	0.1625	9,634,732	0.6	5,780,839	33,108

N_2O Emissions from Wastewater and Sludge Treatment

Q	R	S	T	U	V	W	X	Y
input	input	Q x R	input	S x T	input	U x V	W/1000 x (44/28)	X x 310 x (12/44)
Annual Per Capita Consumption of Protein (2000)	**Fraction of nitrogen in protein**	**Annual per capita consumption of nitrogen in protein**	**State Population**	**State Annual Consumption N in protein**	**Emission Factor**	**State Annual Emissions of N_2O from wastewater**	**N_2O Emissions**	**N_2O Emissions**
kg		kg	people	kg	kg N2O-N/kg sewage-N	kg N_2O-N	metric tons	MTCE
39.20	0.16	6.27	2,776,755	17,415,807	0.01	174,158	274	23,138

Total CH_4 Emissions	**36,787**
Total N_2O Emissions	**23,138**

MUNICIPAL WASTEWATER DARS SCORES

DARS SCORES: CH4 EMISSIONS FROM MUNICIPAL WASTEWATER AND SLUDGE					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*5*	*Because the emission factor is not based on measurement, the highest possible score is 5. It is assumed that the Metcalf and Eddy (1 972) study used pilot study data.*	*4*	*Uncertainty arises if the state uses default values for factors such as the fraction of wastewater treated anaerobically, or the fraction of BOD removed as sludge.*	*0.20*
Source Specificity	*6*	*The emission factor was developed for wastewater treatment, with moderate to high variability.*	*5*	*The "activity" measured (population) is somewhat correlated to the emissions process.*	*0.30*
Spatial Congruity	*5*	*The emission factor was developed for the U.S. as a whole, and spatial variability is probably moderate to high, varying as a function of several factors.*	*5*	*States use state-level activity data to estimate statewide emissions, but variability exists at the treatment system level.*	*0.25*
Temporal Congruity	*5*	*Temporal variability is expected to be moderate to high.*	*10*	*States use annual activity data to estimate annual emissions.*	*0.50*
				Composite Score	*0.31*

DARS SCORES: N2O EMISSIONS FROM MUNICIPAL WASTEWATER AND SLUDGE					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	*3*	*The emission factor is an estimate based on available data.*	*3*	*Activity level is based on population, estimated protein consumption, and estimated fraction of nitrogen in protein*	*0.09*
Source Specificity	*8*	*The emission factor was developed for agricultural use of nitrogen fertilizers*	*5*	*Activity data are somewhat correlated to the emissions process*	*0.40*
Spatial Congruity	*7*	*The emission factor is based on global, not US, data. Spatial variability is expected to be moderate.*	*7*	*States use state-level population data and global estimates for protein consumption and nitrogen fraction in protein, to estimate statewide emissions. Spatial variability is expected to be moderate.*	*0.49*
Temporal Congruity	*5*	*The emission factor is based on an assumption that all N2O emissions from nitrogen fertilizers, wastewater, or sludge are emitted in the same year the fertilizer is applied or the wastewater or sludge is generated.*	*6*	*States use population data from the most recent census, and the most recent available global estimates for protein consumption and nitrogen fraction in protein, to estimate annual emissions. Temporal variability is expected to be moderate.*	*0.30*
				Composite Score	*0.32*

APPENDIX E
LAND-USE AND FOREST MANAGEMENT

Carbon in Timberland Trees. To determine the carbon sink in Iowa's forest trees, dry weight data of "all live biomass" by major species group on timberland was downloaded from the 1990 and 2001 Iowa forest inventories. The data category "all live biomass" is described the total above-ground biomass of a sample tree 1.0 inch in diameter or larger, including all tops and limbs (but excluding foliage) (personal communication, Patrick Miles, North Central Research Station).

The choice to use data for "timberland" instead of "forestland" was for the reason of comparison between inventory years. Timberland is a subset of forestland that produces or is capable of producing a commercial wood crop. Dry weight data for forestland was unavailable for the 1990 inventory. This is due to the fact that prior to 1995 tree measurements such as biomass dry weight, were usually only taken on timberland plots (personal communication, Patrick Miles, North Central Research Station). After 1995 these measurements were taken on all forestland.

It was decided that the use of timberland data would be acceptable for two reasons. The first reason being that alternative methods of calculation allowing for comparisons using "growing stock" on forestland would involve greater generalization and broader assumptions and ultimately greater error. The second reason being that timberland consistently dominates Iowa's forest landscape accounting for 90.5 percent and 92 percent of all forestland in 1990 and 2000 respectively. Thus comparison of timberland trees will introduce less error. For all other forest carbon pools, forestland data was used.

In the worksheet titled "Carbon in Timberland Trees for Years 1990 and 2001" order to estimate the below ground biomass, the dry weight of "all live biomass" (column A) was multiplied by a belowground expansion factor (column B) specified for the major species type (soft vs. hardwood). The total above and belowground dry biomass was multiplied by a regional carbon content fraction from Birdsey (1992). The resulting mass of carbon in pounds was converted to short tons of carbon. This value represents the total amount of carbon that is stored above and below ground in Iowa's timberland trees.

Carbon on the Forest Floor. To estimate the carbon stored in Iowa's forest floors, the area of forestland delineated by Resource Protection Act (RPA) forest type was downloaded for both the 1990 and 2001 forest inventories. RPA Forest type is a category assigned to a plot of land by the forest service based on the dominant tree species present. Within a category, other characteristics are assumed to be similar such as understory species and floor contents. The total forest area by type (column A) is multiplied by a regional carbon content figure (column B) for the particular forest type and converted to short tons of carbon.

For forest types reported in forest inventories that did not have a related carbon coefficient, an average carbon value for Iowa forest floors was used. The value is a direct finding of the 1992 Birdsey study. To get this number, the area of each type of Iowa forestland was multiplied by estimated carbon values pulled from the literature then multiplied by a factor that represents the Iowa forest age distribution. The resulting value, 11,724 lbs/acre, was actually lower than any of the forest specific carbon factors.

Carbon in Forest Understory and Soil. The carbon estimation procedure was essentially the same for forest understory and soil and can be found on the worksheet titled "Carbon in Forest Understory and Soil for Years 1990 and 2001." The total area of 1990 and 2001 forestland was multiplied by the appropriate region specific carbon factor (column B) which came from Birdsey (1992). The figure was then converted to short tons.

Birdsey developed a regression model to relate soil carbon in relatively undisturbed, secondary forests to temperature and precipitation. Using published regional weather records and Iowa average forest age distribution; Birdsey determined an average per acre estimate of soil carbon in Iowa forestland.

For carbon storage in the understory, Birdsey assigned to each forest age class a percentage of overstory carbon that is assumed to equal understory carbon. At age 0, understory biomass equaled 0 and peaked at 5 years. For Iowa forests 55 years and older, it was assumed that 2% of overstory carbon equals the amount of carbon found in the understory in most forests. In douglas fir and red pine forests, 1% of overstory carbon is used. Using Iowa forest age distribution by forest type a weighted average value of carbon per acre was determined.

Carbon in Forest Floor for Years 1990 and 2001

Forest Type	Forest Area	Carbon Coefficient of Forest Floor 1/	Carbon in Forest Floor	Carbon in Forest Floor
	A	B	C	D
	input	input	A x B	D x .0005
	(acres)	(Lbs/ acre)	(Lbs)	(tons C)
1990				
Loblolly-Shortleaf Pine	23,700	23,061	546,545,700	273,273
Oak-Pine	26,300	23,061	606,504,300	303,252
Oak-Hickory	957,600	12,045	11,534,292,000	5,767,146
Elm-Ash-Cottonwood	519,100	11,724	6,085,928,400	3,042,964
Maple-Beech-Birch	507,200	16,663	8,451,473,600	4,225,737
Aspen-Birch	7,300	16,663	121,639,900	60,820
White-Red-Jack Pine	6,300	11,724	73,861,200	36,931
Nonstocked	2,700	11,724	31,654,800	15,827
Total	2,047,500			13,710,123
2001				
Loblolly-Shortleaf Pine	40,094	23,061	924,615,863	462,308
Oak-Pine	32,793	23,061	756,247,156	378,124
Oak-Hickory	988,693	12,045	11,908,811,431	5,954,406
Elm-Ash-Cottonwood	660,434	11,724	7,742,922,413	3,871,461
Maple-Beech-Birch	799,251	16,663	13,317,925,245	6,658,963
Aspen-Birch	11,749	16,663	195,773,587	97,887
Oak-Gum-Cypress	9,504	11,724	111,426,596	55,713
Nonstocked	49,594	11,724	581,440,759	290,720
Unknown	14,517	11,724	170,197,308	85,099
	2,606,630			17,854,680.2

1/ 11,724 is an average carbon storage number determined by region (North Central/Central) and state (IA) and is from Table 2.2 of Birdsey (1992)
The following are from Table 1.4 of Birdsey (1992) which estimates carbon on forest floor by region (North Central/Central) and state (IA)
12,045 lbs/acre is assigned specifically to "Oak-hickory and bottomland hardwoods"
16,663 lbs/acre is assigned specifically to the "Maple-beech and Aspen-birch" forest types
23,061 lbs/acre is assigned specifically to "Pines" forest type
23,122 is assigned specifically to "Spruce-fir" forest type

Carbon in Timberland Trees for years 1990 and 2001

	A	B	C	D	E	F	G
	input	input	A x B	A + C	input	input	D x E x F
	Above Ground Dry Matter 1/	**Below Ground Expansion Ratio 2/**	**Below Ground Dry Matter**	**Above & Below Ground Dry Matter**	**Percent Carbon 3/**	**Unit Conversion Factor**	**Carbon in Trees**
	(dry pounds)		**(dry pounds)**	**(dry pounds)**			**(short tons C)**
1990							
Softwood	2,029,420,858	0.17	345,001,545.90	2,374,422,404.17	0.521	0.0005	618,537.04
Hardwood	151,815,112,737	0.155	23,531,342,474.20	175,346,455,210.95	0.498	0.0005	43,661,267.35
						Total tons C	44,279,804.38
2001							
Softwood	2,141,657,318	0.17	426,864,592.42	2,937,832,783.10	0.521	0.0005	765,305.44
Hardwood	194,713,077,849	0.155	26,663,399,175.79	198,685,329,342.18	0.498	0.0005	49,472,647.01
						Total tons C	50,237,952.45

Change over Decade	5,958,148.06
Percent change over Decade	13.46
Change per year	595,814.81

1/ Source: Forest Inventory Analysis Online Database

2/ Found in Birdsey (1992) Table 1.1 Ratio of total volume to merchantable volume.

3/ Found in Birdsey (1992) Table 1.2 Factors to convert tree volume (cubic feet) to carbon (pounds).

Carbon in Forest Understory and Soil for Years 1990 and 2001

Carbon in Forest Understory on Forestland

	A	B	C	D
	input	input	A x B	C x .0005
Year	**Forest Area (acres)**	**Forest Carbon Coefficient[a] (lbs C/acre)**	**Carbon in Understory (lbs)**	**Carbon in Understory (short tons)**
1990	2,050,200	1,391	2,851,828,200	1,425,914.10
2001	2,606,630	1,391	3,625,822,330	1,812,911.17

Carbon in Soil on Forestland

	A	B	C	D
	input	input	A x B	C x .0005
Year	**Forest Area (acres)**	**Soil Carbon Coefficient 1/ (lbs C/acre)**	**Carbon in Soil (lbs)**	**Carbon in Soil (short tons)**
1990	2,050,200	88,442	181,323,788,400	90,661,894.20
2001	2,606,630	88,442	230,535,570,460	115,267,785.23

[a] Found in Birdsey (1992) Table 2.2 Average Storage of Carbon in the United States by region, State and forest ecosystem component, 1987.

Carbon in Forest Floor for Years 1990 and 2001

	A	B	C	D
	input	input	A x B	D x .0005
Forest Type	Forest Area	Carbon Coefficient of Forest Floor 1/	Carbon in Forest Floor	Carbon in Forest Floor
	(acres)	(Lbs/ acre)	(Lbs)	(tons C)
1990				
Loblolly-Shortleaf Pine	23,700	23,061	546,545,700	273,273
Oak-Pine	26,300	23,061	606,504,300	303,252
Oak-Hickory	957,600	12,045	11,534,292,000	5,767,146
Elm-Ash-Cottonwood	519,100	11,724	6,085,928,400	3,042,964
Maple-Beech-Birch	507,200	16,663	8,451,473,600	4,225,737
Aspen-Birch	7,300	16,663	121,639,900	60,820
White-Red-Jack Pine	6,300	11,724	73,861,200	36,931
Nonstocked	2,700	11,724	31,654,800	15,827
Total	2,047,500			13,710,123
2001				
Loblolly-Shortleaf Pine	40,094	23,061	924,615,863	462,308
Oak-Pine	32,793	23,061	756,247,156	378,124
Oak-Hickory	988,693	12,045	11,908,811,431	5,954,406
Elm-Ash-Cottonwood	660,434	11,724	7,742,922,413	3,871,461
Maple-Beech-Birch	799,251	16,663	13,317,925,245	6,658,963
Aspen-Birch	11,749	16,663	195,773,587	97,887
Oak-Gum-Cypress	9,504	11,724	111,426,596	55,713
Nonstocked	49,594	11,724	581,440,759	290,720
Unknown	14,517	11,724	170,197,308	85,099
	2,606,630			17,854,680.2

1/ 11,724 is an average carbon storage number determined by region (North Central/Central) and state (IA) and is from Table 2.2 of Birdsey (1992)
The following are from Table 1.4 of Birdsey (1992) which estimates carbon on forest floor by region (North Central/Central) and state (IA)
12,045 lbs/acre is assigned specifically to "Oak-hickory and bottomland hardwoods"
16,663 lbs/acre is assigned specifically to the "Maple-beech and Aspen-birch" forest types
23,061 lbs/acre is assigned specifically to "Pines" forest type
23,122 is assigned specifically to "Spruce-fir" forest type

FOREST AND LAND-USE MANAGEMENT DARS SCORES

DARS SCORES: CO_2 Emissions from Forest Management and Landuse Change (Trees Only)					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	8	The default sequestration factor (for tons of carbon per ton of dry matter) is based on an average of species-specific measurements.	6	The US Forest Service makes direct, periodic measurements of forest timber stocks, using sampling. However, the Forest Service does not estimate stocks of non-forest trees (e.g., urban and suburban trees), and excludes some forested land areas due to restricted access.	0.48
Source Specificity	9	The default sequestration factor was developed specifically for forest management and land use change, but does not reflect differences among tree species. (If Birdsey's species-specific values were used, the score here would be ten.)	8	Activity data (change in forest stocks) are closely correlated with the carbon sequestration and emission process for trees.	0.72
Spatial Congruity	9	The default sequestration factor was developed for all states, and spatial variability is low.	10	The US Forest Service measurements of forest stocks are totaled by state.	0.90
Temporal Congruity	9	The default sequestration factor is based on an average of instantaneous measurements, not on measured sequestration over a particular time frame. However, the percentage of carbon in dry matter should not vary over time.	6	Annual change in forest stocks is estimated based on net change in forest stocks over several years. Year-to-year variability in forest harvests within a given state is expected to be moderate.	0.54
				Composite Score	*0.66*

DARS SCORES: CO_2 Emissions from Forest Management and Landuse Change (***Understory, Forest Floor, and Soil Carbon***)					
	Emission Factor Attribute	*Explanation*	*Activity Data Attribute*	*Explanation*	*Emission Score*
Measurement	3	The default sequestration factors (pounds of carbon stored, per forested acre, in the understory, forest floor, and soils) are derived from a model, and are based on forest timber production and forest area for 1987; the assumptions made in the model are not public.	7	The US Forest Service makes direct, periodic measurements of forest area.	0.21
Source Specificity	10	The default sequestration factors were developed specifically for forest management and land use change.	4	Activity data (change in forest acreage) are somewhat correlated with the carbon sequestration and emission process for the understory and forest floor, but not for soil carbon.	0.40
Spatial Congruity	10	Separate default sequestration factors were developed for each state.	10	The US Forest Service measurements of forest acreage are totaled by state.	1.00
Temporal Congruity	7	The default sequestration factors are based on a model that uses 1987 data. Temporal variability is expected to be low to moderate.	8	Annual change in forest acreage is estimated based on net change in forest acreage over several years, but temporal variability is expected to be low.	0.56
				Composite Score	*0.54*